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Livestock and Global Climate Change

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Livestock and Global Climate Change 2008

Editors

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Livestock and Global Climate Change

Foreword

Livestock production occupies 70% of agricultural land, and 30% of the ice-free land surface of the planet! It is responsible for 40% of global agricultural GDP, and is both a contributor to global environmental problems, and part of the solution.

Global demand for livestock products is expected to double during the first half of this century, as a result of the growing human population, and its growing affluence. Over the same period, we expect big changes in the climate globally. The dramatic expansion of crop production for biofuels is already impacting on the resources available globally for food production, and hence on food supply and cost. Food security remains one of the highest priority issues in developing countries, and livestock production has a key role in many of these countries. However, food security is re-emerging as an important issue in many developed countries that had previously regarded it as 'solved'. These interconnected issues are creating immense pressure on the planet's resources. We need high quality animal science to help meet rising demand for livestock products in an environmentally and socially responsible way.

Against this backdrop, the conference organisers felt that there was an urgent need to bring interested parties together to review the latest scientific findings on predictions of climate change and how these will affect livestock production, to examine the contribution that livestock production makes to these changes and how it can help to mitigate them, to consider how livestock production systems can adapt to climate change, and to consider future scientific priorities to help in these areas.

The very strong international line-up of presenters confirms our view of the timeliness and importance of the subject. We hope that all delegates will engage fully with presenters, and each other, to ensure that we all leave with a much clearer vision of the livestock and production systems that we need in future, and the science and technology interaction we need to help us realise that vision.

We are very grateful to the Government of Tunisia for hosting this important event, and we are pleased that Tunisia, a country of openness and understanding, in which the international scientific community can address the challenges that climate change brings to our planet is a most appropriate venue. Our partners and hosts in Tunisia have worked tirelessly to ensure a successful conference, especially the Ministry of Agriculture and Hydraulic Resources and Ministry of Environment and Sustainable Development. The choice of Tunisia as the location for this conference was partly to allow others to learn from the experience of those already used to coping with extreme climatic events. We are confident that the mix of scientists, practitioners and policy makers from so many different regions will prove very stimulating.

We are also very grateful indeed to the sponsors of this meeting, whose support has enabled such wide participation.

Conference Organising Committee: Geoff Simm, Mike Steele, Eileen Wall, Peter Rowlinson (BSAS); Abdelaziz Mougou (IRESA), Said Khlij (OEP), Ali Nefzaoui, Mohamed El Mourid (ICARDA); Philippe Chemineau (INRA); Andrea Rosati (EAAP); Don Peden (ILRI)

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Principal guidelines for a National Climate Change Strategy: Adaptation, mitigation and international solidarity

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Introduction

Climate change, which can be defined as the misbalance, on the long term, of customary weather factors such as temperature, wind and rainfall characteristic of a specific region on Earth, is likely to be one of the main challenges that humankind will face in the current century.

The major scientific studies have shown that increasing average temperature of the Earth is now a reality and increased concentrations of greenhouse gases (GHG) in the atmosphere, due to human activities, mainly the emissions of carbon dioxide resulting from combustion of fossil fuel contribute to the enhancement of global greenhouse effect, the disturbance of the radiative forcing, and consequently the intensification of climate change phenomena.

Climate experts expect that climate change would have serious impacts on ecologic equilibriums, human health, and sustainable development in general, especially in developing countries which do not possess necessary means of adaptation to this global phenomena.

Considering the expected impacts of Earth temperature increase on ecosystems, natural resources, and economic activities in the medium and long run, the international community has granted the matter great importance especially through the elaboration of an international agreement on climate change at the Earth Summit in Rio de Janeiro, 1992.

Principal orientations and national investigations to face Climate Change

The Tunisian approach as to prevention against the expected effects of climate change is mainly based on the following principles:

- Coordination with all international structures and organizations, and contribution in the global efforts to face the climate change issue in the framework of related UN conventions and treaties;
- Support to institutional framework;
- Elaboration of national communications to the UNFCCC and regularly updating it;
- Carrying out studies on the likelihood of damage to ecosystems and economic sectors from possible climate change;
- Elaboration of action programs determining appropriate tools for the adaptation of ecosystems and economic sectors to climate change.

Institutional support in the field of climate change

Since December 2004, Tunisia abided by one important condition for benefiting from this mechanism: it has set up a National Coordination and Follow-up Board in relation to the Clean Development Mechanism.

Elaboration of the national communication on climate change and the greenhouse gas inventory

- Elaboration of the first National communication on Climate Change in November 2001, the only commitment concerning developing countries;
- Elaboration of an inventory of greenhouse gases (GHG) and determining their sources for the reference years 1994 and 1997, and in the energy sector for the reference year 2000;
- Elaboration of studies for the assessment of the means likely to reduce GHG emissions in the energy, agriculture, forest, and waste management sectors.

The studies, carried out at national level in the framework of capacity building projects for the elaboration of the 1st National communication to the UNFCCC, have shown that average rate emissions of greenhouse gases did not exceed 2.66 CO₂ Ton Equivalent (CO₂-TE) per inhabitant in Tunisia in 1994.

This indicator evolved to 2.92 CO₂-TE per inhabitant in 1997. The GHG emissions indicator in relation to Gross National Product also evolved from 1.8 CO₂-TE /1000 Dinars in 1994 to 2.1 CO₂-TE /1000 Dinars in 1997.

This indicator is being updated as to the reference year 2000 in the framework of the elaboration of the 2nd National communication for UNFCCC.

Added to that, and during 2006 started the elaboration of the 2nd National communication to the UNFCCC which is expected to be handed to the Secretariat of the Convention in the course of 2008, once all studies and surveys necessary for the report have been completed. It includes updated studies related to the inventory of GHG as well as the emissions reduction programs and the elaboration of a strategy for adapting to climate change.

Elaboration of studies on ecosystems and economic sectors' vulnerability to possible climate change

Climate-change vulnerability assessment studies have shown that, due to its geographic position and its fragile ecosystems, Tunisia is likely to suffer from possible impacts from average temperature rise, especially sea level rise and fresh-water reserves shrinking as a result of salinization, evaporation and irregular seasonal rainfall, besides the effects produced by the economic productivity downturn of considerable areas of low coastline zones threatened by sea-level rise.

In this respect, Tunisia has implemented many programs and projects, the most important of which are:

- Elaboration of a study on adaptation of agriculture and ecosystems to climate change;
- Elaboration of a study on the impact of sea-level rise on marine ecosystems and on the economy of threatened coastline areas;

Here are the most important results of both studies:

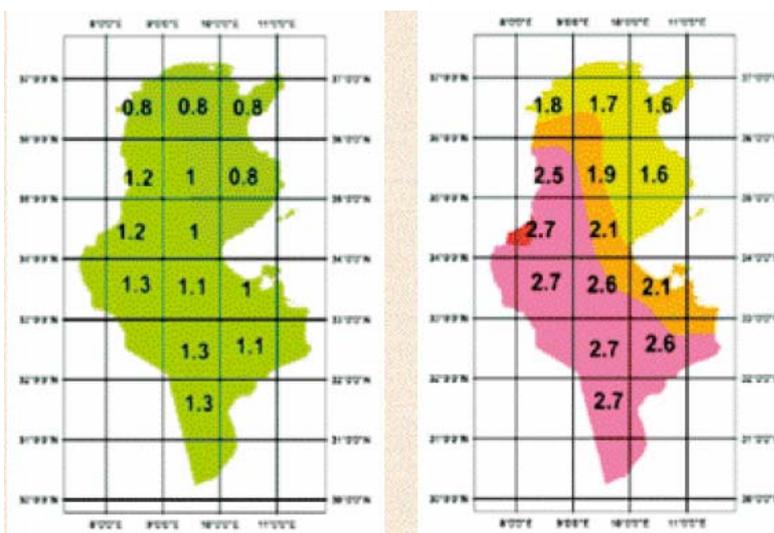
a. Study on adaptation of agriculture and ecosystems to climate change

The most important results of this study instructed by the President of the Republic and related to the elaboration of a strategy up to 2020 compared to the reference 1961-1990 period, are:

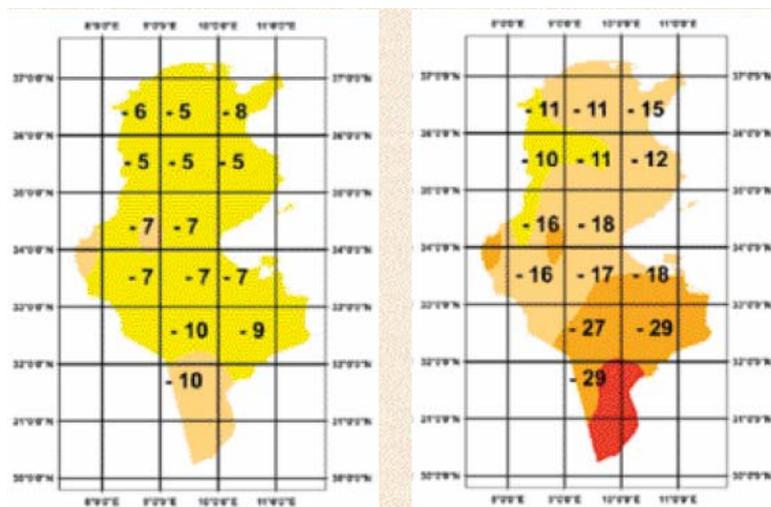
- North region from Cap Bon to North-west: rise of average temperature of about 0.8°C;
- South-west to far South region : rise of average temperature of about 1.3°C;
- North-west to South-east region : rise of average temperature of about 1.0°C.

Mathematic models used show that rainfall averages will decrease by 5% in the north, 8% in the Cap-Bon and the North-east, and by 10% in the far South by the year 2020.

By 2050, the same forecasts tell of a decrease in average rainfalls to a rate ranging between 10% in the north-west and 30% in the south of the country.



Rates of expected annual average temperature rise (in °C) by 2020 (left) and by 2050 (right), compared to the 1961-1990 reference period



Rates of expected annual average rainfall decrease (in %) by 2020 (left) and by 2050 (right), compared to the 1961-1990 reference period

Climate change in Tunisia may especially impact water resources, ecosystems and agro systems (olive oil production, fruit trees, cattle raising, dry cultures) and the economy in general. Climate change would increase present pressures on farmers and the land they are exploiting. Some farming activities may not adapt in extreme manifestations of climate change.

The study has proposed an integrated strategy and an action plan for adaptation of agriculture and natural resources which notably includes:

- The setting up of a climate emergency system, and development of weather forecast systems and dissemination of related information to most sectors;
- Supporting the water-resources management program, taking into account the ecosystems of this vital resource;
- Continuing using the Agriculture Map and readjusting it in view of expected climate changes;
- Enhancing ecosystems' capacity, such as forests, to adapt to climate change, and supporting the programs related to this field.
- Making climate change a national issue and considering the ways of benefiting from opportunities at world level such as the Adaptation Fund set up in the framework of the Kyoto Protocol;
- Fostering institutional mechanisms, financial incentives, scientific research and the insurance system, and supporting coordination between the different sectors for the implementation of the National Action Plan for adapting to climate change.

b. Study on vulnerability and adaptation of coastal areas to the sea-level rise

The results of the first phase of the study, which started in 2006 in the framework of the second National communication on the Climate Change Convention, show that a 50-cm sea-level rise by the year 2100 (worst prediction based on the IPCC scenarios) may cause an increase of marine erosion in a number of very low coastal areas such as the salt lakes of the Hammamet Gulf, the Cap Bon and parts of the Ichkeul and Ghar-el-Melh lakes, as well as Kerkennah, Jerba and Kneiss islands.

From the preliminary conclusions of the study, it is expected that sea-level rise would produce some effects on a number of coastal ecosystems such as water resources, as well as marine biodiversity and some coastal establishments.

In this respect, it is worth mentioning as early as 1995, the setting up of an integrated system for a better management of coastal ecosystem was initiated, aiming at protecting its natural resources and preventing the effects of marine erosion. The system is based on:

Setting up a Coastline Observatory: It aims at monitoring the coastal change and grasping the effects of economic activities in coastal areas, defining the Public Maritime Domain as well as elaborating implementation plans and economic activities monitoring, with the aim of better management of the public maritime domain and insuring its balance and sustainability, and preserving coastal ecosystems.

Elaborating a National Coastal Wetland Management Program: this aims at protecting coastal wetlands against pollution and for their rehabilitating. Seven management plans have been elaborated for the purpose and include Ariana, Kelibia, Soliman, Moknine, Beni Ghayadha, Rades and Sedjoumi.

Elaborating a National Marine Erosion Prevention Program: a preliminary study has been elaborated in this respect and has defined 100 km of coastline prone to marine erosion, 40 km of which are priority beaches.



The second part of the interventions will occur during the 11th National Development Plan by means of ‘artificial beach feeding’.

Other assessment studies have been recently started relating especially to climate change effects on the health sector, and to a climate emergency system for extreme climate phenomena such as droughts and floods.

Implementation of the clean development mechanism at national level

In the framework of the Kyoto Protocol implementation, many activities aiming at setting up appropriate conditions for the exploitation of funding and investment opportunities provided by the Clean Development Mechanism issued from the Kyoto Protocol have been realized. The following initiatives can be mentioned:

- Elaboration of a national strategy for the implementation of the Clean Development Mechanism in Tunisia;
- Elaboration of a project portfolio on the possibilities of reducing GHG emissions in the energy, waste management, forestry and agricultural sectors;
- Elaboration of a project portfolio on the sectors of energy, economy and development of renewable energies that can be funded in the framework of the Clean Development Mechanism.
- After the definition of priority projects for exploiting the opportunities in the framework of the Clean Development Mechanism (CDM), the implementation of an important project on integrated waste management in Tunisia has started. Its activities include the realization of two Clean Development Mechanism projects:
- Methane collecting and flaring in the controlled landfill of Djebel Chakir, which would allow for the reduction of important amounts of GHG worth 3.7 million CO₂-TE equivalent for a ten-year period extending between 2007 and 2016. This project was registered by the CDM Executive Board in October 2006.
- Methane collecting and flaring in 9 controlled landfills over the country, which would allow for the reduction of some amounts of greenhouse emissions worth 3.2 million CO₂-TE equivalent for a ten-year period extending between 2007 and 2016. This project was registered by the CDM Executive Board in November 2006.
- The financial income resulting from selling methane emissions reductions in the framework of these projects will be devoted to the realization of new projects of rehabilitation of anarchic dumps, the creation of new controlled landfills, the planning and the development of waste management systems in Tunisia.
- Besides, the National Board of the Clean Development Mechanism approved about 50 projects, related to:
 - collecting and flaring of methane, and electric-power generation in the controlled landfills;
 - energy co-generation in many industrial units;
 - rural-house lighting and solar-power water pumping;
 - gas exploitation at oil and natural gas production sites;
 - public transport development in the Grand-Tunis;
 - wind power exploitation for electric-power production;
 - replacing liquid fuel by natural gas in a number of industrial areas;
 - N₂O emissions reduction in the nitrate acid production units of the Tunisian Chemistry Group.
- forest planting with pine and eucalyptus trees over an area of 15,440 hectares. It would allow for absorbing huge amounts of more than 12 million CO₂-TE over the 2009-2037 period, and for insuring important revenues from selling emissions reduction deeds. It would also contribute to protecting lands threatened by erosion, enhancing social conditions and providing income sources for the inhabitants of the project target areas.

Enhancing awareness in matters of climate change

Many activities and programs have been elaborated to better disseminate information about climate change and the Clean Development Mechanism among youths in 2006, besides promoters of projects likely to develop into small projects in the framework of the Clean Development Mechanism. The most important of these are:

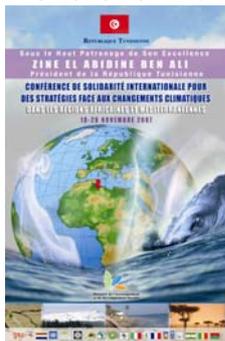
- A web site on the Clean Development Mechanism in Tunisia to serve as a communication interface for different actors and project promoters at national and international level, and a platform for foreign fund raising that would catalyse the rate of achievement of national projects of the Clean Development Mechanism.
- Organization of many training sessions on design and follow-up Clean Development Mechanism projects for project entrepreneurs in both public and private sectors, national consultants, and members of the Clean Development Mechanism National Board;
- Elaboration of an information and awareness-raising CD on the climate change phenomenon;
- Organization of training sessions on diagnosing climate change effects and adaptation and mitigation.

Considering the importance of climate change challenges, the Ministry of Environment and Sustainable Development has set up a comprehensive environmental awareness-raising strategy in relation to the issue and its implications.

It informs about the projects and measures that would allow individuals and institutions, at national and international levels, to contribute to reducing possible climate change effects. In cooperation with all concerned actors, a number of didactic aids and media (educational newsletters) have been elaborated for the dissemination of information on this

global phenomenon and supporting efforts for mitigating its effects, especially in the field of energy saving and exploiting alternative and renewable energies.

Promotion of international cooperation and solidarity to face climate change:



In response to the major environmental and socio-economic challenges- which are currently high on the international agenda- and with a view to contributing to international efforts aimed at raising awareness of the impacts of climate change, Tunisia hosted, on November 18-20, 2007, the “International Solidarity Conference on climate change strategies for the African and the Mediterranean Regions”.

a. Main objectives of the conference

- To identify strategies of adaptation and response to climate change for Africa and the Mediterranean Region ;
- To identify strategies of the developing African as well as Mediterranean countries;
- To instigate international mobilization and action for the developing African and Mediterranean countries so that they can meet the challenges of climate change;
- To strengthen the co-operation and solidarity between the African countries and the countries of the Mediterranean Region on the questions pertaining to climate change;
- To contribute to raising the awareness of African and Mediterranean decision-makers and populations of the potential impacts of climate change, and of the need for effective action in order to implement medium and long term adaptation and response strategies.

b. Major outputs of the Conference

- Tunis Declaration on the strategies of adaptation of Africa and the Mediterranean region to climate change and the mobilization of international solidarity to sustain the implementation of these strategies.
- A concrete plan of action aiming at establishing priority projects of adaptation for governments, enterprises, and civil society, while integrating the gender approach.
- An effective integration of climatic change in the sustainable economic development strategies of the concerned countries of Africa and the Mediterranean region.



Climate Change: An environmental, development and security issue

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Climate Change

Human activities are changing the Earth's climate and further human-induced climate change is inevitable. The question is not whether the Earth's climate will change in response to human activities, but rather where, when and by how much. The Earth's climate has warmed, on average by about 0.7°C, over the past 100 years, with the decades of the 1990s and 2000s being the warmest in the instrumental record, the temporal and spatial patterns of precipitation have changed, sea levels have risen by up to 25 cm, most non-polar glaciers are retreating, and the extent and thickness of Arctic sea ice in summer are decreasing. It is very likely that most of the observed warming (globally and regionally) of the past 50 years can be attributed to human activities increasing the atmospheric concentrations of greenhouse gases resulting from the combustion of fossil fuels and tropical deforestation, rather than changes in solar radiation or other natural factors. Observed changes in sea level, snow cover, ice extent and precipitation are consistent with a warmer climate. Projected changes in the atmospheric concentrations of greenhouse gases and aerosols are projected to result in increases in global mean surface temperatures between 1990 and 2100 of 1.1 to 6.4°C, with land areas warming more than the oceans, and high latitudes warming more than the tropics. Globally averaged precipitation is projected to increase, but with increases and decreases in particular regions, accompanied by more intense precipitation events over most regions of the world, and global mean sea-level is projected to rise by up to 0.5 meters, between 1990 and 2100, even without considering a contribution from melting of the Greenland ice sheets. The incidence of extreme weather events is projected to increase, e.g., hot days, floods and droughts.

Impacts of Climate Change

Observed changes in climate, especially warmer regional temperatures, have already affected biological systems in many parts of the world. There have been changes in species distributions, population sizes, the timing of reproduction or migration events, and an increase in the frequency of pest and disease outbreaks, especially in forested systems. Many coral reefs have undergone major, although often partially reversible, bleaching episodes, when sea surface temperatures have increased by 1°C during a single season, with extensive mortality occurring with observed increases in temperature of 3°C. While the growing season in Europe has lengthened over the last 30 years, in some regions of Africa the combination of regional climate changes and anthropogenic stresses has led to decreased cereal crop production since 1970. Changes in fish populations have been linked to large scale climate oscillations, e.g., El-Nino events have impacted fisheries off the coasts of South America and Africa, and decadal oscillations in the Pacific have impacted fisheries off of the west coast of North America. There is emerging evidence that the oceans are becoming more acidic, thus reducing their capacity to absorb carbon dioxide and affect the entire food chain. In addition, livestock will be affected in a number of ways including, a likely increase in diseases.

Projected changes in climate during the 21st century will occur faster than in at least the past 10,000 years with predominantly adverse consequences for developing countries and poor people within them. Low-lying Small Island States and deltaic regions of developing countries in South Asia, the South Pacific, and the Indian Ocean, could eventually disappear under water, displacing tens of millions of people in the process; peoples' exposure to malaria and dengue fever, already rampant in the tropics and sub-tropics, could become even more severe in some regions; crop production could significantly decrease in Africa, Latin America and in other developing countries, areas where hunger and child malnutrition are already prevalent; hydro-power could become less reliable in areas already energy insecure, and fresh water could become even more scarce in many areas of the world already facing shortages. Climate change will also exacerbate the loss of biodiversity, increase the risk of extinction for many species, especially those that are already at risk due to factors such as low population numbers, restricted or patchy habitats and limited climatic ranges, and adversely impact ecosystem services essential for sustainable development. For the 850 million people who go to bed hungry every night, and the 2 billion others exposed to insect-borne diseases and water scarcity, climate change threatens to bring more suffering in its wake. In this way, climate change may undermine long-term development and the ability of many poor people to escape poverty.

The Challenge

The challenge is simultaneously limit the magnitude and rate of human-induced climate change, by reducing emissions of greenhouse gases from all sectors, including agriculture, and to reduce the vulnerability of socio-economic sectors, ecological systems and human health to climate variability and change by integrating climate concerns into sectoral and national economic planning.

Based on the current understanding of the climate system, and the response of different ecological and socio-economic systems, significant adverse global changes are likely to occur if the global mean surface temperature exceeds 2°C above pre-industrial levels and the rate of change exceeds 0.2°C per decade. Stabilization of the equivalent concentration of carbon dioxide at 450ppm would imply a medium likelihood of limiting changes in the global mean surface temperature to below 2°C above pre-industrial levels.

Reducing emissions of greenhouse gases, which cannot be achieved with continued reliance on today's technologies and policies, must be achieved while improving access to affordable energy in developing countries, which is critical for poverty alleviation and economic growth. Reduced emissions of greenhouse gases will require energy sector reform, appropriate pricing policies, and a technological evolution in both the production and use of energy. However, technological options for significantly reducing greenhouse gas emissions over the long term already exist and large reductions can be attained using a portfolio of options and costs are likely to be lower than previously considered. Priority should be afforded to identifying and implementing policies and technologies that can simultaneously address local and regional air pollution and global climate change. In addition to reducing emissions from the energy sector it will be crucial to reduce the rate of deforestation, reduce emissions of methane from livestock and rice, and nitrous oxide from the use of fertilizers.

Political Situation

The long-term challenge is to meet the goal of Article 2 of the UN Framework Convention on Climate Change (UNFCCC), i.e., "stabilization of greenhouse concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, and in a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner." The UNFCCC also specifies several principles to guide this process: equity, common but differentiated responsibilities, precaution, cost-effective measures, right to sustainable development, and support for an open economic system.

Most industrialized countries have ratified the Kyoto Protocol, which mandates industrialized countries to reduce their emissions on an average by 5.2% between 2008 and 2012 relative to emissions in 1990, with individual industrialized country targets varying. There are no emissions targets for developing countries.

Given that many industrialized countries will not meet their reduction targets with domestic actions alone, this provides significant opportunities for carbon trading, which are likely to provide sustainable development benefits for many developing countries.

The challenge now is to negotiate a long-term global equitable regulatory framework with intermediate targets that can limit greenhouse emissions at a level that limits the increase in global mean surface temperature to 2°C above pre-industrial levels.

Livestock, greenhouse gases and global climate change

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Livestock's role in the global N and C cycles underlying climate change are closely connected to livestock's impact on land use and land-use change. Livestock's land use includes grazing land and cropland dedicated to the production of feed crops and fodder. Considering emissions along the entire commodity chain, livestock currently contribute about 18% to the global warming effect. Livestock contribute about 9% of total carbon dioxide (CO₂) emissions, but 37% of methane (CH₄), and 65% of nitrous oxide (N₂O). The latter will substantially increase over the coming decades, as the pasture land is currently at maximum expanse in most regions; future expansion of the livestock sector will increasingly be crop-based. There are a variety of emission reduction options that can be applied at reasonable costs and that could be target of investments, and further research and development. Such options includes

- a) carbon sequestration on extensively used grazing land,
- b) reduction of methane emissions from low-input ruminant production, in particular, dairy and
- c) reduction of methane and nitrous oxide emissions from animal waste, through energy recovery and improved waste management.

The consequences of global warming for agriculture and food production

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Introduction

Climate change will impact (and has already impacted) upon a large range of physical/biological systems and sectors of human activity, among them agriculture (including livestock) and its main output as food production. It is clear that it needs to not be considered alone as several other driving forces, especially in the economical and societal domain, will determine the evolution during the present century. But it has also to be taken into account as a first-order factor in the context of the enormous challenge of furnishing food for about 9 billion people instead of the current 6 billion.

Existing knowledge

The main effects of the impacts have been established in the 1990s with the perspective of a doubling of CO₂ concentration. Their findings are summarised in a large number of books or conference proceedings, including Parry *et al.*, 1988, IRRI 1989, ASA 1995, Rosenzweig and Hillel 1998, Reddy and Hodges 2000).

While confirming them in their main lines, and furnishing more detailed estimates of the consequences for global food production (Parry *et al.*, 2004), the recent work differs by the introduction of the range of emission scenarios (SRES defined by IPCC around 2000) which gives a corresponding range of impacts depending upon the hypotheses of warming. The analysis of the recent scientific literature performed by IPCC for the edition of the Fourth Assessment Report (AR4) allows for a summary of these recent areas of progress, either in their main lines (IPCC, 2007) or in the detailed analysis of future impacts (Easterling *et al.*, 2007) and already observed changes (Rosenzweig *et al.*, 2007). When considering the outputs in quantified terms, it is now necessary to be aware that they are closely linked to one definite set of scenarios, as well as to a precise temporal horizon (generally 2030, 2050 or 2100), which has led IPCC to express them as a function of the global temperature increase

Foreseen effects on crop functioning

When considering the changes in the eco-physiological functioning of vegetal production, it is firstly necessary to consider the stimulation of photosynthesis by the elevation of CO₂ atmospheric concentration, which will concern pastures, forests and natural vegetation as well as annual crops. For these, even if there is some controversy about the results of experiments with free-air enrichment, the well-established curves of photosynthesis enrichment on an instantaneous basis (Figure 1) lead to an increase of about 10-20% with 550 ppm for C₃ temperate species such as wheat, rice or soybean, whilst it seems to be limited to 0-10% for C₄ tropical species such as maize or sorghum (Easterling *et al.*, 2007).

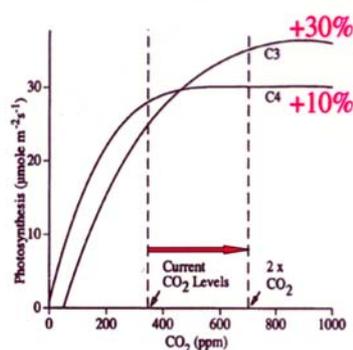


Figure 1 Typical increase of photosynthesis with increase in carbon dioxide concentration

The direct effect of changes in the climatic variables has to be superposed to this increase of potential production. It evidently involves temperature, whose effects may be quite variable. Higher elevated temperatures are generally favourable for growth in cold and temperate climates (except however when they exceed the optimum and even attain detrimental thresholds in the case of extreme events) and are generally unfavourable for warm areas. For the development, the advance in phenology will have as its main consequence, a reduction in the duration of the cycle of determinate species (thus the time during which photosynthesis is working), but also to shift the periods during which the plant is more sensitive to a given factor, as for example the flowers of fruit trees (which may result in an increase of spring frost risks in spite of a reduction of purely climatic frost conditions). But, for perennial species like grass or forests, warmer conditions will speed the budburst at spring and delay the browning in autumn, which results in a significant increase of the duration of the growth season.

Rainfall, on a first range, and other water balance components like potential evapo-transpiration will more or less seriously modulate (or not) the potential changes in plants resulting from these effects of temperature increase. It is sure that tendencies towards drier conditions in some areas like the Mediterranean basin or the south of Africa will fully cancel the positive potential impact of higher CO₂ or milder temperatures!

More generally, we also have to clearly state that the general presentation mainly takes into account the continuous effect of mean values for the climatic conditions, but that both their variability and the occurrence of extreme events (frosts and heat-waves, droughts or torrential rainfall) could totally confirm or inverse this mean tendency.

On the whole, the combination of these various influences leads to a variety of contrasted effects, depending upon the type of crop production and the geographical zone.

Foreseen effects on crop production

If the resulting effects on crop production may be grossly estimated by setting some in-field experiments or using empirical tools like climatic indices, there is a general agreement for considering that the correct use of well-defined and validated deterministic crop models is able to give valuable predictions. The IPCC AR4 report allows a synthetic view of published studies, as depicted in Figure 2.

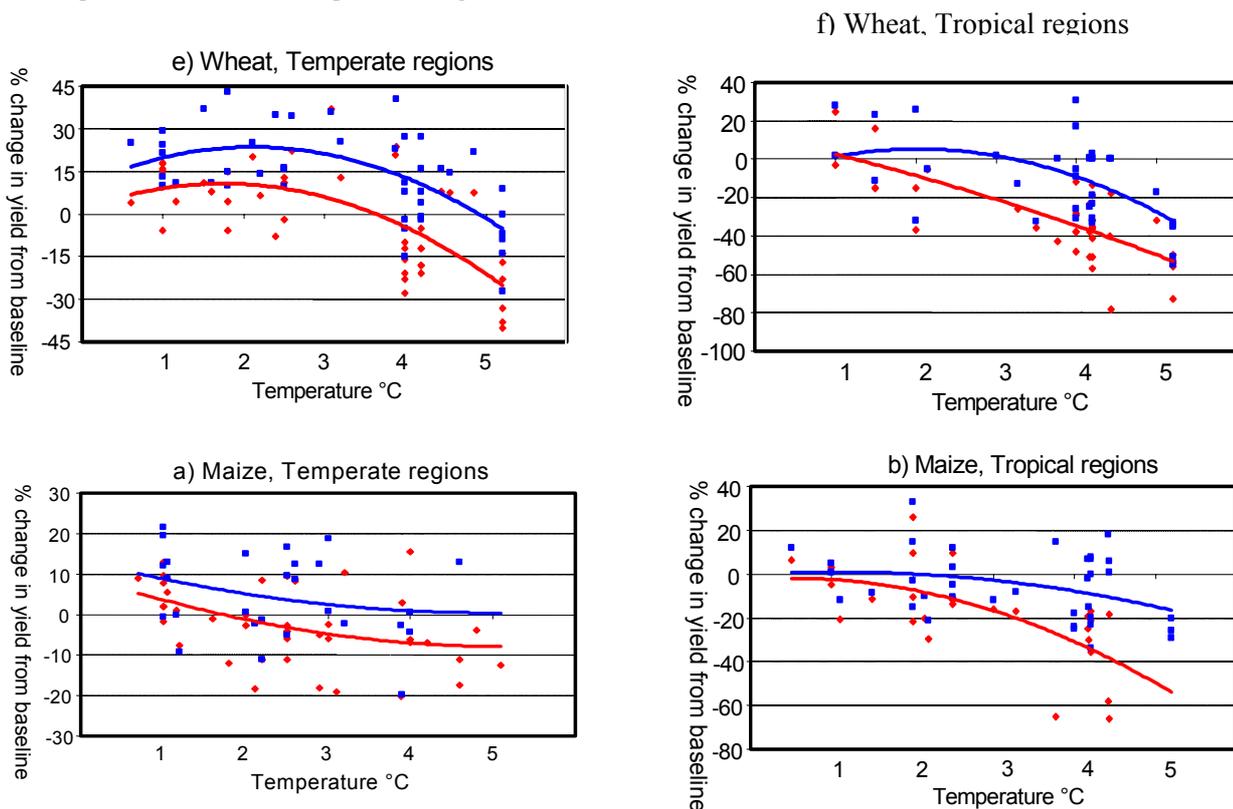


Figure 2 Effects of temperature change on wheat and maize for (left) mid to high latitudes and (right) low latitude (from Easterling *et al.*, 2007)

Generally, crop models are used to simulate the effects of a climate change on crops currently cultivated. Evidently, there will be an adaptation, which will involve changes in the crop/livestock systems combining changes in varieties and cultural practices. As it is possible to estimate from Fig 2 (where the lower line is without adaptation and the higher with it), it seems able to improve the yield by 10 to 15%. The summary given in IPCC (2007) states that “temperate regions, moderate to medium increases in local mean temperature (1° to 3°), along with associated CO₂ increase and rainfall changes, can have small beneficial impacts on crop yields. At lower latitudes, especially the seasonally dry tropics, even moderate increases (1 to 2°) are likely to have negative yield impacts for major cereals. Further warming has increasingly negative impacts in all regions”. Of specific relevance to livestock, the chapter by Easterling *et al* (2007) indicates the same tendency for pasture production in terms of biomass production. It will be accompanied by changes in community structure (still to be clarified) and forage quality and grazing behaviour (confirmed). On the animal side, the thermal stress is known to reduce productivity and conception rate, rather than to be potentially life-threatening for livestock. Here too, the increased climate variability, especially with the occurrence of droughts, may lead to serious loss.

Observed changes in agriculture and livestock resulting from the recent warming are still poorly perceptible, in contrast with observations on the advances in phenology (flowering of fruit trees, advances in harvest of vines and cereals), except for the case of the wine production in terms of quality (sugar and alcohol content, acidity). It is hardly discernable from other driving forces for regional yield and global production or market, which are more (up to now)

influenced by the climate variability. Among the various recent events, severe droughts have confirmed the large sensitivity of pasture production, with large-scale losses of 50% and more, far larger than those of cereals.

Consequences for global food production

A complete view of the future would also involve an assessment of the future adaptation by geographical displacement of production zones. If it seems easy to give a general idea of possible shifts (like the potential extension of grain maize or vines towards the north or the east in Europe), it is much more difficult to quantitatively assess the large-scale consequences.

Also, the forcing function of economy on the agricultural production (as we can see with the totally unforecasted recent jumps in cereal prices and the competition for land use with biofuels) is such that it is only possible to give the main tendencies caused by climate change. When it is attempted to aggregate up to the global trade market, it is confirmed that most of the increase in production will come from the agriculture of developed countries (which mostly benefit from climate change), which will have to compensate for declines projected, for the most part, in developing countries (Parry *et al* 2004), with declines in agricultural productivity approaching 20 to 25% for some countries like Mexico, Nigeria or South Africa (Cline 2008 on the website of the Peterson Institute for International Economics). The resulting increase in the number of people marginally at risk of hunger (from 380 millions up to 1300 millions in 2080, depending upon the future emission scenario) could even be underestimated in the case of surprises due to the increased frequency and severity of extreme events.

References

- ASA, 1995, Climate change and agriculture: analysis of potential international impacts, ASA special publication, number 59, 382 pp
- Easterling, W.E., P.K. Aggarwal, P. Batima, K.M. Brander, L. Erda, S.M. Howden, A. Kirilenko, J. Morton, J.-F. Soussana, J. Schmidhuber and F.N. Tubiello, 2007: Food, fibre and forest products. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 273-313.
- IPCC. 2007. Climate change 2007. Impacts, adaptation and vulnerability, Summary for policymakers and technical summary, WG II contribution to the AR4, 93 pp.
- IRRI, 1989, Climate and food security, 602 pp
- Parry.M.L., T.R Carter and N T Konijn. 1988, The impact of climatic variations on agriculture, IIASA Laxenburg ed, 2 volumes (I cool temperate and cold regions, 876 pp, II semi-arid regions 764 pp)
- Parry.M.L., C. Rosenzweig, A. Inglesias, M. Livermore and G. Fischer. 2004. Effects of climate change on global food production under SRES emission s and socio-economic scenarios. Global Environmental Change, Part A, 14(1), 53-67 pp
- Rosenzweig, C., G. Casassa, D.J. Karoly, A. Imeson, C. Liu, A. Menzel, S. Rawlins, T.L. Root, B. Seguin, P. Tryjanowski, 2007: Assessment of observed changes and responses in natural and managed systems. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 79-131.
- Reddy. K.R. and Hodges H.F,2000, Climate change and global productivity, CABI Publishers, 472 pp
- Rosenzweig, C. and D Hillel. 1998. Climate Change and the Global Harvest: Potential Impacts of the Greenhouse Effect on Agriculture, Oxford University Press, 324 pp

The role of the carbon cycle for the greenhouse gas balance of grasslands and of livestock production systems

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Introduction

Grasslands and rangelands contribute to the livelihoods of over 800 million people including many poor smallholders (Reynolds *et al.* 2005) and provide a variety of goods and services to support flora, fauna, and human populations worldwide. The global livestock sector generates directly or indirectly 18% of global greenhouse gas emissions as measured in CO₂ equivalent (FAO, 2006) (see Steinfeld *et al.*, this volume). Worldwide the soil organic C sequestration potential is estimated to be 0.01–0.3 GtC year⁻¹ on 3.7 billion ha of permanent pasture (Lal, 2004). Thus, soil organic C sequestration by the world's permanent pastures could potentially offset up to 4% of the global greenhouse gas (GHG) emissions.

A meta-analysis of 115 studies in pastures and other grazing lands worldwide (Conant *et al.* 2001), indicated that soil C levels increased with improved management (primarily fertilisation, grazing management, and conversion from cultivation or native vegetation) in 74% of the studies considered. To increase SOC sequestration on rangelands generally requires improved grazing management, introduction of legumes, and control of undesirable species. Follett and Schuman (2005) reviewed grazing land contributions to C sequestration worldwide using 19 regions. A positive relationship was found, on average, between the C sequestration rate and the animal stocking density, which is an indicator of the pasture primary productivity. Based on this relationship they estimate a 0.2 Gt SOC sequestration/year on 3.5 billion ha of permanent pasture worldwide. Using national grassland resource dataset and NDVI time series data, and assuming a constant ratio of aboveground to belowground biomass for each grassland type, Piao *et al.* (2007) estimated that the total (above- and below-ground) biomass C stocks of China's grasslands increased by 126.67 Tg C over the past two decades, with an increase of 7.04 Tg C year⁻¹.

In temperate regions, like Europe, SOC sequestration would be favoured by grazing compared to cutting and by a close to optimal N fertilizer application (Soussana *et al.*, 2007). However, this N fertilizer supply also increases strongly the N₂O emissions from soils. Moreover, increasing the animal stocking density also leads to greater methane emissions from enteric fermentation. We review here the biosphere–atmosphere exchange of radiatively active trace gases in grasslands and discuss their implications for the greenhouse gas balance of livestock production systems.

The carbon balance of managed grasslands

The nature, frequency and intensity of disturbance play a key role in the C balance of grasslands. In a cutting regime, a large part of the primary production is exported from the plot as hay or silage, but part of these C exports may be compensated for by farm manure and slurry application. Under intensive grazing, up to 60 % of the above ground dry matter production is ingested by domestic herbivores (Lemaire and Chapman, 1996). However, this percentage can be much lower during extensive grazing. The largest part of the ingested carbon is digestible and, hence, is respired shortly after intake. Only a small fraction of the ingested carbon is accumulated in the body of domestic herbivores or is exported as milk.

Additional carbon losses (*ca.* 5 % of the digestible carbon) occur through methane emissions from the enteric fermentation (see O'Mara, this volume). The non-digestible carbon (20–40 % of intake) is returned to the pasture in excreta (mainly as faeces). In intensive husbandry systems, the herbage digestibility tends to be maximised by agricultural practices such as frequent grazing and use of highly digestible forage cultivars. Consequently, the primary factor which modifies the carbon flux returned to the soil by excreta is the grazing pressure. Organic matter is mostly incorporated in grassland soils through rhizodeposition (Jones and Donnelly, 2004). This process favours carbon storage (Balesdent and Balabane, 1996), because direct incorporation into the soil matrix allows a high degree of physical stabilisation of the soil organic matter.

With the advancement of micrometeorological studies of the ecosystem-scale CO₂ exchange (Baldocchi and Meyers, 1998), eddy flux covariance measurement techniques have been applied to grassland and rangelands. Eddy covariance measurements estimate net ecosystem exchange (NEE) of CO₂ over heterogeneous covers such as pastures. Moreover, since the measurement uses a free air technique, as opposed to enclosures, there is no disturbance of the measured area which can be freely accessed by herbivores.

Gilmanov *et al.* (2007) have analysed tower CO₂ flux measurements from 20 European grasslands covering a wide range of environmental and management conditions. Annual net ecosystem CO₂ exchange (NEE) varies from significant net uptake (650 g C m⁻² yr⁻¹) to significant release (160 g C m⁻² yr⁻¹), though in 15 out of 19 cases grasslands performed as net CO₂ sinks. Four sites became C sources in some years, two of them during drought events and two of them with a significant peat horizon. The carbon source was associated with organic rich soils, grazing, and heat stress (Ciais *et al.*, 2005). These findings confirm earlier estimates for North America (Follett, 2001) that these ecosystems predominantly act as a sink for atmospheric CO₂.

In cut grasslands, biomass is exported off site and neither this carbon export, nor the import of carbon from organic fertilizers, is detected by the atmospheric budget. Therefore, accounting for exports and imports of organic carbon is essential to compare cut and grazed grasslands in terms of their net carbon storage (NCS). The average NCS was estimated at 104 ± 73 g C m⁻² yr⁻¹ for 9 European sites measured during two years. Since more organic C was harvested

from, than returned to, the grassland plots the NCS reached only 45 % of the NEE. The NCS declined with the degree of herbage utilisation through cutting and grazing (Soussana *et al.*, 2007).

Changes in soil carbon through time are non linear after a change in land use or in grassland management. A simple two parameters model has been used to estimate the magnitude of the soil carbon stock change after a change in grassland management (Soussana *et al.*, 2004b). Land use change from grassland to cropland systems causes losses of SOC in temperate regions ranging from 18% (± 4) in dry climates and to 29% (± 4) in moist climates. Converting cropland back to grassland uses for 20 years was found to restore 18% (± 7) of the native carbon stocks in moist climates (relative to the 29% loss due to long-term cultivation) and 7% (± 5) of native stocks in temperate dry climates (Conant *et al.*, 2001). Grasslands that are degraded for 20 years typically have 5% (± 6) less carbon than native systems in tropical regions and 3% (± 5) less carbon in temperate regions. Improving grasslands with a single practice caused a relatively large gain in SOC over 20 years, estimated as 14% (± 6) in temperate regions and 17% (± 5) in tropical regions, while having an additional improvement led to another 11% (± 5) increase in SOC (IPCC, 2004).

As a result of periodic tillage and resowing, short duration grasslands tend to have a potential for soil carbon storage intermediate between crops and permanent grassland. Part of the additional carbon stored in the soil during the grassland phase is released when the grassland is ploughed up. The mean carbon storage increases in line with prolonging the lifespan of covers, *i.e.* less frequent ploughing (Soussana *et al.*, 2004a).

The greenhouse gas balance of managed grasslands

When assessing the impact of land use and land use change on greenhouse gas emissions, it is important to consider the impacts on all greenhouse gases (Robertson *et al.*, 2000). N₂O and CH₄ emissions are often expressed in terms of CO₂ or CO₂-carbon equivalents, which is possible because the radiative forcing of nitrous oxide, methane and carbon dioxide, can be integrated over different timescales and compared to that for CO₂. For example, over the 100-year timescale, one unit of nitrous oxide has the same global warming potential as 310 units of carbon dioxide, whereas, on a kilogram for kilogram basis, one unit of methane has the same GWP as 21 units of carbon dioxide (IPCC, 2001a). An integrated approach is needed to quantify in CO₂-C equivalents the fluxes of all three trace gases (CO₂, CH₄, N₂O).

Biogenic emissions of N₂O from soils result primarily from the microbial processes nitrification and denitrification. N₂O is a by-product of nitrification and an intermediate during denitrification. Nitrification is the aerobic microbial oxidation of ammonium to nitrate and denitrification is the anaerobic microbial reduction of nitrate through nitrite, nitric oxide (NO) and N₂O to N₂. Major environmental regulators of these processes are temperature, pH, soil moisture (*i.e.* oxygen availability) and carbon availability. In most agricultural soils, addition of fertiliser N or manures and wastes containing inorganic or readily mineralisable N, will stimulate N₂O emission, as modified by soil conditions at the time of application.

The IPCC (1996a) methodology assumes a default emission factor (EF₁) of 1.25 % (range 0.25 to 2.25 %) for non tropical soils emitted as N₂O per unit nitrogen input N. In one recent study, annual emission factors from fertilized European grassland systems were highly variable, but the mean emission factor (0.75%) was substantially lower than the IPCC default value of 1.25% (Flechard *et al.*, 2007). Indirect emissions of N₂O induced by the recycling of N derived from fertilizers (IPCC, 2006) may, however, lead to an overall emission factor of 3–5% (Crutzen *et al.*, 2006).

In soils, methane is formed under anaerobic conditions at the end of the reduction chain when all other electron acceptors such as, for example nitrate and sulphate, have been used. Methane emissions from freely drained grassland soils are, therefore, negligible. In wet grasslands as in wetlands, the development of anaerobic conditions in soils may lead to methane emissions (Hendricks *et al.*, 2007). In contrast, aerobic grassland soils tend to oxidise methane at a larger rate than cropland soils (6 and 3 kg CH₄ ha⁻¹ yr⁻¹ respectively), but less so than uncultivated soils (Boeckx and Van Cleemput, 2001).

Under grazing conditions, most of the variability in the enteric methane production of grassland plots lies in the number of animals per unit land area. The daily methane emission rate per unit liveweight varies also markedly at grazing between different animal types. This rate, measured with the SF₆ dual tracer technique, was comprised between 0.33 and 0.45 gCH₄ kg⁻¹LW d⁻¹ for heifers and bulls and reached 0.68-0.97 gCH₄ kg⁻¹LW d⁻¹ for lactating cows (Pinares-Patino *et al.*, 2007, Soussana *et al.*, 2007). Respiration by cattle is ‘short-cycling’ carbon, which has been fixed by photosynthesis earlier and has thus no net effect on atmospheric concentrations.

Budgeting equations can be extended to include fluxes of non CO₂ radiatively active trace gases and calculate a net exchange rate in CO₂-C equivalents, using the global warming potential of each gas at the 100 years time horizon (IPCC, 2001). A shorter time horizon would increase the relative weight of CH₄, since this trace gas has a shorter lifespan in the atmosphere than CO₂ and N₂O. On average of nine European sites, based on a 100 years time horizon, managed grasslands displayed annual N₂O and CH₄ emissions of 14 \pm 5 and 32 \pm 7 gCO₂-C equivalents m⁻² yr⁻¹, respectively. These emissions compensated 19 % of the NEE (CO₂) sink activity. By further including i) offsite CO₂ and CH₄ emissions directly induced by the digestion and enteric fermentation of the forage harvests, ii) manure and slurry applications adding organic C to the soil, the net GHG balance of the grasslands was found to be, on average, a small sink (85 \pm 77 g CO₂-C equivalents m⁻² yr⁻¹).

Taken together, these results show that European grasslands are likely to act as a relatively large atmospheric CO₂ sink (Janssens *et al.*, 2003). By contrast to forests, approximately half of the sink activity is stored in labile carbon pools (*i.e.* forage), which will be digested within one year by herbivores. When expressed in CO₂-C equivalents, on site N₂O and CH₄ emissions from grassland plots do not compensate, on average, the atmospheric CO₂ sink activity. Nevertheless, the off site digestion by livestock of the harvested herbage leads to additional emissions of CO₂ and CH₄ that tend to offset the carbon sink activity.

Livestock production systems

A grazing livestock farm consists in a productive unit that converts various resources into outputs as milk, meat and sometimes grains too. In Europe, many ruminant farms have mixed farming systems: they produce themselves the roughage and, most often, part of the animal's feeds and even straw that is eventually needed for bedding. Conversely, these farms recycle animal manure by field application. Most farms purchase some inputs, such as fertilizers and feed, and they always use direct energy derived from fossil fuels. The net emissions of greenhouse gases (methane, nitrous oxide and carbon dioxide) are related to carbon and nitrogen flows and to environmental conditions.

Until now, there are only few recent models of the farm GHG balance. Most models have used fixed emission factors both for indoors and outdoors emissions (e.g. FARM GHG Olesen *et al.* 2006, Lovett *et al.*, 2006). Although, these models have considered the on and off farm CO₂ emissions (e.g. from fossil fuel combustion), they did not include possible changes in soil C resulting from the farm management. Moreover, as static factors are used rather than dynamic simulations, the environmental dependency of the GHG fluxes is not captured by these models.

A dynamic farm scale model (FarmSim) has been coupled to mechanistic simulation models of grasslands (PASIM) and croplands (CERES ECGC). The IPCC methodology Tier 1 and Tier 2 is used to calculate the CH₄ and N₂O emissions from cattle housing and waste management systems. The net greenhouse gas balance at the farm gate is calculated in CO₂ equivalents. Emissions induced by the production and transport of farm inputs (fuel, electricity, N-fertilizers and feedstuffs) are calculated using a full accounting scheme based on life cycle analysis. The FarmSim model has been applied to seven contrasted cattle farms in Europe (Salètes *et al.*, 2004). The balance of the farm gate GHG fluxes leads to a sink activity for four out of the seven farms. When including pre-chain emissions related to inputs, all farms - but one - were found to be net sources of GHG. The total farm GHG balance varied between a sink of -70 and a source of +310 kg CO₂ equivalents per unit (GJ) energy in animal farm products. As with other farm scale models, the annual farm N balance was the single best predictor of the farm GHG budget (Schils *et al.*, 2007).

Conclusions

There are still substantial uncertainties in most components of the GHG balance of livestock production systems. Methods developed for national and global GHG inventories are inaccurate at the farm scale. Carbon sequestration (or loss) plays an important, but often neglected, role in the farm GHG budget. Livestock production systems can be ranked differently depending on the approach (farm gate budget, farm cycle analysis) and on the criteria (emissions per unit land area or per unit animal product) selected. Further development of farm scale models carefully tested at benchmark sites will help reduce uncertainties. Mitigating emissions and adapting livestock production systems to climate change will require a major international collaborative effort.

Implications

The carbon sequestration potential by grasslands and rangelands could be used to partly mitigate the greenhouse gas emissions of the livestock sector. This will require avoiding land use changes that reduce ecosystem soil carbon stocks (e.g. deforestation, ploughing up long term grasslands) and a cautious management of pastures, aiming at preserving and restoring soils and their soil organic matter content. Combined with other mitigation measures, such as a reduction in the use of N fertilisers, of fossil-fuel energy and of N rich feedstuffs by farms this may lead to substantial reductions in greenhouse gas emissions per unit land area. Trade-offs between greenhouse gas emissions and animal production need to be better understood at the farm and regional scales, through a continued development of observational, experimental and modelling approaches.

References

- Baldocchi, D., and Meyers, T. 1998. *Agriculture and Forest Meteorology* 90:1–25.
- Balesdent, J., and Balabane, M. 1996. *Soil Biology and Biochemistry* 28:1261–1263.
- Boeckx, P., and Van Cleemput, O. 2001. *Nutrient Cycling in Agroecosystems* 60:35–47.
- Ciais P. Reichstein M. Viovy N. Granier A. Ogee J. Allard V. Aubinet M. Buchmann N. Bernhofer C. Carrara A. Chevallier F. De Noblet N. Friend AD. Friedlingstein P. Grunwald T. Heinesch B. Keronen P. Knohl A. Krinner G. Loustau D. Manca. 2005. *Nature* 437(7058):529–533.
- Conant, R.T., Paustian, K., and Elliott, E.T. 2001. *Ecological Applications* 11:343–355.
- Delgado, C.L. 2005. In: McGilloway (Ed.), *Grassland: A Global Resource*, pp. 29–41. Wageningen Acad. Publisher. ISBN907699871X.
- Flechar, C.; Ambus, P.; Skiba, U.; Rees, R.M.; Hensen, A.; Amstel, A.R. van; Pol, A. van den; Soussana, J.F.; Jones, M.; Clifton-Brown, J.C.; Rachi, A.; Horvath, L.; Neftel, A.; Jocher, M.; Ammann, C.R.; Leifeld, J.; Fuhrer, J.; Calanca, P.; Thalman, E.; Pilegaard, K.; Di Marco, G.S.; Campbell, C.; Nemitz, E.; Hargreaves, K.J.; Levy, P.E.; Ball, B.; Jones, S.K.; Bulk, W.C.M. van de; Groot, T.; Blom, M.; Domingues, R.; Kasper, G.J.; Allard, V.; Ceschia, E.; Cellier, P.; Laville, P.; Henault, C.; Bizouard, F.; Abdalla, M.; Williams, M.; Baronti, S.; Berretti, F.; Grosz, B. 2007. *Agriculture Ecosystems and Environment* 121(1-2):135–152.
- Follett, R.F. 2001. In: Follett, R.F., Kimble, J.M., and Lal, R. (Eds.), *Potential of US Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect*, pp. 65–86. Lewis Publishers Inc., Boca Raton.
- Gilmanov, T.G., Soussana, J.F., Aires, A., Allard, V., Ammann, C., Balzarolo, M., Barcza, C., Bernhofer, C., Campbell, C.L., Cernusca, A., Cescatti, A., Clifton-Brown, J.C., Dirks, B.O.M., Dore, S., Eugster, W., Fuhrer, J., Gimeno, C., Gruenwald, T., Haszpra, L., Hensen, A., Ibrom, A., Jacobs, A.F.G., Jones, M.B., Lanigan, G., Laurila, T., Lohila, A., Manca, G., Nagy, Z., Pilegaard, K., Pinter, K., Pio, C., Raschi, A., Rogiers, N., Sanz, M.J., Stefani, P., Sutton, M., Tuba, Z., Valentini, R., Williams, M.L., Wohlfahrt, G. 2007. *Agriculture, Ecosystems and Environment* 121:93–120.

Hendriks, D.M.D., van Huissteden, J., Dolman, A.J., and van der Molen, M.K. 2007. *Biogeosciences* 4:411–424.

European Environment Agency (EEA) 2005. *The European Environment: State and outlook 2005. Part A. Integrated assessment* 245 pp. EEA.

IPCC 1996a. *Revised guidelines for national greenhouse gas inventories*. Intergovernmental Panel on Climate Change, IPCC, Cambridge University Press.

IPCC 2001a. *Climate change 2001: The scientific basis*. Intergovernmental Panel on Climate Change, Cambridge University Press.

IPCC 2001b. *Good practice guidance and uncertainty management in national greenhouse gas inventories*. Intergovernmental Panel on Climate Change, Institute for Global Environmental Strategies, Tokyo, Japan.

IPCC 2004. *Good practice guidance on land use change and forestry in national greenhouse gas inventories*. Intergovernmental Panel on Climate Change, Institute for Global Environmental Strategies, Tokyo, Japan.

IPCC 2006. *IPCC Guidelines for National Greenhouse Gas Inventories*. Vol. 4, Chapter 11, N₂O emissions from managed soils, and CO₂ emissions from lime and urea application, IGES, Hayama, Japan, 2006.

Janssens, I.A., Freibauer, A., Ciais, P., Smith, P., Nabuurs, G.-J., Folberth F., Schlamadinger B., Jutjes R. W. A., Ceulemans R., Schulze A.-D., Valentini R. and Dolman A. J. 2003. *Science* 300:1538–1542.

Jones, M.B., and Donnelly, A. 2004. *New Phytologist* 164:423–439.

Lal, R. 2004. *Science* 304:1623–1627.

Lemaire, G., and Chapman, D. 1996. In: Hodgson, J., Illius, A.W. (Eds.), *The Ecology and Management of Grazing Systems*. CABI, Wallingford.

Olesen, J.E., Schelde, K., Weiske, A., Weisbjerg, M.R., Asman, W.A.H., and Djurhuus, J. 2006. *Agriculture, Ecosystems and Environment* 112:207–220.

Pinares-Patino, C.S., Dhour, P., Jouany, J.-P., and Martin, C. 2007. *Agriculture, Ecosystems and Environment* 121:30–46.

Robertson, G.P., Paul, E.A., and Harwood, R.R. 2000. *Science* 289:1922–1925.

Salètes, S., Fiorelli, J.L., Vuichard et al. 2004. In: *Greenhouse Gas Emissions from Agriculture – Mitigations Options and Strategies*; Int Conference February, 2004, Leipzig, Germany 203-208.

Schils, R.L.M., Olesen, J.E., del Prado, A., and Soussana, J.F. 2007. *Livestock Science* 112, 240–251.

Soussana, J.F., Loiseau, P., Vuichard, N., Ceschia, E., Balesdent, J., Chevallier, T., and Arrouays, D. 2004a. *Soil Use and Management* 20:219–230.

Soussana, J.F., Salètes, S., Smith, P., Schils, R., and Ogle, S. 2004b. In: Sezzi, E., Valentini, R. (Eds.) *CarboEurope GHG, Synthesis of the European Greenhouse Gas Budget*. U. Tuscia, Viterbo, Italy.

Soussana, J.F.; Allard, V.; Pilegaard, K.; Ambus, P.; Ammann, C.; Campbell, C.; Ceschia, E.; Clifton-Brown, J.; Czobel, S.; Domingues, R.; Flechard, C.; Fuhrer, J.; Hensen, A.; Horvath, L.; Jones, M.; Kasper, G.; Martin, C.; Nagy, Z.; Neftel, A.; Raschi, A.; Baronti, S.; Rees, R.M.; Skiba, U.; Stefani, P.; Manca, G.; Sutton, M.; Tuba, Z.; Valentini, R. 2007. *Agriculture, Ecosystems and Environment* 121:121–134.

Vuichard, N., Ciais, P., Viovy, N., Calanca, P., and Soussana, J.F. 2007b. *Global Biogeochemical Cycles* 21:13. GB1005. doi:10.1029/2005GB002612.

Impacts on livestock agriculture of competition for resources

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Introduction

All agriculture of necessity impacts on its immediate, proximate and distant environments. Growing awareness of the impacts of anthropogenic climate change has directed attention to the impacts that agriculture has on greenhouse gas emissions and to the options for mitigation and adaptation that could accrue. With the two major agricultural greenhouse gases both being intimately associated with livestock production, there has been real pressure on animal production systems to address the problems of methane and nitrous oxide emissions. Whilst understandable in the current political climate, I believe that such an approach is incomplete unless it looks at climate change impacts alongside the other impacts (both positive and negative) that livestock agriculture causes. The concept of a systems-based approach to costs and benefits forms the basis of “Sustainable Agriculture”. Unfortunately this approach gives rise to two major problems. The first is the need to compare benefits and disbenefits that often have different currencies. For example, appropriate levels of grazing are essential to preserve pastoral flora and maintain landscape and biological diversity in unimproved grasslands. However, the greenhouse gas emissions “footprint” of extensive systems is significantly higher than that of more intensive systems when expressed per unit of agricultural production. How much extra methane is a rare orchid worth? How does its worth diminish as it becomes more widespread? Currently we do not have such a common currency, although some researchers are considering how this might be developed (Pretty, 2007).

The second major problem is that the weight given to various elements of sustainability will differ in both time and space. UK livestock production systems for example are not significantly constrained by water availability. By contrast, the production of many of the components of bought-in feed for UK livestock occurs in countries where water is a major limitation, yet this does not figure in most discussions of the sustainability of UK systems. The end result of this is that it is unwise in my view to consider the mitigation of the greenhouse gas footprint of livestock agriculture in isolation and much preferable to consider it as one element of improving sustainability (Pollock and Pretty, 2007). Under these circumstances, the important issues are those which may have a negative impact on sustainability, and particularly how they interact with one another. The livestock sector is particularly vulnerable to change, given that it competes substantially with direct human feeding for key resources. The purpose of this summary is to identify and discuss key elements of this competition and consider where they may impinge on mitigation or adaptation to climate change. Unfortunately most of the changes that we are likely to see over the next 50 years are going to make both mitigation and adaptation more difficult and do, in my view, present real challenges to the livestock industry.

Competition for feed

Current intensive livestock production systems, even those involving ruminants, rely substantially on bought-in feedstuffs. Maize, wheat and soybeans are major components of animal feed worldwide, together with residues such as rape meal and molassed beet. It is possible to run ruminant (and to a lesser extent poultry and pig-based) systems exclusively on pasture and foraging, but productivity is low in comparison. Mixed farming, where animal and crop-based enterprises coexist, is a half-way house and Wilkins (2007) argues strongly for the virtues of such an approach. However, in all cases grain fed to animals is grain that cannot be fed to humans. Demand for animal products is increasing worldwide, driven mainly by increasing prosperity in Asia and to a lesser extent South America, and IFPRI have estimated that an extra 300 MT of grain will be needed by 2050 just to feed to livestock. At the same time, overall human demand for arable crops is increasing, driven mainly by population growth, predicted to reach 9 billion within the 21st century. Feeding large amounts of grain to livestock is the basis of most intensive production systems. These will generate the lowest greenhouse gas footprint per unit of production, but may not be sustainable even in the short-term, as the UK pig industry is discovering. Wheat prices have more than doubled within the last 12 months, and whilst increased plantings will go some way to stabilize prices, it is difficult to see a return to a situation where bought-in feed represents a small proportion of enterprise costs. This is an excellent example of the “sustainability dilemma” The development of eco-efficient livestock systems (Wilkins, 2007) is a logical response to increased prices and reduced security of bought-in feed but will, inevitably, lead to an increase in greenhouse gas emissions per unit of production.

Competition for water

The competition for water between different strands of human activity will be one of the defining issues of the 21st century. In a detailed analysis of the impact of this on pastoral agriculture, Rosegrant *et al* (2005) suggest that global demand for non-irrigation water will increase by two-thirds by 2025 if current trends continue. Modeling this against water availability suggests that agricultural demand will increase much more slowly, limited by availability and price. This in turn will have a constraining effect upon crop production and will compound the issues discussed above in terms of increased competition for the outputs of arable agriculture. These authors argue further that any steps taken to use water more sustainably will require some element of water pricing to reflect its true cost of delivery. This could further impact on elements of livestock agriculture in that it has been calculated that 14 times as much water is needed to deliver the same amount of profit from irrigated pasture as from fruit and vegetable production. Pasture irrigation is

rare in developing countries but widespread in the USA and Australia. Were this to become uneconomic because of proportionate water pricing, then it would significantly impact on the global supply of animal products.

Rainfed agriculture is seen by Rosegrant *et al* (2005) as the key to sustainable development of livestock production. Direct water consumption by livestock is small (less than 2% of total water consumption) but intensive animal production systems consume much more in total. Estimates vary between 3500 and 20500 litres of water per kg product, the vast majority of which is used in irrigated pasture and feed crops. However, the overall productivity of such systems, particularly in warmer climates is lower, and direct effects of climate change on patterns of rainfall are likely to reduce production even more in lower latitudes. It is very difficult to estimate the economic impact of a switch away from irrigation within the intensive production cycle, but it seems to me inevitable that it will make animal products more expensive and supply more uncertain. Temperate areas with large acreages of grassland and abundant rainfall such as New Zealand and parts of Northern Europe may well benefit under such a scenario, but increased difficulties in other areas will more than compensate. Here the “sustainability dilemma” is that the need to manage water supplies more sustainably will inevitably impact on agricultural production in general and livestock production in particular at a time when demand is growing significantly

Competition for land

Even a crowded country like the UK has only a small part of its landscape urbanized. Some 85% of the UK land area is rural, with over 50% as grassland. Although increased economic development and increasing population will worsen this situation, it will not change it radically. However, I believe that competition for land will impinge directly on agriculture in general and rain-fed pasture agriculture in particular. There are two reasons for this. The first is that there is increasing recognition of the importance of agriculture in delivering a range of ecosystem services (clean water, clean air, biodiversity, landscape diversity, recreation opportunity etc) and the second is competition between food and non-food agriculture.

In terms of the former, there are actions that can be taken to mitigate the impact caused by increase in intensification and increase in cultivated area. These are discussed in Firbank *et al* (2007) and include a range of habitat management approaches coupled with greater precision in the use of inputs. However, there is an in-built tension in that successful agricultural techniques like weed control, winter sowing and the shift from hay to silage inevitably increase the proportion of incoming solar radiation that is captured by the agricultural food chain at the expense of that captured by the “natural” food chains that coexist. This was demonstrated very clearly by Firbank (2003) in studies on the implications on farmland biodiversity of improved weed control using herbicide-tolerant crops. Thus there is a production cost to ecological management of farmland. This cost will vary with site and system, and its impact will depend upon the proportion of land under cultivation within any given region. In addition, certain agroecosystems are more important in ecosystem service terms than others and may be more fragile. In general terms, extensive pastoral systems utilizing rain-fed unimproved pastures represent unique reserves of biodiversity that are dependent upon intermittent grazing. Once again the tensions between increased demand and conservation are clear, and greenhouse gas mitigation options that rely on intensification to reduce animal numbers and increase animal productivity will exacerbate the problem.

The competition between food- and non-food agriculture potentially impacts even more starkly on pastoral agriculture. First generation biofuels use materials (starch, sucrose and edible oils) that are also foodstuffs. Second generation fuels will rely on the ability to ferment recalcitrant lignocellulose to give simple sugars, and thence ethanol or butanol. Globally this feedstock will come from wood (which is already in short supply) or from energy grasses such as *Miscanthus* which will have to be cultivated (for the reasons discussed above) on land currently used for rain-fed pastoral agriculture. It is ironic that the chemistry of ruminant digestion is precisely the chemistry that the fuel biotechnologists wish to use to generate second-generation biofuels. Currently, the technology is imperfect but progress is inevitable. Countries like the USA, with large areas of rangeland will increasingly face stark choices about what that land will be used for, and I fear that, in the name of climate change mitigation, the impact on fragile agroecosystems will be very large.

Conclusions

Reducing greenhouse gas emissions from agriculture is a laudable and necessary objective. It should be done, however, in the knowledge that:

- There will be disbenefits as well as benefits
- The disbenefits will be compounded by issues relating to competition for resources
- Pressures to increase production will grow at the same time as pressures to reduce footprint will intensify
- The intensive livestock sector is particularly vulnerable to these conflicting pressures

Implications

This summary reflects the views of the author and is not based on any external support or funding. The conclusions are open to debate and disagreement. If, however, the conclusions are borne out by events in the next few years, the implications for the industry, the food chain and policy makers are considerable. The delivery of a more sustainable

food chain for livestock products will require policy and regulatory change, changes in consumer behaviour and awareness and forward planning on behalf of the industry.

References

Firbank, L.G. 2003. The Implications of spring-sown genetically-modified herbicide-tolerant crops for farmland biodiversity: a commentary on the farm-scale evaluations of spring-sown crops. London, UK. Department for Environment, Food and Rural Affairs.

Firbank, L.G., Petit, S., Smart, S., Blain, A., Fuller, R.J. *Philosophical Transactions of the Royal Society* 363. 777-787

Pollock, C.J, Pretty, J. 2007. Pastures New. *New Scientist* 194 (2600)18.

Pretty, J. 2007. *Philosophical Transactions of the Royal Society* 363, 447-465.

Rosegrant, M.W., Valmonte-Santos, R.A., Cline, S.A., Ringler, C., Li, W. 2005. Water Resources, agriculture and pasture: implications of growing demand and increasing scarcity. In: *Grassland: a Global Resource*.(D.A. McGilloway, ed). Wageningen: Wageningen Academic Publishers, 227-238.

Wikins, R. 2007. *Philosophical Transactions of the Royal Society* 363, 517-525

Water and livestock

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Introduction

Projected increased demand for food in developing countries over the next 30 years implies a correspondingly great need for additional agricultural water unless integrated research and development can achieve much higher water-use efficiencies. Without appropriate innovations in water management, poor access, quality and supply will continue to constrain food production. A global consortium recently completed the *Comprehensive Assessment of Water Management and Agriculture* (CA 2007) and identified many options for overcoming water-related constraints to sustainable food production in developing countries. Historically, research and development of water resources has neglected the potential benefits and impacts of livestock. Apart from drinking water, livestock professionals have not given adequate attention to the use of and impact of domestic animals on water and related environmental health. In the absence of good science, popular literature is often highly critical of livestock production because of its perceived excess depletion of vital water resources. The CA uniquely attempted to address this issue (Peden, 2007). This paper summarizes the CA's findings about livestock for the benefit of this meeting on Livestock and Climate Change and the wider livestock research community.

Livestock water productivity (LWP)

LWP is the ratio of the net beneficial animal products and services produced in an agricultural production system to the amount of water depleted as a cost of producing them. Production system scales can vary in size ranging from farms and fields to watersheds and river basins. Depleted water is water lost from production systems such as evaporation, transpiration and downstream discharge.

Figure 1 presents a simplified version of the LWP assessment framework (Peden 2007) used to estimate the amount of water depleted in diverse livestock systems. While much is known about drinking requirements

of animals, direct consumption of water does not contribute to water depletion because water drunk remains in the production system even though drinking may be vital to animal survival. Strategic feed sourcing, conserving of water and enhancing animal productivity provide multiple options for increasing LWP. The first two strategies help ensure that feed and pasture supplied to animals makes best use of available water and, where appropriate, shifts water depletion pathways from unwanted run-off or discharge and evaporation to transpiration and infiltration. The productivity-enhancing pathway is the traditional domain of the animal sciences. Collectively, we can help increase LWP by maximizing the value of animal products and services produced with available feed that is produced where transpiration is high and other forms of water depletion are low.

Implications for Sub-Saharan Africa

Livestock production is an important part of African agriculture and animal densities are higher and lower respectively in irrigated and pastoral areas than in mixed crop-livestock systems. Africa is vulnerable to drought, water scarcity and water-borne animal diseases including zoonotic ones. Increasing LWP through better management of livestock-water interactions holds promise for sustainably improving livelihoods of the continent's poor and making more fresh water available for other human needs and ecosystem services. Evidence from the CA (Peden, 2007) indicates that investments in agricultural water development are often not sustainable and do not achieve potential returns on investments due to lack of integration of livestock. Contrary to much popular opinion, LWP compares favourably with marginal returns arising from investments in irrigated horticultural crops and is higher than observed in rain-fed grain crops. Water used for production of animal source food is currently the most effective means to meet protein, Vitamin B12, Iron and Selenium requirements of millions of malnourished Africans. The overarching message of the CA is that livestock-water interactions are important and under-researched and that huge opportunities exist to improve the productivity of water associated with livestock production. To achieve this will require active engagement of animal scientists in research and development of agricultural water in developing countries. Through an appropriate mix of technologies, management practices and policies, we estimate that current levels of animal production can be maintained while reducing water depletion by more than half in Sub-Saharan Africa.

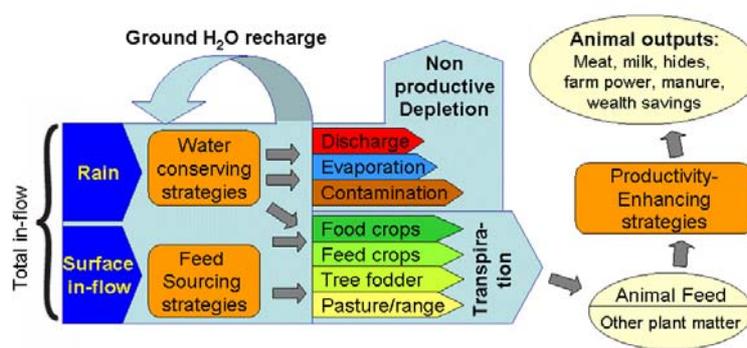


Figure 1 Simplified assessment framework that helps identify strategies for improving livestock water productivity

(Source: Peden, 2007)

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References

CA (Comprehensive Assessment of Water Management in Agriculture), 2007. *Water for Food, Water for Life: the Comprehensive Assessment*. Earthscan, London, UK and International Water Management Institute (IWMI) Colombo, Sri Lanka.

Peden D., Tadesse G, and Misra AK. 2007. Water and livestock for human development. In *Water for Food, Water for Life: the Comprehensive Assessment* (Ed D Molden), pp. 486-514. Earthscan, London, UK and IWMI, Colombo, Sri Lanka.

Climate change, vulnerability and livestock keepers: challenges for poverty alleviation

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Introduction

Livestock systems in developing countries are changing rapidly in response to many drivers. Globally, human population is expected to increase from around 6.5 billion today to 9.2 billion by 2050. More than 1 billion of this increase will occur in Africa. Rapid urbanisation will likely continue in developing countries, and the global demand for livestock products will continue to increase significantly as populations increase and incomes rise (Delgado *et al.*, 1999). In addition, the climate is changing, and with it climate variability, and this adds to the already considerable development challenges faced by many countries in the tropics and subtropics. The potential impact of these global drivers of change on livestock systems and the resource-poor people who depend on them is considerable. At the same time, one of the challenges for development partners is to ensure that the poor can benefit from the income-generating opportunities that are presented by rises in demand for livestock products. Smallholders are major players in the dairy sector, and almost all the meat and milk in Africa is produced in agro-pastoral and mixed systems (de Haan *et al.*, 1997). In comparison, most of the demand in the rapidly-growing poultry sector in Asia is being satisfied via highly intensive / industrial systems. Such regional and systems' differences highlight the importance of targeting interventions that are pro-poor in a rapidly-changing world. Here, we outline work to identify livestock systems that are particularly vulnerable to climate change and some of the likely impacts on livestock keepers, focusing on sub-Saharan Africa (SSA). We discuss some priority livestock development issues linked to climate change that need to be addressed, if the vulnerability of livestock keepers is to be reduced and their incomes increased in the coming decades.

The broad context of climate change

The world's climate is continuing to change at rates that are projected to be unprecedented in recent human history. The global average surface temperature increased by about 0.6 °C during the twentieth century (IPCC, 2007). Current climate models indicate that for the next two decades, a warming of about 0.2°C per decade is projected for a range of different emission scenarios. After that, projections of what may occur depend increasingly on socio-economic scenarios and the resulting emissions pathways, but the increase in global average surface temperature to 2100 may be between 1.8 and 4.0 °C (IPCC, 2007). However, broad trends will be overshadowed by local differences, as the impacts of climate change are likely to be highly spatially variable. Precipitation increases are very likely in high latitudes, while the tropics and subtropical land regions are likely to see decreases in most areas (IPCC, 2007). At the same time, weather variability is likely to increase, although with current knowledge, little is known about the extent and spatial variation of this increased variability. The combination of generally increasing temperatures and shifting rainfall amounts and patterns will clearly have impacts on crop and livestock agriculture. At mid- to high latitudes, crop productivity may increase slightly for local mean temperature increases of up to 1-3 °C, depending on the crop, while at lower latitudes, crop productivity is projected to decrease for even relatively small local temperature increases (1-2 °C) (IPCC, 2007). In the tropics and subtropics in general, crop yields may fall by 10 to 20% to 2050 because of warming and drying, but there are places where yield losses may be much more severe (Jones and Thornton, 2003).

Climate change will alter the regional distribution of hungry people, with particularly large negative effects in SSA. Smallholder and subsistence farmers, pastoralists and artisanal fisherfolk will suffer complex, localised impacts of climate change, due both to constrained adaptive capacity in many places and to the additional impacts of other climate-related processes such as snow-pack decrease and sea level rise (IPCC, 2007). Increasing frequencies of heat stress, drought and flooding events are likely, and these will undoubtedly have adverse effects on crop and livestock productivity over and above the impacts due to changes in mean variables alone (IPCC, 2007). Major changes can thus be anticipated in livestock systems.

Targeting vulnerable livestock keepers

The overall prognosis for climate change impacts on crop and livestock agriculture in tropical regions is not good. Furthermore, there is a major gap in our understanding of what the local-level impacts are likely to be. This is partly because of long-term inadequacies in Global and Regional Circulation Models, and also because of the uncertainties involved in downscaling climate model output to the high spatial resolutions needed for effective adaptation work. Nevertheless, work is being done to generate relatively high-resolution information concerning possible impacts on crop and livestock production and productivity. Broad-brush approaches can be used to identify likely "hotspots" that are already vulnerable and that are likely to suffer substantial impacts as a result of climate change. Vulnerability can be seen as a state that is governed not just by climate change itself but by multiple processes and stressors. Addressing it involves dealing with biophysical vulnerability, or the sensitivity of the natural environment to an exposure to a hazard; and social vulnerability, or the sensitivity of the human environment to the exposure. In such an approach, an impact is thus a function of hazard exposure and both types of vulnerability. To identify geographic areas where climate change and subsequent impacts on crop and livestock agriculture may be relatively large, length of growing period (LGP) is a useful proxy. It is crop-independent and is an effective integrator of changes in rainfall amounts and patterns and temperatures. We have carried out several studies where we estimate changes in the length of growing season from current conditions to 2050, and use these changes as indicators of climate hazard for subsequent analysis (for example,

see Thornton *et al.*, 2006). Results show that there may be considerable spatial heterogeneity of response of LGP to projected climate change. Some areas will see expansion in growing seasons, while many others, particularly in the tropical zones, may see contractions. Depending on the emissions scenario and climate model used, up to 25% of Africa's landmass may suffer reductions in LGP of 20% or more, and currently nearly 280 million people live in these areas. To identify the populations and areas that are particularly vulnerable, LGP change hotspots can be combined with indicators of biophysical and social vulnerability (such as crop suitability, market access, the human poverty index, and infant mortality). Many already-vulnerable regions in SSA are likely to be adversely affected by climate change, including the mixed arid-semiarid systems in the Sahel, arid-semiarid rangeland systems in parts of eastern Africa, the systems in the Great Lakes region of eastern Africa, the coastal regions of eastern Africa, and many of the drier zones of southern Africa (Thornton *et al.*, 2006).

Such broad-scale analysis is helpful in prioritising research resource allocation, but it hides considerable variability and heterogeneity in households' access to resources, poverty levels, and ability to cope. We are now working on more detailed impact assessments at the community or household level, using tools such as crop, livestock and household simulation models, so that the resource, economic and household well-being implications of changes in climate and climate variability can be appropriately assessed and the interactions between household enterprises (crops, livestock, off-farm income, etc) evaluated.

Priority livestock development issues linked to climate change

Impact of livestock on climate change

The relationships between livestock populations and the environment are complex. The climate change impacts of livestock production (see Steinfeld *et al.*, 2006) have been widely highlighted, particularly those associated with rapidly-expanding industrial livestock operations in Asia. In smallholder crop-livestock and agro-pastoral and pastoral livestock systems, however, livestock are one of a limited number of broad-based options to increase incomes and sustain the livelihoods of an estimated 1 billion people. In addition, these people in general have a much more limited environmental footprint compared with populations in developed countries: there is a real emissions North-South divide. Livestock are particularly important for increasing the resilience of vulnerable poor people, subject to climatic, market and disease shocks through diversifying risk and increasing assets (Krishna *et al.*, 2004; Freeman *et al.*, 2007). Greenhouse gas (GHG) emissions from livestock in these systems are relatively modest when compared with the contribution that livestock make to the livelihoods of this huge number of people (Herrero *et al.*, 2008). There are thus complicated trade-offs between resource use, GHG emissions, and livelihoods that need to be assessed, and these are made more complex still when food security issues that may arise in relation to biofuels are added to the mix.

Impact of climate change on livestock and livestock systems

There are many ways in which climate change may affect livestock and livestock systems. Table 1 attempts to tabulate some of these as related to water, feeds, biodiversity, and livestock (and human) health (see Thornton *et al.* (2008) for a more extensive survey). There is quite a lot of information on some of these impacts and much less on others. In general, three types of "knowledge gap" can be distinguished concerning these impacts. First, there are areas of enquiry in which the impacts of changing climate and climate variability are fairly well understood at an aggregated level -- an example is the study on the regional impacts of climate change on crop production in response to different GHG emission scenarios by Lobell *et al.* (2008). But there are major gaps in our knowledge of the localised impacts which seriously inhibits current pro-poor targeting of adaptation options. Second, there are situations in which the impacts are fairly well understood on many of the component processes, but where the impacts at the systems level interact heavily, and our knowledge of them is much less certain. An example is what we know about the general impacts of changing temperature, rainfall and CO₂ concentrations on plant growth processes. There is much less information, however, concerning how these impacts will interact at the level of the system in specific situations, and how these may affect livestock and the people who depend on them. Third, there are situations in which the impacts of climate change are relatively well-understood, but the nature of the adaptation or mitigation problem is such that many different kinds of action are needed if poor people are to benefit. For example, while technical options for mitigating emissions through management of ecosystems services in pastoral systems do exist, there are formidable problems to implementing many of these, related to the need to set in place incentive systems, institutional linkages, policy reforms, monitoring techniques for carbon stocks, and appropriate verification protocols, for example (Reid *et al.*, 2004).

Table 1 Some of the impacts of climate change on livestock and livestock systems (taken from broader reviews in Thornton *et al.*, 2007 and 2008).

Factor	Impacts
Water	Increasing water scarcity is an accelerating condition for 1-2 billion people. Coupled with population growth and economic development, climate change impacts will have a substantial effect on global water availability in the future. <ul style="list-style-type: none"> • <i>Land use and systems change</i>
Feeds	As climate changes and becomes more variable, species niches change (plant and crop substitution). May modify animal diets and compromise the ability of smallholders to manage feed deficits. For example: in parts of East Africa, maize being substituted by crops more suited to drier environments (sorghum, millet); in marginal arid southern Africa, systems converting from a mixed crop-livestock to

rangeland-based.

- *Changes in the primary productivity of crops, forages and rangeland*

Effects depend significantly on location, system, species. But in C₄ species, temperature increases up to 30-35 °C may increase productivity of crops, fodders and pastures (as long as water and nutrients do not significantly limit plant growth).

In C₃ plants, temperature has a similar effect but increases in CO₂ levels will have a positive impact on the productivity of these crops.

For food-feed crops, harvest indexes will change and so will the quantity of stover and availability of metabolisable energy for dry season feeding.

In the semi-arid rangelands where contractions in the growing season are likely, rangeland productivity will decrease.

- *Changes in species composition*

As temperature and CO₂ levels change, optimal growth ranges for different species also change, species alter their competition dynamics, and the composition of mixed grasslands changes.

Proportion of browse in rangelands will increase in the future as a result of increased growth and competition of browse species due to increased CO₂ levels (Morgan *et al.*, 2007).

Legume species will also benefit from increases in CO₂ and in tropical grasslands, the mix between legumes and grasses could be altered.

- *Quality of plant material*

Increased temperatures increase lignification of plant tissues and thus reduces the digestibility and the rates of degradation of plant species. Resultant reduction in livestock production may have impacts on food security and incomes of smallholders.

Interactions between primary productivity and quality of grasslands will demand modifications in grazing systems management to attain production objectives.

Biodiversity

In places, will accelerate the loss of genetic and cultural diversity in agriculture already occurring as a result globalisation (Ehrendfeld, 2005), in crops as well as domestic animals.

A 2.5 °C increase in global temperature above pre-industrial levels will see major losses: 20-30% of all plant and animal species assessed could be at high risk of extinction (IPCC, 2007).

Ecosystems and species show a wide range of vulnerabilities to climate change, depending on the imminence of exposure to ecosystem-specific, critical thresholds, but assessments are fraught with uncertainty related to CO₂ fertilisation effects etc.

Livestock (and human) health

Major impacts on vector-borne diseases: expansion of vector populations into cooler areas (higher altitude areas, such as malaria and livestock tick-borne diseases) or into more temperate zones (such as bluetongue disease in northern Europe).

Changes in rainfall pattern may also influence expansion of vectors during wetter years, leading to large outbreaks of disease (Rift Valley Fever virus in East Africa).

Helminth infections are greatly influenced by changes in temperature and humidity.

Climate change may affect trypanotolerance in subhumid zones of West Africa: could lead to loss of this adaptive trait that has developed over millennia and greater disease risk in the future.

Effects (via changes in crop, livestock practices) on distribution and impact of malaria in many systems and schistosomiasis and lymphatic filariasis in irrigated systems (Patz *et al.*, 2005).

Increases in heat-related mortality and morbidity (Patz *et al.*, 2005)

Climate variability impacts on food production and nutrition can affect susceptibility to HIV/AIDS as well as to other diseases (Williams, 2004).

Conclusions

Despite the role that livestock have been shown to play in coping with risk and providing livelihood options, there is still only limited knowledge about the interactions of climate with other drivers of change in livestock-based systems and on broader development trends. This is an imbalance that needs to be rectified. Many possible adaptation options exists, from technological changes to increase or maintain productivity, through to learning, policies and investment in specific sectors and risk reduction options, which may increase the adaptive capacity of poor livestock keepers. Given this range of options, there is a real need for methods and tools to assess what may be appropriate where. This includes the collation of toolboxes of adaptation options and the identification of the domains where these may be relevant, at broad scales through the use of spatial analysis, and at more localised scales through more participatory, community-based approaches. This work should revolve around the development of collaborative learning processes to support the adaptation of livestock systems to better cope with the impacts of climate change. Farmers already have a wealth of indigenous knowledge on how to deal with climate variability and risk, but well-targeted capacity building efforts are needed to help farmers deal with changes in their systems that go beyond what they have experienced in the past. In sum, the livestock development issues raised by climate change are highly intertwined and complex; some of the possible impacts at broad scales are reasonably well-researched while others are not, and currently many of the agricultural and other impacts at local scales are simply not known. How these impacts may combine to affect household vulnerability, and how adaptive capacity may be most effectively increased, are critical issues that need

considerable attention. There are many factors that will determine whether specific adaptation options are appropriate and viable in particular locations. Understanding what these factors are and where they operate is key to identifying vulnerable households and implementing adaptation options that can maintain or raise incomes and household food security. In many of these places livestock will have a crucial role to play.

Implications

Livestock systems in developing countries are characterised by rapid change, driven by factors such as population growth, increases in the demand for livestock products as incomes rise, and urbanisation. Climate change is adding to the considerable development challenges posed by these drivers of change. But there are considerable gaps in our knowledge of how climate change and increasing climate variability will affect livestock systems and the livelihoods of the people who depend on them. There is an urgent need for detailed assessment of localised impacts and for identifying appropriate options that can help livestock keepers adapt to climate change and increased climate variability.

References

- de Haan C, Steinfeld H, Blackburn H, 1997. Livestock and the environment: finding a balance. WRENmedia, Fressingfield, UK.
- Delgado C, Rosegrant M, Steinfeld H, Ehui S, Courbois C, 1999. Livestock to 2020: the next food revolution. Food, Agriculture and the Environment Discussion Paper 28. IFPRI/FAO/ILRI, Washington, DC, USA.
- Ehrenfeld D, 2005. Conservation Biology 19 (2), 318-326.
- Freeman A, Kaitibie S, Moyo S, Perry B, 2007. Livestock, livelihoods and vulnerability in Lesotho, Malawi and Zambia. ILRI and FAO.
- Herrero M, Thornton P K, Kruska R L, Reid R S, 2008. Agriculture, Ecosystems and Environment (in press).
- IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Summary for policy makers. Online at <http://www.ipcc.cg/SPM13apr07.pdf>
- Jones P G, Thornton P K, 2003. Global Environmental Change 13, 51-59.
- Krishna A, Kristjanson P, Radeny M, Nindo W, 2004. Journal of Human Development 5, 211-226.
- Lobell DB, Burke M B, Tebaldi C, Mastrandrea M D, Falcon W P, Naylor R L, 2008. Science, 319, 607-610.
- Morgan J A, Milchunas D G, LeCain D R, West M, Mosier A R, 2007. PNAS 104, 14724-14729.
- Patz J A, Campbell-Lendrum D, Holloway T, Foley J A, 2005. Nature 438 (17 November 2005), 310-317.
- Reid R S, Thornton P K, McCrabb G J, Kruska R L, Atieno F, Jones P G, 2004. Environment, Development and Sustainability 6, 91-109.
- Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C, 2006. Livestock's long shadow: environmental issues and options. FAO, Rome, Italy.
- Thornton P K, Jones P G, Owiyo T, Kruska R L, Herrero M, Kristjanson P, Notenbaert A, Bekele N, Omolo A, 2006. Mapping climate vulnerability and poverty in Africa. ILRI, Nairobi, Kenya, May 2006, 200 pp.
- Thornton P K, Herrero M, Freeman A, Okeyo M, Rege E, Jones P G, McDermott J, 2007. Journal of Semi-Arid Tropical Agricultural Research 4(1) (online at <http://www.icrisat.org/Journal/specialproject.htm>).
- Thornton P K, Notenbaert A, van de Steeg J, Herrero M, 2008. The livestock-climate-poverty nexus: A discussion paper on ILRI research in relation to climate change. ILRI, Nairobi, Kenya, 90 pp.
- Williams J, 2004. Sustainable development in Africa: is the climate right? IRI Technical Report IRI-TR/05/01. The International Research Institute for Climate Prediction, Palisades, New York.

Impacts on livelihoods

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Introduction

It is already clear that poor livestock keepers are among those whose livelihoods are most vulnerable to climate change. Extensive grazing systems will become less viable in semi-arid areas that become even more warm and dry. As pests and diseases move into new areas, the poor who can either not afford or access animal health services are more likely to experience increased morbidity and mortality among their animals. And the poor are the first to suffer market impacts of climate change on the cost of inputs. In low lying coastal areas, poor livestock keepers facing loss of land to rise in sea levels, will find it difficult to find alternative sites on which to re-establish their livelihoods. On the other hand, climate change is likely to lead to new market opportunities for livestock keepers.

But changes in levels and variability of physical, environmental parameters such as precipitation and temperature are only one part of the context within which households create their livelihoods; there are many other sets of factors that influence their options, the choices they make, and the outcomes they achieve. These include institutions that affect the accessibility and security of the resources at their disposal: institutions such as land tenure arrangements, financial services, knowledge and information services, local and central government systems. The market environment, for both inputs and produce, helps to determine the viability of livelihood options in the short and long term; while the social context affects the social capital to which the individual and household can look for support in times of hardship, uncertainty and change. When looking at the implications of climate change for livelihoods of livestock keepers, therefore, we need to keep in mind the whole livelihood system. Two features of livelihood systems in the face of short term shocks and long term trends are their degree of resilience and of adaptability.

Adaptation and innovation: lessons from history

Looking back over the past 100, even 20, years we have seen both livestock systems and livelihood systems change radically in response to a variety of pressures and opportunities. Some have vanished altogether. Less than a hundred years ago, most draught power on UK farms was provided by horses. A family farm would keep a large number of horses, and a range of skilled staff to care for and manage them. In less than twenty years, they all but vanished in the face of the relentless march of fossil-fuelled traction. Restrictions on the movement of livestock – from increasing competition with settled farmers and civil unrest, among other influences – have led to new patterns of transhumance in the semi-arid regions of west and east Africa. In India's cities, urban dairying has developed and thrived – despite an often hostile institutional context in terms of byelaws prohibiting the keeping and movement of livestock within urban areas. In other places, households have “downsized” from bovines to smallstock as per capita land area has shrunk and common grazing has been lost. Many countries have seen rapid intensification of poultry production, in the face of increasing demand from urban populations. And in many rural areas – including in most African countries – rural livelihoods have become more diverse as individuals and households respond to new opportunities and pressures.

It is inappropriate, then, to look at livelihood and livestock systems as fixed entities that are liable to break down under pressure. It is more relevant to ask how resilient are these systems to short term shocks and to longer term trends? do they have the capacity to adapt to new emerging situations? and can action be taken that will make them more resilient, through short term coping strategies, and longer term adaptation and innovation? Coming back to the UK, we can see how short term shocks – which are related to market changes that are not closely linked to climate change – are having a devastating impact on the pig sector, with many producers going out of business and others operating at a loss. And the dairy sector, having lost hundreds of producers over the past five years because they could not balance the books with the prevailing milk price, is now benefiting from a substantial increase in prices which is once more encouraging those farmers still in the sector to invest in new equipment and expand their herds.

Although history is not necessarily a good guide to the future, especially in the face of the unprecedented rate of environmental change that many livestock keepers face, it can tell us something about resilience and adaptation – and the relative significance of environmental versus other factors in the trajectory of livestock and livelihood systems. Timelines drawn up with farmers in the very different contexts of semi-arid Eritrea and relatively high rainfall areas of Kenya show that institutional and market factors have been the main triggers of change within living memory; while in Ethiopia, human-induced environmental change (notably the clearing of forest from hillsides) has also reduced the availability of grazing and fodder.

Changes at the system level mask the great diversity of responses at the individual level. Different households and individuals experience climate change and other pressures differently, and will respond differently. As transhumance becomes more difficult, for example, some will adapt to a more settled lifestyle, taking on new livelihood activities to supplement a reduced output of livestock products and services; others may find it less easy to adapt and will slip into chronic poverty. In the UK, it is the smaller, perhaps less efficient in the narrow sense of the economist, units that have gone out of business in the pig and dairy sectors – some to new successful patterns of livelihood, others to a premature forced retirement. Resilience and adaptation can be identified at household as well as system level.

Conclusion and implications

The last thing that policy makers and development agencies should do is to try to freeze livelihoods in their current state. That is more likely to lead to catastrophic collapse at some time in the future. More important is to support process of innovation, adaptation and change while helping to protect livelihoods from the negative impact of short term shocks.

Three things that can be done are:

- (1) help livestock keepers build strong institutions that can facilitate both collective and individual adaptation and response to climate change and other external pressures, both short and long term; examples of such institutions include self-help groups in India through which poor households can access credit, animal health and knowledge services as well as the social capital that comes from group membership; and the Meru Goat Breeders Association in Kenya;
- (2) create and intensify learning opportunities, to broaden the set of information and knowledge available to farmers and support local innovation: Livestock Field Schools are an example of how this can be done;
- (3) help livestock keepers identify opportunities, to enrich the set of options they have when making livelihood choices: re-thinking how advisory services are provided, particularly to small-scale, relatively poor livestock keepers, is an important ingredient.

Livestock and climate change: coping and risk management strategies for a sustainable future

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Livestock and Climate Change

The environmental challenges of the 21st century are more complex, more difficult to comprehend and to resolve than ever before. However, unrivalled by any time before, is the awareness of the global community and the willingness of many to take collective actions needed to save the planet earth. A number of initiatives have been pledged during the past two decades, which - if adopted - could lead to successes in efforts to combat desertification, protect biodiversity, mitigate the impact and cope with the vulnerabilities to climate change. The global community is aware of the need to stabilise the human population at 8 billion or less by 2050 and have pledged to cut extreme poverty, hunger and disease by 2015 (Sachs, 2008, The Millennium Ecosystem Assessment, 2005).

The international community recognises climate change as an immediate threat that is caused by extended (medium-term or long-term?) periods of fluctuations in temperature and precipitation, recurrence of extreme events such as droughts, floods and heat and cold weather. Wisely, the global community admits the responsibility of human activity, directly or indirectly, in altering the composition of the global atmosphere (UNCCC – FCCC, 1992, FAO – LEAD, 2007), and pays attention towards finding solutions and building on the opportunities.

The livestock producers – nomadic, sedentary or agro-pastoralists – have traditionally taken numerous adaptive and environmentally friendly measures to climatic uncertainties such as the opportunistic seasonal mobility, mixed crop-livestock farming, efficient water harvesting. However, increased human population, urbanisation, the spread of modern economic growth, increased consumption of animal source foods and commercialisation have rendered these coping mechanisms ineffective. On the other hand, while a few innovative or development based solutions have shown promising results, their impact remains limited.

Adoption challenges and mitigation opportunities

This presentation is complementary to the other presentations in this International Conference. The focus is solely on coping and risk management strategies whether known and tried before (IFAD Rural Poverty KnowledgeBase, Global Livestock CRSP, 2000-2008) new ideas developed in response to national initiatives that emerged from projects developed in response to UNCCC (AIACC - Mongolia Government, GEF, UNEP 2006, Government of Tunis, 2007), studies (Thomas *et al.*, 2008, Tibbo, 2008) or expert consultations (ICARDA, 2008, FAO, 2008).

The fact that livestock is a major contributor to environmental problems contributes both to challenges and to opportunities (FAO, LEAD):

- The challenges are assuring sustainable livestock systems that could cope with the various serious Climate Change *impacts* (extreme heat, fluctuating precipitation, floods, droughts) and *vulnerabilities* (low forage and range yield, low livestock productivity, water stress, transmission of new diseases, changes in flock /herd management and composition) .
- The opportunities are the possibility of mitigating the current negative impacts of the livestock sector on the environment (GHG - carbon emission, anthropogenic methane production, waste and pollution) through new technologies and innovations built on, or linked with, sound conventional and traditional practices.

Examples of coping and risk management strategies:

- Improved integrated pasture management systems and legislation that leads to increased conservation of nature and ecosystems, and effective development of cultivated pastures. Associated benefits: carbon sequestration, reduced overgrazing of rangelands
- Improved livestock capacity to cope with climate change through the identification and improvement of local breeds adapted to the local feed resources and tolerant to heat / cold stress. Associated benefits: conservation of biodiversity and animal genetic resources
- Adjusted livestock management and flock/ herd composition practices. Associated benefits: Improved production and secured income
- Livestock Early Warning Systems (LEWS) and other forecasting and crisis preparedness systems. Associated benefits: improved knowledge of Climate Change; stable rural economy
- Identified restocking and destocking options and policies that allow livestock producers to sell their animals in situations of emergencies and to rebuild flocks/ herds subsequently. Associated Benefits: reduced chances of range degradation and overgrazing
- Weather-based index insurance linked to measurable climate change events such as extreme heat, low rainfall. Associated benefits: the livestock producers are part of the solution
- Rural financial incentives (e.g. risk funds, micro-credit) that allow livestock keepers to cope with uncertainties and adopt favorable and sustainable livestock keeping practices; thus reducing their vulnerabilities. Associated benefits: stable rural communities, strengthened partnership between the private- public and civil society

- Increased role of science and technology in helping livestock agriculture adapt to climate change, and in better understanding the causes and impacts of climate change.
- Improved capacity of the livestock producers to cope with Climate Change vulnerabilities (water stress, heat stress, low yield)
- Assured participation of the livestock keepers (e.g. the pastoralists and agro-pastoralists who manage vast areas of lands and forests) in devising coping and risk management approaches to Climate Change through awareness building, collective action
- Identified options for risk management and crises mitigation through diversification of the livelihoods options of the livestock keepers

References

- AIACCC - Mongolia Government, GEF, UNEP 2006- Final Report for the Assessment of Impacts and Adaptation to Climate Change (AIACC) Project No As 06.
- FAO – LEAD, 2007. Livestock ‘s Long Shadow.
- FAO – LEAD. Steinfeld H. *et al* The livestock long shadow.
- FAO. 2008. 29th FAO regional Conference for the Near East ; Climate Change : Implications in the Near East Cairo March 2008.
- Global Livestock CRSP – 2000- 2008 East Africa and Mongolia – Livestock Early Warning Systems (LEWS). USAID – University of California Davis
- Government of Tunis (2007) National Climate Change Adaptation Strategy for Tunisian Agricultural Ecosystems.
- ICARDA 2008 Expert Consultation on small ruminant research and development strategy Cairo Egypt March 2008.04-19.
- IFAD Rural Poverty KnowledgeBase - Livestock and Rangeland KnowledgeBase www.ifad.org
- Sachs J D. 2008. Common Wealth: Economics for a Global Planet (to be published)
- The Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-Being. Synthesis (Robert Watson and A.H Zakri. A report for the Millennium Ecosystems Assessment
- Thomas R., *et al.* 2008. Increasing the resilience of Dryland Agro-ecosystems to Climate Change. ICARDA Aleppo Syria.
- Tibbo M. 2008. Livestock and Climate Change. unpublished draft for Caravan- ICARDA
- UNCCC – FCCC, 1992. Kyoto Protocol – 1998.

Mitigating climate change: the role of livestock in agriculture

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The publication of the Stern review in 2006 (Stern, 2006) stimulated action by a number of governments around the world to initiate bills with targets of up to 80% reduction in emissions of greenhouse gases over the next 40 years. The time for discussion on whether climate change is, or is not, mainly due to human activity is therefore past, experts in all sectors need to be helping governments to identify the best way to reduce the emissions from their sector, while balancing other needs such as economic growth and food production.

The aims of this talk are firstly to highlight some of the issues associated with decreasing greenhouse gas (GHG) emissions from livestock production within the context of increasing concerns about food security and secondly to stimulate discussion as to how the animal science community can best work with governments to provide a robust evidence base for the development and implementation of climate change bills.

Globally, agriculture was estimated to account for an estimated 10-12% or between 5.1 and 6.1 Gt CO₂ equivalents of global human-induced GHG emissions in 2005 (Smith *et al.*, 2007) 4th assessment IPCC report, but these estimates do not take into account the carbon emissions associated with the fossil fuel used for agricultural activities (e.g. cultivation of soil, harvesting, animal housing) or those associated with land use change. On this basis, the direct emissions of methane from enteric fermentation of 1.9 Gt CO₂ equivalents (EPA <http://epa.gov/osa/spc/2peerrev.htm>) represent up to 37% of agriculture's contribution. Such figures are used to suggest that action should be taken by individuals and governments to decrease the proportion of livestock products in human diets, or indeed to encourage consumers to switch consumption from one species to another. This paper highlights some of the issues which often get ignored in this debate and identifies areas where there is an urgent need for more accurate data based on expert understanding of livestock systems.

The contribution of livestock to human diets

At a global level, livestock products contribute ~30% of the protein in human diets, while in industrialised nations this rises to 53%. This figure is predicted to increase, with the global production of meat predicted to increase from 229 million tonnes in 1999/2001 to 465 million tonnes in 2050 and milk from 580 tonnes to 1043 tonnes in the same period (Steinfeld *et al.*, 2006). In 2005/6, the mix of species contributing to global meat production was 24% from cattle, 31% from poultry, 39% from pigs and 5% from sheep and goats (FAO Stats).

Emissions by species

Estimations of the GHG emissions from livestock are associated with a high degree of uncertainty, given the impact of feed, individual animal productivity and management systems on the emissions per kg product, but estimates have been made. Foster *et al.* (2006) used estimates of 17.4 kg CO₂ equivalents /kg product for sheep meat (mutton and lamb); 13.0 for beef, 6.35 for pigs, 4.57 for poultry and 1.32 for milk in the UK, although these figures have also been subject to challenge. There is an urgent need for such figures, however, to enable government and consumers to make choices as to how to decrease the impact of human consumption on GHG emissions. In other words, an opportunity (and indeed a responsibility) for animal scientists to provide accurate evidence as a basis for policy.

Livestock species and food security

Globally, the area of land used for grazing is more than twice that used for arable and permanent crops. While some grazed land can be ploughed up for crop production, such a change in land use has a net release of carbon to the atmosphere and in many parts of the world is a high risk venture, due to unpredictable rainfall. It is difficult to see how it would be possible to feed an increasing human population without making use of this grazing land. In addition, the livestock sector accounts for 40% of agricultural GDP, employs 1.3 billion people and creates livelihoods for 1 billion of the world's poor (Steinfeld *et al.*, 2006). Significant progress towards the Millennium Development Goals does not therefore needs the increasing demand for livestock products: but as animal scientists we need to be giving advice as to best to achieve this while minimising our carbon footprint.

Money is the main currency underpinning free trade agreements and carbon the main currency underpinning climate change bills. As natural resources become ever scarcer, greater consideration may need to be given to efficient utilisation of resources which are edible by humans. Maybe we need to be considering an additional 'currency' of human edible resources?

One of the arguments against livestock is that they are inherently inefficient components of the food chain, since the production of feed, prior to its consumption by animals represents a 2-stage process, with each stage 'leaking' energy through less than 100% conversion efficiencies. The CAST report (CAST, 1999) provided alternative ways of calculating efficiency. It gave comparisons of the relative efficiencies of livestock systems in producing food for a range of countries on the basis of both gross efficiencies and 'human-edible return'. This latter ratio recognises the

contribution which livestock can make by converting fibrous feeds which are not used by humans into livestock products which do meet human needs. Some examples are given in Tables 1 and 2.

Table 1 Beef: gross efficiencies of conversion of diet energy and protein to product and returns on human-edible inputs in products^a

Country	Energy		Protein	
	Gross efficiency	Human edible return	Gross efficiency	Human edible return
Argentina	0.02	3.19	0.02	6.12
Egypt	0.03	NC ^b	0.02	NC
Kenya	0.01	NC	0.01	NC
Mexico	0.06	16.36	0.02	4.39
South Korea	0.06	3.34	0.06	6.57
United States	0.07	0.65	0.08	1.19

^a Gross efficiencies calculated as outputs of human-edible energy and protein divided by total energy and protein inputs. Human-edible returns calculated as human-edible outputs divided by human-edible inputs.

^b NC = not calculated. Human-edible returns for Egypt and Kenya were not calculated because human-edible inputs are very low or nil, which would have resulted in values approaching infinity.

Table 2 Swine: gross efficiencies of conversion of diet energy and protein to product and returns on human-edible inputs in products^a

Country	Energy		Protein	
	Gross efficiency	Human edible return	Gross efficiency	Human edible return
Argentina	0.15	0.24	0.07	0.11
Egypt	0.16	0.64	0.09	0.43
Kenya	0.16	0.54	0.10	0.39
Mexico	0.13	0.25	0.08	0.21
South Korea	0.20	0.35	0.16	0.51
United States	0.21	0.31	0.19	0.29

^a Gross efficiencies calculated as outputs of human-edible energy and protein divided by total energy and protein inputs. Human-edible returns calculated as human-edible outputs divided by human-edible inputs.

These data indicate the range of efficiencies in resource use in livestock systems around the world. The data are incomplete and livestock systems are ever changing, largely in response to economic factors. Again there is an opportunity and a responsibility for animal scientists to provide an accurate evidence base to underpin the choices of individuals and governments on how to achieve food security, while also taking account of climate change and the availability of natural resources.

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Eric Bradford and Lee Baldwin who were both eminent animal scientists and key thinkers behind the CAST report both died in 2007. Their legacy lives on.

References

- CAST (1999) Animal Agriculture and Global Food Supply. Council for Agricultural Science and Technology, USA.
- Foster, C., Green, K., Bleda, M., Dewick, P., Evans, B., Flynn, A. & Mylan, J. (2006) Environmental Impacts of Food Production and Consumption. A Report to the Department for Environment, Food and Rural Affairs, London.
- Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B. & Sirotenko, O. (2007) Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. & de Haan, C. (2006) Livestock's Long Shadow: environmental issues and options. FAO, Rome, Italy.
- Stern N. (2006) Review on the Economics of Climate Change. http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

Livestock emissions and global climate change: some economic considerations

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This paper addresses some economic considerations relating to global livestock emissions mitigation. There is currently no global protocol that transposes national emissions abatement obligations onto agriculture, or livestock in particular. But in developed countries (or within Kyoto signatories), there are good reasons why emissions regulation may be extended. Greenhouse gas emissions have specific global public good attributes because the physical damages arise irrespective of where emissions originate. But the cost of mitigation is not equal across the world. A theoretically efficient global mitigation policy might equalise the marginal costs of mitigation across countries and industries, such that a central planner could seek out specific countries or sectors as being relatively low cost mitigation options. But the world is not one country, and no single sector can be managed globally. In reality national policy choices on mitigation will depend on government aversion to further regulatory burden, and assessment of ability to pay by sector. This will then determine a choice between command and control versus market-based instruments for emissions control. Because of global income disparities, there are compelling livelihood reasons for emissions reductions not to be made binding in developing countries. This lack of obligations means that a globally efficient mitigation strategy cannot be attained. As in other sectors, there will be differentials between how livestock emissions from developed versus developing countries will be treated. The emergence of a global price for carbon provides a window for market-based transactions through trading or incremental cost finance. In the meantime, questions about the future pattern of global livestock production will remain. Growing global demand for livestock products and the absence of emissions regulation, point to potential pollution havens in the south. On the other hand, temperature increases and extreme events in the same countries, could shift a comparative advantage towards intensive efficient confined feeding operations in the cooler north, which has a head-start in dealing with more efficient production methods and catering for consumer niches.

Introduction

That climate change is happening is beyond dispute, with the most pressing questions being how to affect stabilisation of greenhouse gas concentrations, and about what the warming scenarios will be and how adaptation will take place (United Nations 2007). Global warming has been termed 'the greatest market failure the world has ever seen' (Stern 2006). This is because the atmosphere is a global public good that any country can pollute. Conversely, any country can free-ride on efforts to mitigate pollution. A market failure then arises because the 'clean' country cannot extract a payment for the benefit subsequently enjoyed by the 'dirty' country. If the world were one country, then the problem of free riding would not exist. But this is not the case, and what countries do is within their jurisdictional control and, without compensation, doing nothing is an option.

Fortunately however, there is collective agreement to some extent in Kyoto and the global objective of stabilising greenhouse gas emissions. Again, in a one country world, a central regulator could systematically search for the cheapest ways of reducing emissions. This could for example end up with regions specialising in certain forms of production. But the real world is made up of different countries and different stages of development, and dependence on some production forms and ability and willingness to reduce their relatively 'cheap' emissions. This picture largely explains the current differing national strategies in relation to Kyoto. In developed countries, strategies are informed by externally binding Protocol commitments, which is driven by a position of moral responsibility for leadership and historical emissions. External commitments are then handed down as internal sector liabilities; by and large, focusing on high profile and easily monitored point source polluters such as energy generation and heavy industry.

In developing countries in recognition of financial constraints, there is no such binding commitment. Indeed, there is recognition of the need for these countries to have their 'fair share' of pollution-intensive development. Developing countries are therefore loosely obliged to reduce emissions without targets, with the recognition that they can be incentivised by incremental cost (IC) financing and potential to transact into the Clean Development Mechanism (CDM)¹.

These differing national obligations will inevitably translate into the way a sector (as opposed to a country) is characterised as dealing with its global climate liabilities. To date, agriculture largely escapes regulatory nets, but as developed countries seek ways to meet their obligations, a light is being shone on its contribution relative to other sectors². In planning any regulatory response, a number of key questions relate to the magnitude of emissions from the

¹ IC finance is traditionally brokered via the Global Environmental Facility and its implementing bodies (UNDP, World Bank, FAO and others). It essentially channels top up or incremental funding to developing countries to design more globally-friendly projects in the areas of climate change, biodiversity, international waters and land degradation. The CDM is a conduit to allow lower cost mitigation to be purchased between developed and developing countries.

² http://www.occ.gov.uk/activities/analytical_audit/SECTORAL_ANNEX.pdf

sector, the marginal costs of abatement through different means, and the nature of regulatory options including pollution trading.

This largely technocratic approach needs to be considered relative to the fact that no such pressures are binding on developing countries where extensive systems, are both more polluting, and where the marginal costs of abatement are relatively low. On the other hand, in the same countries poorer households have a relatively greater dependence on livestock production.

This paper considers some of the relevant economic questions that run through the debate about dealing with global livestock emissions in the context of national commitments on mitigation. The paper highlights that fact that while the global warming impacts per tonne are equal, the costs mitigation are not. This is all the more so when social or livelihood costs are taken into account. An efficiency objective of combating warming at least cost leads to some unavoidable issues about equity and justice. The first section considers the magnitude of emissions from the livestock sector. The following section considers the significance of a global price for carbon equivalent emissions. Final sections consider the potential strategies adopted in the face of global income disparities.

Livestock emissions

There has been some debate about the length of livestock's climate externalities or "shadow", the magnitude of which varies in length depending on what environmental damages one attributes to global livestock, and where one chooses to locate the point of obligation³ for emissions related to livestock production and consumption. The debate about the accurate measurement of emissions from agricultural more generally, has focussed attention on the specificity of default IPCC emissions factors (Lokupitiya and Paustian, 2006). The general consensus of research in many countries is that livestock emissions are a significant source of the agricultural share, though in some countries agricultural liabilities can be neutralised or offset within a broader definition of "land based activities" which account for re forestation.

Beyond measurement, the question about emissions mitigation focuses on the need to identify the hierarchy of mitigation options and the merits of intensive versus extensive livestock systems. This discussion in turn juxtaposes practices in developed versus developing countries, and the potential for global specialisation to meet a rising global demand for meat products. This discussion also raises the high dependence on livestock production by some of the poorest households in many developing countries. Regulation or global specialisation is therefore likely to incur significant social costs.

While a global perspective on mitigation is relevant to a global public good problem, relevant regulations are determined within national boundaries. Research is therefore focussed on mitigation options within region and country-specific systems.

Mitigation in developed countries

There are many possible technical abatement options delivered through improved livestock efficiency to convert more energy into the rate of weight gain and/or milk production, thereby reducing losses through waste products. Such gains might be sought through breed selection, with a preference for larger but faster growing breeds, or through manipulation of dietary regimes. The latter could be achieved most rapidly through more prescriptive management – notably zero grazing systems and higher concentrate feed usage, probably necessitating a greater reliance on housed systems – and/or through the use of dietary supplements to improve the digestibility of feed intake. More careful management of waste products, for example through improved (covered) slurry storage facilities, also offers potential emission savings (Mosier *et al.*, 1998; Amon *et al.*, 2001, 2006; Schils *et al.*, 2005; Hensen *et al.*, 2006; Monteny *et al.*, 2006; Garnett, 2007; GFP, 2007).

From a public perspective (i.e. government) the economic appraisal of emissions abatement through any of these routes must compare the costs of investment in any mitigation option(s) with the benefits in terms of avoided emissions damages. The latter is approximated by the shadow price of carbon (SCC), which is derived from the best estimate of the present value of damages associated with a tonne of greenhouse gas emission. The current figures are a focal point of much research in the economics of climate change. Nevertheless, the figure that emerges is now adopted as an element for judging regulatory policy. Defra (2007) sets out SCC estimates to be used in appraisal of public mitigation policies (Table 1). These figures are rising through time to reflect increasing marginal damage of a tonne added to a growing stock. This SCC is useful because it provides a benchmark against which to judge the efficiency of mitigation options. Put simply, the marginal abatement cost of a tonne of greenhouse gas should not exceed the social benefit (avoided damage) as measured by the SCC. More technically, abatement strategies need to look across industries to apply the principle of equalising the marginal cost of abatement across sectors. So an important research agenda comes down to working out whether agricultural emissions are least cost relative to other sectors (i.e. industry and households).

³ The point of obligation refers to the agent who is responsible for emissions.

Table 1 Defra shadow price of carbon to 2040 (2007 prices, 2% per annum increase)

Year	2007	2010	2015	2020	2025	2030	2040	2050
£/t CO ₂ e	25.4	26.9	29.7	32.8	36.2	40.0	48.8	59.6

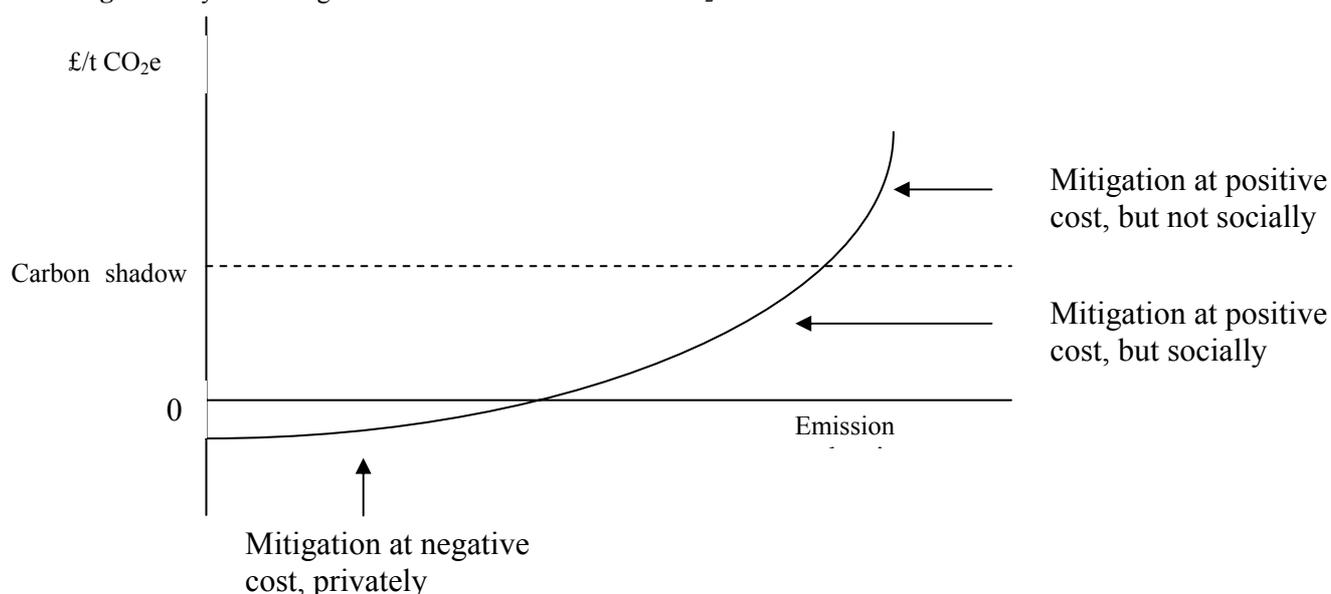
Source: Defra (2007) www.defra.gov.uk/environment/climatechange/research/carboncost/step2.htm

The notional comparison of marginal cost and benefits can be set out in Figure 1, which shows the rising cost of mitigation relative to the shadow price for any given year. The mitigation cost curve rises to reflect the fact that initially, tonnes of carbon can be mitigated at low or even negative cost. Thereafter, more costly interventions imply that each successive unit of greenhouse gas mitigation is achieved at a successively greater cost. At some point the cost of the last unit locked up through whichever method is just equal to the damage it would cause. In many OECD countries, the cost of some agricultural mitigation strategies can be shown to fall below the shadow price threshold. Various attempts have been made to estimate the cost-effectiveness of different mitigation options, both individually and to trace-out MACs. Some, such as ECCP (2001) and Weiske (2005, 2006), offer essentially qualitative judgements. Others, such as US-EPA (2005, 2006), Weiske & Michael (2007) and Smith *et al.* (2007a,b,c) offer quantitative estimates; NERA, (2007) offers an interesting study for the UK as part of an assessment of extending greenhouse gas trading into the agricultural sector.

Note that this notional analysis of the efficiency of greenhouse gas mitigation does not include other ancillary benefit (e.g. diffuse water pollution) that will typically be associated with managing emissions at the farm level. Note also that this decision framework applies only to notional *public* decisions. In reality, private decisions need not be guided necessarily by reference to the notional damage cost of emissions. Producers have no requirement and currently no policy incentive to mitigate at all. As mitigation obligations increase however, this implicit price will be made more apparent whether in direct (command and control) regulation, or through market based instruments. At that point, producers will be faced with a new emissions price. In theory a market based approach could mean taxing emissions on polluting inputs and or a trading regime, which may include a link to the existing EU Trading Scheme. Both mean that polluters can be faced with a price for their emissions. In the case of a tax, the rate would most likely be set to reflect the marginal damage cost of emissions - a price which is now notionally set by the social cost of carbon 25/tCO₂e by 2015. In a trading regime the price of permits is very much dependent on the demand and supply conditions imposed on the participants. The market based approach has properties that in theory lead to least cost mitigation. Both methods represent a notional transfer of the property right to pollute, and in both cases, the cost of maintaining that right can be palliated by more or less favourable allowances to lower marginal tax rate or initial pollution quotas.

In the latter case, a reasonable approach is the use of pollution permits and trading (Nera, 2007). While the practicalities of such a system are still under debate (in the UK at least), its operation would imply a price for emissions rights that is dependent on the supply and demand conditions of the market. This permit price does not necessarily equate to the SCC.

Figure 1 Stylised Marginal Abatement Cost Curve for CO₂e



Mitigation in developing countries

While the theory still applies, the prevalence of small extensive agricultural systems in the south suggests considerable potential for low cost abatement in developing countries. However, the hierarchy of cost effective measures is likely to be more extensive in terms of non agricultural options (e.g. household fuel use) that can reduce marginal emissions even more cheaply without similar social costs that relate to the high dependence of low income groups on livestock rearing. In developing countries, a polluter pays approach runs into existing arguments about livelihoods security and

the equity and justice arguments that have already been played out over the issue of the right to grow, responsibility for emissions, and ability to mitigate.

Increasing demand for livestock products in the south suggests a development transition towards more concentration and industrialisation in production methods. There are compelling equity arguments for this transition to be unfettered by stringent emissions regulation, especially since increased temperatures are likely to increase domestic production costs. A lack of domestic incentives may have to be palliated by international incentives for clean growth, possibly under the guise of payments for environmental services (PES). In the livestock context, the PES agenda may apply more successfully to within country transactions for say, the control of diffuse pollution to water. Such transactions may bring climate benefits, it is more likely that north south transactions for global environmental services will be necessary on an incremental cost basis.

Implications

A basic economic principle of greenhouse gas mitigation policy is that the cost of mitigating a tonne of greenhouse gas should not be greater than the benefits in terms of the avoided global damage costs caused by emissions. Options for the mitigation of greenhouse gas from livestock need to be considered in the light of this principle, and more specifically by comparing mitigation options with the shadow price of carbon. This comparison suggests that there are potential opportunities for the sector to play a role in global greenhouse gas emissions reductions. A forward look at research in livestock science also suggests that there are ways of reducing mitigation costs still further.

But there is no global protocol imposing reductions on the livestock sector and different countries must consider a range of other social impacts associated with addressing climate change policy through the livestock sector. In this regard it is possible to distinguish between OECD countries and developing countries characterised by high livelihoods dependence among relatively poor households on livestock products. A global policy on livestock emissions is therefore challenged by the realities of unequal global development. This inequity suggests that different incentive structures will be required to affect greenhouse gas mitigation from the sector in developed and developing countries.

Efficiency considerations are set against a reality of growing global demand for livestock products and warmer temperatures in areas where production is set to become more concentrated. It is unclear whether and how the growing demand in the south can be met by the south without undue environmental damages as production moves into marginal areas.

Warming in the south has a mirror image in the north where climate conditions are actually likely to be even more conducive to feed and to production operations. The implication is that there is space for northern production to develop into niches, which also entails intensive and extensive modified systems.

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References

- Amon, B., Kryvoruchko, V., Amon, T. & Zechmeister-Boltenstern, S. 2006. Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. *Agriculture, Ecosystems & Environment*, 112, 153-162.
- Defra. 2007. The Social Cost Of Carbon And The Shadow Price Of Carbon: What They Are, And How To Use Them In Economic Appraisal In The UK
<http://www.defra.gov.uk/environment/climatechange/research/carboncost/pdf/background.pdf>
- ECCP. 2001. Agriculture. Mitigation potential of Greenhouse Gases in the Agricultural Sector. Working Group 7, Final report of European Climate Change Programme, COMM(2000)88. European Commission, Brussels.
http://ec.europa.eu/environment/climat/pdf/agriculture_report.pdf
- FAO. 2007. Paying farmers for environmental services http://www.fao.org/es/esa/en/pubs_sofa.htm
- FAO. 2007. Livestock's long shadow environmental issues and options
http://www.virtualcentre.org/en/library/key_pub/longshad/A0701E00.htm
- Fiala, N. 2008. Meeting the demand: An estimation of potential future greenhouse gas emissions from meat production. *Ecological Economics* (in press)
- Garnett, T. 2007. Exploring the livestock sector's contribution to the UK's greenhouse gas emissions and assessing what less greenhouse gas intensive systems of production and consumption might look like. Working paper produced a part of the work of the Food Climate Research Network, University of Surrey.
<http://www.fcrcn.org.uk/frcnresearch/publications/PDFs/TG%20FCRN%20livestock%20final%206%20Nov%20.pdf>
- GFP. 2007. A study of the scope for the application of research in animal genomics and breeding to reduce nitrogen and methane emissions from livestock based food chains - AC0204. On-going research being conducted on behalf of Defra by the Genesis Faraday Partnership,
http://www2.defra.gov.uk/research/Project_Data/More.asp?I=AC0204&M=CFO&V=GFP
- Hanley, N (2007) The Economics of climate change policy in Scotland, paper David Hume Institute, Edinburgh

Hensen, A., Olesen, J. E., Petersen, S. O., Sneath, R., Weiske, A., Yamulki, S. 2006. Mitigation of greenhouse gas emissions from livestock production, *Agriculture, Ecosystems and Environment* 112 (2-3) 105-248.

Lokupitiya E. and K. Paustian. 2006. Agricultural Soil Greenhouse Gas Emissions: A Review of National Inventory Methods, *Journal of Environ Qual* 35:1413-1427

Mosier, A., Duxbury, J., Freney, J., Heinemeyer, O., Minami, K. & Johnson, D. 1998. Mitigating agricultural emissions of methane. *Climatic Change*, 40, 39-80.

Monteny, G.-J., Bannink, A & Chadwick, D. 2006. Greenhouse gas abatement strategies for animal husbandry. *Agriculture, Ecosystems and Environment*, 112, 163-170.

Moxey A. 2007. Reviewing and developing agricultural responses to climate change, report to RERAD

Nera. 2007. Market Mechanisms for Reducing GHG Emissions from Agriculture, Forestry and Land Management, report for Defra.

Schils, R.L.M., Verhagen, A., Aarts, H. & Sebek, L. 2005. A farm level approach to define successful mitigation strategies for GHG emissions from ruminant livestock systems. *Nutrient Cycling in Agroecosystems*, 71, pp. 163-175.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O. (2007a) Agriculture. In B. Metz, B. Davidson, O. Bosch, P. Dave, R., & Meyer, L. 2007. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.mnp.nl/ipcc/pages_media/FAR4docs/final%20pdfs%20of%20chapters%20WGIII/IPCC%20WGIII_chapter%208_final.pdf

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Uwe Schneider, U. & Towprayoon, S. , Wattenbach, M. & Smith, J. 2007b. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society, B.*, 363.doi:10.1098/rstb.2007.2184.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Uwe Schneider, U. & Towprayoon, S. 2007c. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture, *Agriculture, Ecosystems and Environment*, 118, 6–28.

The Stern Review of the Economics of Climate Change
http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

United Nations. 2007. Human Development Report Fighting Climate Change: Human solidarity in a divided World. http://hdr.undp.org/en/media/hdr_20072008_en_complete.pdf

US-EPA. 2005a. Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture. EPA 430-R-05-006. Washington, DC: U.S. Environmental Protection Agency. <http://www.epa.gov/sequestration>

US-EPA. 2005b. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003. EPA 430-R-05-003. Washington, DC: U.S. Environmental Protection Agency. http://www.epa.gov/climatechange/emissions/usgginv_archive.html

US-EPA. 2006. Global Mitigation of Non-CO2 Greenhouse Gases. United States Environmental Protection Agency, EPA 430-R-06-005, Washington, D.C. www.epa.gov/nonco2/econ-inv/downloads/GlobalMitigationFullReport.pdf

Weiske, A. 2005. Survey of technical and management-based mitigation measures in agriculture. MEACAP WP3 D7a, Institute for Energy and Environment paper under EU Sixth Framework Programme, Priority 8: Policy-Oriented Research. http://www.ieep.eu/publications/pdfs/meacap/WP3/WP3D7a_mitigation.pdf

Weiske, A. 2006. Selection and specification of technical and management-based greenhouse gas mitigation measures in agricultural production for modelling. MEACAP WP3 D10a, Institute for Energy and Environment paper under EU Sixth Framework Programme, Priority 8: Policy-Oriented Research. http://www.ieep.eu/publications/pdfs/meacap/D10a_GHG_mitigation_measures_for_modelling.pdf

Weiske, A. & Michel, J. 2007. Greenhouse gas emissions and mitigation costs of selected mitigation measures in agricultural production. MEACAP WP3 D15a, Institute for Energy and Environment paper under EU Sixth Framework Programme, Priority 8: Policy-Oriented Research. http://www.ieep.eu/publications/pdfs/meacap/WP3_D15_ghg_mitigation%20costs.pdf

WHRI. 2007a. *AC0401*: Direct energy use in agriculture: opportunities for reducing fossil fuel inputs. Report to Defra by Warwick Horticultural Research Institute & FEC Services. http://www.defra.gov.uk/science/Project_Data/DocumentLibrary/AC0401/AC0401_6343_FRP.pdf

Emission of greenhouse gas, developing management and animal farming systems to assist mitigation

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Introduction

Animal production may have adverse effects on many environmental aspects including air and water pollution, degradation of soil quality, reduction of biodiversity and global climate change. According to FAO (Steinfeld *et al.*, 2006) about 12% of total emission of greenhouse gas is related to livestock production. This contribution is even higher (18%) when the deforestation related to the expansion of livestock production area is also considered. The emission of greenhouse gas in livestock production systems originates mainly from the animals (enteric fermentations), the manure, and the fields used for the production of feed and forages. This means that mitigation can be achieved in different ways related to animal feeding and management, manure collection, storage and spreading, and management of crops for feed production, and also by more drastic changes of the whole production system.

In this paper, we will first present the respective contributions of the different processes involved in the emission of greenhouse gas from conventional animal production systems. We will then try to evaluate the variability existing among production systems. Finally, the effects of different mitigation options will be considered.

Contribution of the different production process to GHG emission in animal farming systems

The relative contributions of enteric fermentation, manure handling and production of forages and feed to total GHG emission in pig and dairy farm are given in Table 1. These data were calculated by life cycle assessment (LCA). The emissions for pig production are for a typical conventional pig farm with good agricultural practices in Brittany region (France). It was estimated from Basset-Mens and van der Werf (2005). The emissions for dairy production correspond to the average calculated from 46 farms also from Brittany. It was estimated from Roger *et al.* (2007). In that calculation global warming potential is determined in kg CO₂-equivalent, CO₂:1, N₂O:310, CH₄:21 (IPCC, 2006). In LCA the functional units used to express emissions can be either the product or the land used for production. It is generally recommended to express the emissions per unit of product in the case of global impacts, such as global warming, whereas the emissions per ha of land has also to be considered for local impacts, such as eutrophication. The expression per ha of land may also be of interest when comparing different productions, such as pork and dairy production.

Table 1 Evaluation of greenhouse gas emissions (eq CO₂) in swine and dairy production

	Pork production ¹		Dairy production ²	
	kg eq CO ₂	% of total	kg eq CO ₂	% of total
Per unit product (kg pig, L milk)	2.47	100	0.88	100
Origin				
Enteric fermentation	0.08	3.2	0.35	40.0
Manure handling	0.68	27.6	0.16	18.0
Production of forages and feed	1.67	67.6	0.32	36.0
Others	0.04	1.6	0.05	6.0
Total				
Type of gas				
CH ₄	0.49	19.9	0.46	52.8
N ₂ O	1.03	41.8	0.26	29.2
CO ₂	0.95	38.3	0.16	17.9
Per ha of land per year	4240		5080	

¹adapted from Basset-Mens and van der Werf (2005)

²adapted from Roger *et al.* (2007)

The results shown in Table 1 indicate that the average GHG emission per ha of land is slightly higher for dairy than for pig production. However, the most significant difference between the two production systems relates to the origin of the GHG. In the case of ruminants most of the GHG production is related to enteric fermentation (40%), the second most relevant contribution being that related to the production of forages and feeds (36%). In the case of monogastric animals the production of feed is the major contributor (68%) followed by manure handling (28%), with a very limited contribution of enteric fermentation. This results in major differences in the contribution of the different gases to total emission. Nitrous oxide and CO₂ are the major contributors for pork production systems whereas CH₄ contributes most in the case of dairy production.

The strategy for mitigation in a given system will depend on both the contribution of the different activities, including animal raising, manure handling and feed production, to total emission, and the possible improvement within each activity. A marginal improvement of a highly contributing activity might be as efficient as a more drastic improvement

of a modest contributing activity. However this requires information about the variations of emissions between systems, for instance comparing conventional and organic farming, and between farms in a given system, in order to identify the possible improvements.

Variability of GHG emission between livestock farming systems

Different estimations of GHG emissions from dairy and pig production systems found in the literature are reviewed in Figure 1. In the case of milk production the values were plotted against the amount of milk produced per ha, giving an indication of intensity of land use. This was not possible for pig production systems because in most studies the information about land use was not available.

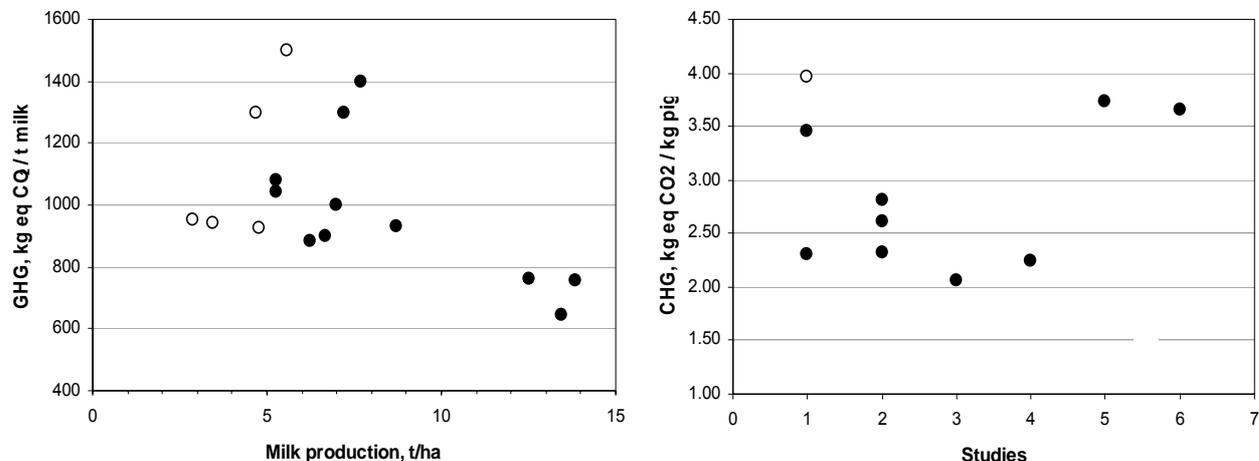


Figure 1 Estimation from literature studies of GHG emission in conventional (●) or organic (○) dairy (6 studies) and pig production (6 studies) systems. From Cederberg and Mattson (2000), Haas *et al.* (2001), Cederberg and Flysö (2004), Thomassen *et al.* (2008), Roger *et al.*, 2007 and Basset-Mens *et al.* (2007) for dairy systems, and Basset-Mens and van de Werf (2005), Cederberg, (2002), Dalgaard and Halberg (2005), Blonk *et al.* (1997, cited by Basset-Mens and van de Werf, 2005), Carlsson-Kanyama (1998).

The estimations of GHG emission are highly variable among studies, between 600 and 1500 kg eq CO₂ per t milk, and between 2 and 4 kg eq CO₂ per kg pig. Part of this variability might be related to differences in methodology, but it can also be explained by differences in production systems between studies. In the case of pig production the highest values were found in alternative production systems. This was partly related to the raising of fattening pigs on straw bedding which increased the emission of N₂O from manure and to the lower productivity of animals and land in these systems (Basset-Mens and van de Werf, 2005). In that study, organic pig farming resulted in a significantly higher emission of GHG per kg pig produced compared to conventional production. However when expressed per ha of land used GHG emission was similar for both systems. GHG emissions from organic and conventional dairy farms were compared in five studies (figure 1). The results indicate very similar emissions for both systems, with on average 1090 and 1120 kg eq CO₂ per t milk for the conventional and the organic production systems, respectively. However, because of a lower milk production per ha of land for organic farming, its GHG emission per ha was lower (4800 versus 7000 kg eq CO₂ per ha). According to the data presented in figure 1 there is no clear relationship between the emission of GHG per t milk and the intensity of milk production per ha. However, the studies having the highest milk production per ha present the lowest level of GHG emission per kg milk. For the intermediate range of milk production per ha there is a large variations in the level of emissions per t milk, suggesting possible improvements for all systems. In the same way, Basset-Mens and van der Werf (2005) estimated the variability of emissions of GHG in different pig production systems and suggested that variation within systems was as high as between systems.

Another important point to consider is the uncertainty of the estimation of GHG emissions which may also contribute to explain differences between studies. Indeed, the information relative to the emission in some systems is scarce and values are based on a very limited number of studies. For instance, the emission of N₂O is generally not well known, although in some systems the contribution of this gas may be very high. Basset-Mens *et al.* (2006) evaluated the uncertainty of GHG emission in different pig production systems using a sensitivity analysis. According to their results uncertainty was large (> 50%) and originated mainly from the estimation of field emissions of N₂O and, when the pigs were housed on litter bedding, of emissions of N₂O from manure. This highlights the necessity of improving our knowledge on the factors affecting the emissions of GHG.

Mitigation strategies

The improvement of animal productivity was suggested by FAO (2006) as an efficient way to increase world production of animal products and meet the increasing world demand, without increasing the use of land or the emission of GHG. As indicated in table 1 most of the GHG emission is related to the production of feed and its digestion by animals. Moreover the amount of manure and consequently GHG emissions from manure are also related to the amount of feed used. The efficiency of conversion of feed to animal products depends on the relative contributions of maintenance and production to the total requirement. When animal production rate is low, maintenance contributes

more, resulting in more feed required per kg product and consequently in more emissions. In meat producing animals the efficiency is also affected by the composition of the meat, the amount of energy required to produce fat being much higher than for lean tissues. In the case of pig production we can estimate from the results of French farms that, compared to the average performing farms, GHG emission is reduced or increased by about 7% in the 30% best- and 30% worst-performing farms, respectively. This means that all the practices, including genetic, nutrition, reproduction or health improvement, that result in the improvement of feed efficiency are potential ways to reduce GHG emissions per unit of product. But maximal feed efficiency does not always mean maximal production or maximal economic efficiency.

The composition of the feed has been shown to influence enteric fermentation and emission of CH₄ from the rumen or the hindgut. In monogastric animals, although some improvements may be expected, the effect is limited because of the rather low contribution of enteric CH₄ to total emissions (less than 5%) and because the possible variation in diet composition is limited. In ruminants the effect of feed composition is much higher. Methane emission (as a percentage of energy intake) decreases when feeding level increases or when digestibility of the ration is improved. Consequently, as indicated by the equations proposed by Giger-Reverdin *et al.* (2000), CH₄ production in the rumen decreases when the proportion of concentrate in the ration increases. The composition of the diet also affects the excretion of N and organic matter, which both will affect the emission of GHG (N₂O and CH₄, respectively) during manure storage and spreading. As a consequence, improving the composition of the diet to decrease N excretion, which is often proposed to reduce eutrophication (NO₃⁻) and acidification (NH₃) impacts, might also be of interest for the reduction GHG. In monogastric animals, the use of synthetic amino acids (SAA) and phase feeding have been shown to be very efficient ways to reduce N excretion (Dourmad and Jondreville, 2007). However to evaluate the real impact of changing the composition of the diet on GHG emission it is necessary to consider the effects on the whole system. For instance increasing the incorporation of SAA in pig diets will result in a reduced incorporation of soybean or rapeseed meal and an increased incorporation of cereals. LCA allows taking all these effects into account (van de Werf *et al.*, 2005). In this context the impact of three scenarios of feed choice was studied by Strid Eriksson *et al.* (2005). The scenarios differed in the origin of the protein fraction, either imported soybean meal, locally produced peas and rapeseed cake or SAA. GHG emission was the lowest for the pea diet, the highest for the soybean meal diet and intermediate for the SAA diet. In ruminants the real impact of modifying the diet is even more difficult to assess. For instance feeding cows on pasture, which tends to increase enteric production of CH₄ compared to cereals based diets, induces drastic changes in manure management, most of the excreta being spread by the cows on the fields, and in mechanisation and use of fertilizers. As a consequence GHG emissions associated to the management of manure and the production of feed are reduced. This could explain why GHG emissions in outdoor pasture-based systems (Basset-Mens *et al.*, 2007) in New-Zealand (about 800 kg eq CO₂ / t milk) are lower than in indoor cereals based systems (about 1300 kg eq CO₂ / t milk) in the Netherlands (Thomassen *et al.*, 2008), although the opposite was expected when only enteric CH₄ was considered.

GHG emission from manure has an important contribution to total emission and offers mitigation opportunities. GHG emitted from manure are mainly CH₄ and N₂O. Methane is produced in anaerobic conditions and is the main GHG emitted from liquid manure. The intensity of production depends mainly on manure organic matter and on temperature and duration of storage. This means that systems with long term storage of liquid manure indoors or outdoors at high ambient temperature will result in much higher CH₄ emission. The production of nitrous oxide requires aerobic conditions that can be found in solid manure or during the spreading of liquid manure, especially on wet soils. Methane may also be emitted from anaerobic zones in solid manure. This means that, depending on litter management, more CH₄ or more N₂O will be emitted. Rigolot *et al.* (2007) estimated that, compared to liquid slurry, the use of straw or sawdust litter bedding in pig production resulted in 120% increase of GHG emission from manure. This originated from an increased emission of N₂O which was only partially compensated by a decreased CH₄ emission. However these results are highly sensitive to the management of the litter (Hassouna *et al.*, 2005). For instance in litters from ruminants CH₄ seems to remain the main contributor to GHG suggesting that conditions are more anaerobic. Consequently, as regard to GHG emission it seems that litter-based systems should not be recommended, but other dimensions have also to be considered in that choice, such as animal health and welfare which are generally improved in these systems. For liquid slurry the main mitigation options are reducing storage duration, especially in hot conditions, the treatment of manure and improved spreading techniques. In this context a rapid removal of the slurry followed by an anaerobic digestion appears a very efficient way to reduce, or even nearly suppress, not controlled CH₄ emission during storage. Moreover this process results in the production of renewable energy. In the case of ruminants, raising the animals on pasture is an efficient way to reduce CH₄ emission from manure, because storage is suppressed.

Implications

Greenhouse gas emission in animal production is highly variable between and even more, within production systems. This is not surprising, because this criterion has never been considered in the optimisation, or the management, of animal production systems. Many mitigation strategies have been identified and are already available. New technologies can also be expected in the future. In this context it seems important to develop on-farm evaluation tools, based on farm modelling, to assist decision. More research is also needed to better evaluate the emission of GHG, especially N₂O, in alternative production systems.

References

- Basset-Mens C, Ledgard S, Boyes M 2007. Eco-efficiency of intensification scenarios for milk production in New Zealand. *Ecological Economics*. doi:10.1016/j.ecolecon.2007.11.017.
- Basset-Mens C, van der Werf H 2005. Scenario-based environmental assessment of farming systems: the case of pig production. *Agriculture, Ecosystems & Environment* 105, 127-144.
- Basset-Mens C, van der Werf H, Durand P, Leterme P 2006. Implication of uncertainty and variability in the life cycle assessment. *International Journal of Life Cycle Assessment* 11, 298-304.
- Carlsson-Kanyama A 1998. Energy consumption and emissions of greenhouse gases in the life-cycle of potatoes, pork meat, rice and yellow peas. Technical report 26 ISSN1104-8298. Department of Systems Ecology, Stockholm, Sweden.
- Cederberg C 2002. Life cycle assessment of animal production. PhD Thesis. Department of Applied Environmental Science, Göteborg University, Sweden.
- Cederberg C, Flysjö A 2004. Life cycle inventory of 23 dairy farms in south-Western Sweden. In: SIK report n° 728, SIK, Göteborg, Sweden.
- Cederberg C, Mattson B 2000. Life cycle assessment of milk production – a comparison of conventional and organic farming. *Journal of Cleaner Production* 8, 49-62.
- Dalgard R, Halberg N, 2005. Life cycle assessment of Danish pork. In: *Green Pork Production*, ed. INRA, Paris, 25-27 May 2005.
- Dourmad JY, Jondreville C 2007. Impact of nutrition on nitrogen, phosphorus, Cu and Zn in pig manure, and on emissions of ammonia and odours. *Livestock Science*, doi:10.1016/j.livsci.2007.09.002.
- Giger-Reverdin S, Sauvant D, Vermorel M, Jouany J-P 2000. Empirical modelling of methane losses from ruminants. *Rencontres Recherche Ruminants*, 7, 187-190.
- Haas G, Wetterich F, Köpke U 2001. Comparing intensive and organic grassland farming in southern Germany by process life cycle assessment. *Agriculture Ecosystems & Environment* 83, 43-53.
- Hassouna M, Robin P, Texier C, Ramonet Y, 2008. NH₃, N₂O and CH₄ emission from pig-on-litter systems. In: *Green Pork Production*, ed. INRA, Paris, 25-27 May 2005.
- IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Egglestone, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (eds.). Institute for Global Environmental Strategies, Hayama, Japan. Available at <http://www.ipcc-nggip.iges.or.jp>.
- Rigolot C, Espagnol S, Hassouna M, Dourmad JY 2007. Modelling of manure production by pigs. Effect of feeding, storage and treatment on manure characteristics and emissions of ammonia and greenhouse gases. 58th annual meeting of the European Association for Animal Production (EAAP). Dublin, 26-29 August 2007.
- Roger F, van der Werf H, Kanyarushoki C 2007. Systèmes bovins lait bretons : consommation d'énergie et impacts environnementaux sur l'air, l'eau et le sol. *Rencontres Recherches Ruminants* 14, 33-36.
- Steinfeld H, Gerber P, Vassenaar T, Castel V, Rosales M, de Haan C 2006. *Livestock long shadow*. Environmental issues and options. Ed. FAO (2006), Rome, 390 pp.
- Strid Eriksson I, Elmquist H, Nybrant T 2005. Environmental system analysis of pig production. *International Journal of Life Cycle Assessment* 10, 143-154.
- Thomassen MA, van Calster KJ, Smits MCJ, Iepema GL, de Boer IJM 2008. Life cycle assessment of conventional and organic milk production in the Netherlands. *Agricultural Systems* 96, 95-107.
- Van der Werf H, Petit J, Sanders J 2005. The environmental impact of the production of concentrated feed: the case of pig feeding in Bretagne. *Agricultural Systems* 83, 153-177.

Reduction of greenhouse gas emissions of ruminants through nutritional strategies

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Introduction

Ruminants produce greenhouse gases (GHG) in a number of ways. Enteric fermentation gives rise to methane (CH₄), nitrogen excreted especially by grazing ruminants promotes the formation of nitrous oxide, and stored manure gives rise to both CH₄ and nitrous oxide. Ruminant production systems also use fossil fuels and electrical power, and use products such as fertiliser, feedstuffs, pesticides that have incurred emission of GHG in their production. Many mitigation strategies have been proposed. This review examines a number of nutritional strategies to reduce of enteric CH₄. It does not consider biotechnology based interventions (e.g. immunisation, bacteriophages and bacteriocins, enzyme additives, yeast additives) or non-nutrient chemical additives (e.g. halogenated analogues).

Accumulation of hydrogen produced by microbial metabolism is avoided mainly by CH₄ synthesis by rumen methanogens, which is a normal part of the fermentation process. Strategies to reduce enteric CH₄ production can therefore seek to reduce the production of hydrogen, inhibit methanogenesis and redirect hydrogen into alternative products, or provide alternative sinks for hydrogen. Nutritional abatement strategies are generally based around one of these fundamental processes. However, at a whole system level, nutrition can impact in other ways. For instance if animal performance is improved through better nutrition, energy for maintenance is reduced as a proportion of total energy requirement, and CH₄ associated with maintenance is reduced. Thus CH₄ emissions per kg milk or meat will be reduced. Similarly if improved animal performance leads to animals reaching target slaughter weight at a younger age, then total lifetime CH₄ emissions are reduced. On the other hand, going for increased performance may reduce longevity and thus even increase total lifetime emissions when accounting for rearing for replacement. For this reason, and because CH₄ mitigation strategies can impact on emissions of other GHG at some other point of the production system, the effect of mitigation strategies should be assessed on the full production system, i.e. a life-cycle analysis. To date, there are few such assessments of nutritional abatement strategies.

Some other considerations are needed. Mitigation strategies need to be financially neutral at worst, and feasible at farm level, otherwise farmers will not willingly adopt them. They need to be acceptable by society, and what is acceptable in one society may not be in others (e.g. ionophores are banned in the EU, but are used in many other regions). Finally, different animal production systems throughout the world mean that mitigation strategies are not universally applicable.

Diet quality – replacing roughage with concentrates

Many experimental databases suggest that a higher proportion of concentrate in the diet leads to a reduction in CH₄ emissions as a proportion of energy intake (Blaxter and Clapperton, 1965; Yan *et al.*, 2000) due mainly to an increased proportion of propionate in ruminal VFA. The scope for reductions in CH₄ emissions depends on the starting level of concentrates, as there are dietary limitations, and there are large differences in current usage of concentrates in different regions of the world. Maximum impact would be to change meat producing cattle and sheep from a predominantly forage diet, with approx 0.06 – 0.07 of GE being emitted as CH₄ and put them onto a feedlot diet, with emissions of 0.03 of GE (Johnson and Johnson, 1995). This would involve a radical change to the production systems in many areas of the world. Grain based feeding of beef cattle is primarily a North American system with this feeding practice being used to a lesser extent in Europe and Australia, and to a much smaller extent in other world regions. The scope in the dairy sector is lower, and milk quality is impacted once concentrates go above about 0.5 of the diet, a level which has already been reached in North America and many European countries.

Because other factors impact the total GHG budget (production increases so less animals are needed for a given output, and less land and/or less fertiliser is required for the animal enterprise; beef cattle or sheep reach target slaughter weight at an earlier age, with less lifetime emissions; extra concentrates need to be grown and processed, and associated GHG emissions need to be accounted for), this strategy should be considered from a whole system perspective. Lovett *et al.* (2006) examined the effect on on-farm and off-farm emissions of increasing concentrate feeding from 376 to 810 and 1540 kg/cow/lactation. Total emissions (both on and off-farm) were 1.149, 1.103 and 1.040 kg CO₂ equivalents per kg milk respectively, for low, medium and high concentrate levels, i.e. a decrease of 9.5% between the extremes. Lovett *et al.* (2006) did not consider a possible increase in emissions from manure (Hindrichsen *et al.*, 2006), so this reduction may be a slight overestimate. The financial cost to the producer of implementing the measure depended on the pedigree index of the cows. With low or medium index cows, costs were higher. With high index cows, it was profitable to go to the higher concentrate level. However, concentrate costs have increased substantially since this study was published.

The implication of these studies is that careful consideration needs to be given at an individual farm level to ensure that the measure is cost effective and that a sufficiently large net reduction in GHG emissions is achieved to justify this attempt and its associated other problems.

Diet quality – carbohydrate type

Structural carbohydrates (cellulose and hemicellulose) ferment at slower rates than non-structural carbohydrates (starch and sugars) and yield more CH₄ per unit of substrate fermented due to a greater acetate:propionate ratio (Czerkawski, 1969). It has also been suggested that non-structural carbohydrates should be further subdivided as soluble sugars have a higher methanogenic potential than starch (Johnson and Johnson, 1995). This suggests that cereal feedstuffs will result in lower emissions than by-product feedstuffs with higher fibre levels. However if looking at a systems analysis, GHG emissions associated with the cultivation and subsequent processing of starch-based animal feeds will have to be fully attributed to the animal feed whereas the emissions associated with cultivation and processing of by-products (e.g. sugar beet pulp) have to be divided between the waste product (beet pulp) and the main product (sugar). Consequently a greater net benefit to the atmosphere might result from the use of more fibrous concentrates due to their lower embedded GHG emissions. This subject needs experimental data as well as whole system or life cycle analysis.

Forage species

The forage species fed to ruminants has been shown to influence CH₄ emissions. Animals fed legume forages have been observed to emit less CH₄ compared to emissions from grass-fed animals (e.g., Beever *et al.*, 1985), although others (e.g., Van Dorland *et al.*, 2007) reported no differences. McCaughey *et al.* (1999) speculated that this may in part be due to the higher levels of intake and digestibility generally associated with legumes, and thus a modified ruminal fermentation pattern combined with higher passage rates. However, Beever *et al.* (1985) reported the same effect at comparable intake levels when working with pure swards of clover and perennial ryegrass. While this strategy has promise, farmers are often slow to replace grass with clover for reasons such as pasture management and the risk of bloat. Grass-clover mixtures are better adopted in that respect. As there are also possible benefits from reduced use of fertiliser nitrogen, it is worthy of further investigation, and in particular of whole system analysis.

Pasture management

Improving pasture quality is often cited as a means of reducing emissions (e.g., McCrabb *et al.*, 1998), especially in less developed regions, because of improvements in animal productivity, as well as a reduction in the proportion of energy lost as CH₄ due to a reduction in dietary fibre. However, there is evidence that the impact of pasture quality on CH₄ emissions per kg of pasture consumed is small in temperate, well-managed swards. Molano and Clark (2008) reported no difference in CH₄ emissions per kg of grass dry matter intake (DMI) between lambs fed pasture with OM digestibility of 666 or 766 g/kg. Measurements with beef heifers in Ireland fed zero-grazed pastures with a similar range in digestibility showed no impact on CH₄ emissions per kg of DMI, although there was a significant increase in DMI of the high quality pasture (T. Boland, personal communication). So while it appears that pasture quality in well managed pastures will not have a large effect on emissions per kg of pasture consumed, there could be significant improvements in lifetime emissions or emissions per kg of product which should be examined in a whole system analysis. If pasture improvement leads to increased stocking densities, it could lead to greater emissions per ha. The effect of pasture improvement in Australian sheep farms was recently modelled by Alcock and Hegarty (2006), who reported only a small reduction in CH₄ output per kg liveweight. But in their case, the assumed individual sheep productivity was already quite high, and the pasture improvement was calculated to lead mainly to an increase in stock numbers. In addition, the simulation showed little effect on digestibility of the forage, but rather gave an increase in the quantity of forage available. Lovett *et al.* (2008) modelled dairy production systems in contrasting soil types (wet and impermeable vs dry and free-draining) and reported that the drier soils with a substantially longer grazing season supported milk production with significantly lower GHG emissions per kg of milk produced.

Quality and type of ensiled forage

Farmers ensile grass, maize, or other cereals crops to provide winter forage. When fed to ruminants, maize or other cereal silages could be expected to give reduced CH₄ emissions compared to grass silage due to a higher propionate fermentation because of the starch in the cereal silages, a higher voluntary intake of the cereal silages which will give lower ruminal residence time and restricted fermentation, and the higher voluntary intake may also give better animal performance and thus reduced emissions per kg of animal product. However, there is a need for animal studies to confirm this, and a need for whole system modelling to determine the impact on whole farm emissions. In terms of the effect of quality of cereal silages, there is recent evidence of a decline in CH₄ emissions per kg DM intake as starch content of maize silage increased (E McGeough, personal communication).

Plant secondary compounds and plant extracts

There is currently interest in the role of plant secondary compounds such as saponins and tannins in reducing CH₄ emissions (Wallace, 2004; Patra *et al.*, 2006). Saponins have been shown to possess strong defaunating properties both *in vitro* (e.g., Wallace *et al.*, 1994) and *in vivo* (e.g. Navas-Camacho *et al.*, 1993) which could reduce CH₄ emissions. Beauchemin *et al.* (2008) recently reviewed literature related to their effect on CH₄ and concluded that there is evidence for a reduction in CH₄ from at least some sources of saponins, but that not all are effective. Likewise they reported that there is evidence that some condensed tannins (CT) can reduce CH₄ emissions. Some legumes contain CT, but unfortunately these may reduce forage digestibility and the CT containing varieties tend to have weak agronomic performance. McAllister and Newbold (2008) reported that extracts from plants such as rhubarb and garlic could

decrease CH₄ emissions. While there is insufficient evidence to conclude on the potential of plant secondary compounds or extracts as mitigation strategies, this is likely to be an area of significant research over the coming years.

Adding lipid to the diet

It has long been noted that CH₄ emissions decrease with increasing fat and oil supplementation (e.g. Czerkawski *et al.*, 1966). There is some evidence that the magnitude of the effect is source dependent. Oils containing C12 (lauric acid) and C14 (myristic acid) are particularly toxic to methanogens (Machmüller *et al.* 2000; Dohme *et al.* 2001). Lipids cause the depressive effect on CH₄ emissions by toxicity to methanogens (Machmüller *et al.*, 2003), reduction of protozoa numbers (Czerkawski *et al.*, 1975) and therefore protozoa associated methanogens, and a reduction in fibre digestion (Van Soest, 1991). This latter point could cause an impact on total tract diet digestibility, and lipids can also depress DMI. Therefore this strategy could negatively impact animal performance. However, if total dietary lipid is kept below 60-70 g/kg DM, the depressive effects on intake and digestibility are generally small. Beauchemin *et al.* (2008) recently reviewed the effect of level of dietary lipid on CH₄ emissions over 17 studies and reported that with beef cattle, dairy cows and lambs, there was a proportional reduction of 0.056 in CH₄ (g/kg DM intake) for each 10 g/kg DM addition of supplemental fat. While this is encouraging, many factors need to be considered such as the type of oil, the form of the oil (whole crushed oilseeds vs pure oils), handling issues (e.g. coconut oil has a melting point of c. 25°C), and the cost of oils which has increased dramatically in recent years due to increased demand for food and industrial use. In addition, there are few reports of the effect of oil supplementation on CH₄ emissions of dairy cows, where the impact on milk fatty acid composition and overall milk fat content would need to be carefully studied. Strategies based on processed linseed turned out to be very promising in both respects recently (Martin *et al.*, 2007). Most importantly, a comprehensive whole system analysis needs to be carried out to assess the overall impact on global GHG emissions.

Organic acids

Organic acids are generally fermented to propionate in the rumen, and in the process reducing equivalents are consumed. Thus they can be an alternative sink for hydrogen and reduce the amount of hydrogen used in CH₄ formation. Newbold *et al.* (2005) reported fumarate and acrylate to be the most effective in batch culture and artificial rumen. There have been some recent *in vivo* studies. Newbold *et al.* (2002) reported a dose-dependent response to fumarate in sheep. Wallace *et al.* (2006) described a proportional reduction of 0.4 – 0.75 when encapsulated fumaric acid (0.1 of diet) was fed to sheep. On the other hand, others (e.g. McGinn *et al.*, 2004; Foley *et al.*, 2007) reported no or small reductions in CH₄ (l/kg DM intake) when beef cattle received were fed malate. While the level of reduction in CH₄ emissions that could be achieved is somewhat uncertain, the main impediment to this strategy is the current cost of organic acids which makes their use uneconomical.

Ionophores

Ionophores (e.g. monensin) are antimicrobials which are widely used in animal production to improve performance. Tadeschi *et al.* (2003) reported in a recent review that on feedlot and low forage diets, they tend to marginally increase average daily gain whilst at the same time reducing DMI, thus increasing feed efficiency by about 6%. Monensin should reduce CH₄ emissions because it reduces DMI, and because of a shift in rumen VFA proportions towards propionate and a reduction in ruminal protozoa numbers. *In vivo* studies have shown that animals treated with monensin emit reduced levels of CH₄ (e.g. McGinn *et al.*, 2004; van Vugt *et al.*, 2005) but others have reported no significant effect (e.g. Waghorn *et al.*, 2008 van Vugt *et al.*, 2005). Van Soest and Demeyer (1996) reviewed 9 experiments, and concluded that on average monensin reduces CH₄ production as a proportion of gross energy intake by 0.18, with the extent of the reduction being related to the dose and type of diet. Some work has suggested that the monensin induced reduction in CH₄ production may be transitory with CH₄ emissions returning to pre-treatment levels in a period as short as 14 days (e.g. Rumpler *et al.*, 1986). This is despite the changes in VFA proportions persisting (e.g. Mbanzamihigo *et al.*, 1995). Not all long term studies have shown that the effect is transitory (e.g. Davies *et al.*, 1982). The reason for the differences between studies is not clear and further work is needed to determine the reduction potential, particularly in dairy cow feeding where the supplementation is long term. But even if the response is transitory, the impact on DMI persists, and should reduce CH₄ emissions by up to 5%, due to the strong relationship between CH₄ production and DMI. However, there are regulations to prevent the use of ionophores as a dietary additive in the EU.

Conclusions

While there are several nutritional strategies that may reduce CH₄ emissions, there is insufficient data on many of these to judge their effectiveness. The greatest lack of information is in the area of whole system or life cycle analysis. This is urgently needed to judge the likely effectiveness of the mitigation strategies, to identify the most important gaps in our knowledge, and to help in directing research efforts to most promising strategies. Other strategies such as plant secondary compounds and extracts require much more research before their potential can be satisfactorily evaluated, while some strategies such as organic acids appear to have little prospect of commercialisation at present. Overall, there does not appear to be the possibility for large or quantum reductions in CH₄ emissions from ruminant systems from currently available nutrition-based technologies. However, technical efficiency in production systems should be optimised so as to minimise emissions per kg of milk or meat produced, and there is a key role for animal nutrition in achieving this optimisation.

Implications

With our current knowledge, it is not possible to significantly reduce GHG emissions from animal agriculture using practical and acceptable nutrition-based strategies. Some of the proposed measures are too costly or are insufficiently proven to be adopted at this stage. In particular the lack of whole system or life cycle analysis inhibits effective evaluation of mitigation strategies, which have generally been assessed to date in short-term studies where one GHG (e.g. CH₄) was studied. There are some potential strategies and further research is warranted. In addition, efficiency in animal production systems should be optimised to minimise emissions per kg of milk or meat produced.

References

- Alcock D, Hegarty RS 2006. In 'Greenhouse Gases and Animal Agriculture: An Update. (Ed. Soliva CR, Takahashi J, and Kreuzer M), pp.103-105 (Elsevier International Congress Series 1293, Amsterdam, The Netherlands).
- Beauchemin KA, Kreuzer M, O'Mara F, McAllister TA 2008. *Australian Journal of Experimental Agric.* 48, 21-27.
- Beever DE, Thompson DJ, Ulyatt MJ, Cammell SB, Spooner MC 1985. *British Journal of Nutrition*, 54,763-775.
- Blaxter KL, Clapperton L 1969. *British Journal of Nutrition* 19, 511-522.
- Czerkawski JW 1969. *World Review of Nutrition and Dietetics* 11:240-282.
- Czerkawski JW, Blaxter KL, Wainman FW 1966. *British Journal of Nutrition* 20:349-362.
- Czerkawski JW, Christie WW, Breckenridge G, Hunter ML 1975. *British Journal of Nutrition* 34:25-44.
- Davies A, Nwaonu HN, Stanier G, and Boyle FT. 1982. *British Journal of Nutrition* 47:565-576.
- Dohme FA, Machmüller A, Wasserfallen A, Kreuzer M.2000. *Canadian Journal of Animal Science* 80, 473-482
- Foley PA, Callan J, Kenny DA, Johnson KA, O'Mara FP 2007. *Proc. of the Agricultural Research Forum*, pp. 112.
- Hindrichsen IK, Wettstein H-R, Machmüller A, Kreuzer M 2006. *Agriculture, Ecosystems and Envir.* 113, 150-161.
- Johnson KA, Johnson DE 1995. *Journal of Animal Science* 73, 483-2492.
- Lovett DK, Shalloo L, Dillon P, O'Mara FP 2006. *Agricultural Systems* 88, 156-179.
- Lovett DK, Shalloo L, Dillon P, O'Mara FP 2008. *Livestock Science*, Corrected Proof, Available online 27 Dec 2007.
- Machmüller A, Ossowski DA, Kreuzer M 2000. *Animal Feed Science and Technology* 85, 41-60
- Machmüller A, Soliva CR, Kreuzer M 2003. *British Journal of Nutrition* 90, 529-540
- Martin, C., Ferlay, A, Chilliard, Y, Doreau, M. (2007): In: *Energy and Protein Metabolism and Nutrition (Ortigue-Marty, I., ed.)*. EAAP Publ. 124, Wageningen Academic Publishers, Wageningen, The Netherlands, 609-610
- Mbanzamihigo L, Van Nevel CJ, Demeyer DI 1995. *Reproduction, Nutrition, Development* 35, 353-365.
- McAllister TA, Newbold CJ 2008. *Australian Journal of Experimental Agriculture* 48, 7-13.
- McCraib GJ, Kurihara M, Hunter RA 1998. *Proceedings of the Nutrition Society of Australia*. 22:55.
- McGinn SM, Beauchemin KA, Coates T, Colombatto D 2004. *Journal Animal Science* 82, 3346-3356.
- Molano G, Clark H 2008. *Australian Journal of Experimental Agriculture* 48, 219-222.
- Navas-Camacho A, Laredo MA, Cuesta A, Anzola H, Leon JC 1993. *Livestock Research for Rural Dev.* 5, 58-71.
- Newbold CJ, Ouda JO, Lopez S, Nelson N, Omed H, Wallace RJ, Moss AR 2002. In: *Greenhouse gases and animal agriculture*, Eds J. Takahashi and B.A. Young, Elsevier, pp 151 - 154.
- Newbold CJ, López S, Nelson N, Ouda JO, Wallace RJ, Moss AR 2005. *British Journal of Nutrition* 94, 27-35
- Patra AK, Kamra DN, Agarwal N 2006. *Animal Feed Science and Technology* 128, 276-291. Rumpler *et al.*, 1986
- Tedeschi LO, Fox DG, Tylutki TP 2003. *Journal of Environ. Qual.* 32, 1591-1602
- Van Dorland HA, Wettstein HR, Leuenberger H, Kreuzer M 2007. *Livestock Science* 111, 57-69.
- Van Nevel CJ 1991. In: *Rumen microbial metabolism and ruminant digestion.* (Ed: J.P. Jouany). INRA. Paris, France
- Van Nevel CJ, Demeyer DI 1996. *Environmental Monitoring and Assessment.* 42:73-97.
- Van Vugt SJ, Waghorn GC, Clark DA, Woodward SL 2005. *Proceedings of the New Zealand Society of Animal Production* 65, 362-366.
- Waghorn GC, Clark H, Taufa V, Cavanagh A 2008. *Australian Journal of Experimental Agriculture* 48, 65-68.
- Wallace RJ 2004. *Proceedings of the Nutrition Society* 63, 621-629.
- Wallace RJ, Arthauo L, Newbold CJ 1994. *Applied Environmental Microbiology.* 60, 1762-1767.
- Wallace RJ, Wood TA, Rowe A, Price J, Yanez DR, Williams SP, Newbold CJ 2006. In 'Greenhouse Gases and Animal Agriculture: An Update. (Ed. Soliva CR, Takahashi J, and Kreuzer M), pp.148-151 (Elsevier International Congress Series 1293, Amsterdam, The Netherlands).

Developing breeding schemes to assist mitigation

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Introduction

Half of the land in the European Union (EU) is farmed. It plays an essential role in food production, protecting the environment and biodiversity, and providing amenities. However, agriculture adds to greenhouse gas (GHG) emissions; mitigating these can play a vital role in providing solutions to the EU's overall climate change challenges. Under the UN Kyoto Protocol (1997) the EU is committed to reduce GHG emissions by 8% by 2012 (European Union, 2000).

Livestock account for up to 35-40% of the world methane production, a large proportion (80%, de Haan *et al.*, 1996) of which comes from enteric fermentation and a smaller proportion (20%, Safely *et al.*, 1992) from anaerobic digestion in liquid manure. 64% of global nitrous oxide emissions are due to agriculture, chiefly due to fertilizer use. Ruminant production (cattle and sheep) needs to consider both CH₄ and N₂O, whereas monogastric production (pigs and poultry) species are mainly considered with N₂O (and NH₃). The majority of the UK land area (18.6 m² ha) is classed as agricultural land (including woodlands) of which 11.3 million hectares are under grass. This grass supports a ruminant animal population of 11.4 million cattle and 44.7 million sheep.

Genetic improvement of livestock is a particularly effective technology, producing permanent and cumulative changes in performance. This review will highlight some of the options for including mitigation in livestock breeding goals, focusing on ruminant species. There are essentially three routes through which genetic improvement can help to reduce emissions per kg product: 1) as a result of improved productivity and efficiency; 2) as a result of reducing wastage at the herd or flock level; and 3) as a direct response to selection on emissions, if or when these are measurable. We look at each of these options in more detail below, as well as discussing methods for accommodating mitigation in breeding programmes.

Mitigation as a result of breeding for improved productivity and efficiency

Typically, selective breeding can achieve annual rates of response of between 1 and 3% of the mean in the trait (or index) under selection (see Simm *et al.*, 2004 for a review). Selection for productivity and efficiency helps mitigate GHG production in two ways. Firstly, higher productivity generally leads to higher gross efficiency as a result of diluting the maintenance cost of the productive (and non productive) animals e.g. the Select line of Holstein dairy cows in our long running Langhill experiment have 17% higher yield per lactation, and a 14% higher gross efficiency (Veerkamp *et al.*, 1995). Secondly, a given level of production (e.g. a national milk quota) can be achieved with fewer high yielding animals and followers. For example, there has been an overall reduction of methane emissions of 28% from 1990 to 1999 in the UK (Defra, 2001). Similarly, the dairy sector in Canada has reduced its methane emissions by 10% since 1990 also by reducing the number of animals (Désilets, 2006).

Increasing the efficiency of production will help reduce the finishing period for meat animals, therefore reducing emissions per unit output. The studies of Mrode *et al.* (1990 a,b) compared the two strategies of selection on lean growth rate and food conversion ratio (FCR=daily food intake/growth rate). The increase in carcass lean and reduction in food conversion ratio with selection for lean growth were similar to the responses with selection for FCR (Mrode *et al.* 1990b) resulting in an overall improvement in FCR of 7% compared to a control line. However, growth rate was increased with selection for lean growth, but not with selection for FCR (Mrode *et al.* 1990b). Therefore, in terms of genetic improvement in feed efficiency and growth rate, selection for lean growth rate is preferable to selection for FCR, such that it is not necessary to measure food intake. Hyslop (2003) demonstrated that efficiency of the beef production system was paramount in reducing the GHG emissions/unit output showing that intensive concentrate based systems produce the lowest emissions. Further analyses of the data showed that there was also a significant breed difference suggesting that bigger continental breeds of cattle produced less emissions/unit output than the smaller British breeds (Hyslop, 2003).

Feed utilisation has been considered directly in selection programmes for pig and poultry species. In industry breeding programmes, annual genetic change in food conversion ratio for layer and broiler chickens of about 1% and 1.2% respectively have been reported (Presisinger and Flock, 2000; Mackay *et al.*, 2000). Due to the nature of many ruminant production systems, with less opportunity for intensive feed recording, the use of such traits in selection has been limited but there have been some examples. Hegarty *et al.* (2007) showed that there is a decreased enteric methane production per day in animals selected for lower residual feed intake. Reduced residual feed intake is akin to selection for high feed efficiency as an animal is eating less but maintaining a similar growth rate (high net feed efficiency) and therefore less feed is required to produce a unit of output. Lines were divergently selected for high and low residual feed intake and showed no significant differences for most production traits. This shows the possibilities for selection of reduced GHG emissions through the selection of animals which use less feed and produce less methane than average to achieve a given level of performance.

Mitigation as a result of breeding for reduced wastage at the herd or flock level

Many fitness traits have been shown to have a genetic component and so there is scope to improve them via genetic selection. Current broader breeding goals that select on both production and fitness traits can help to mitigate GHGs from many livestock systems as some examples below demonstrate.

Selection for fitness traits (lifespan, health, fertility) will help to reduce emissions by reducing wastage of animals. Improving lifespan in dairy cows and maternal line animals (i.e. ewes and beef cows) will reduce wastage by reducing the number of followers. For example by improving lifespan in dairy cows from 3.02 to 3.5 lactations will reduce methane emissions by 3%.

Improving health and fertility will reduce involuntary culling rates. This reduces emissions from dairy systems and beef and sheep systems (increased maternal survival) by reducing the numbers of followers required. Improving fertility will reduce calving/lambing intervals and inseminations resulting in shorter dry/unproductive periods. This reduces management costs as well as emissions. Improving health reduces incidence of health problems/diseases, thereby improving animal welfare and reducing treatment costs (and lower antibiotic use) and reducing emissions by maintaining the productivity level of the animal (which is reduced during periods of poor health). Garnsworthy (2004) estimated, via modelling, that if cow fertility was restored to 1995 levels from 2003 levels, that methane emissions from the dairy industry would reduce by 10-15%.

Direct selection to reduce emissions

Direct selection for methane emissions and their reduction would ideally be based on direct measurement of methane emissions. It is important to note that direct measurement of all sources of methane emissions from individual animals (exhaled by the animal due to enteric fermentation, manure management and flatulence) may prove difficult. However, expired air samples may be taken from individual animals or groups of animals. Air samples can be analysed for their methane concentrations using infrared spectroscopy, gas chromatography, mass spectroscopy or a tuneable laser diode. Several techniques have been used to take air samples, such as, respiration chambers, head boxes, hoods, masks and polytunnels. Not only is there variation between animals, between breeds and across time (Herd *et al.*, 2002) potential for improvement through genetic selection. However, measuring methane directly from animals is currently difficult and direct selection on reduced methane emissions may prove difficult in practice. Development of new measurement techniques, on direct and indirect emissions traits, will help to enhance the capability of reducing emissions through genetic selection.

Developing new indices to include mitigation options

Broader breeding goals have become the norm in many livestock species, - that is, selection is usually on a combination of production and "fitness" (health, fertility, longevity) traits. Breeding goals can be built in a number of ways including the popular method of creating an index by weighting traits by their relative economic value (REV). These REV's tend to be calculated by estimating the economic dis/benefit to the system of a unit change in the traits being examined. A lot of the example traits given earlier have been incorporated into indices for particular livestock sectors. However, livestock industries have more recently needed to consider societal views of aspects of farming systems, including issues such as welfare, biodiversity, food safety, health properties and environment.

Taking account of societal views in the economic framework of selection indices can be difficult as there may be no clear and direct monetary return from such considerations. Using restricted or desired gains approaches to selection indices allow the weightings to be derived that will see the desired response in traits of interest. For example, Wall *et al.* (2007a) showed how restricted index methodology could be used to halt the expected genetic decline in fitness traits in dairy cattle if selection were to continue on the available economic index. The difficulty in restricted/desired gains index methodology is developing a robust way of deciding on the desired outcomes of the selection index. As selection considers the longer term changes in a system the desired outcomes of selection cannot change year on year.

Another method would be to use the economic index framework but utilise new methodology to calculate economic weights for traits that have no clear direct market value. Amer (2006) suggested methods of calculating economic values using market research approaches such as conjoint analysis which asks consumers to assign preferences for the differing components of the product. This method would allow public perception to be used to help to be included in deriving economic weights that aim to reduce the emissions from farming systems.

Many traits described earlier, including those routinely included in current selection indices, have an indirect environmental impact and therefore the effect of a change in these traits can be expressed in an environmental impact unit such as Global Warming Potential or carbon equivalents (e.g., lifespan example given earlier). Farm models could be used to model the emissions from a livestock system and the effect that a change in a trait (e.g., fertility) would have on overall emissions. This is similar to the framework used to estimate REV's and weightings ("*relative environmental values*") derived could be used as an environmental selection index.

Although this review has focussed on the potential role that genetics may play in mitigating emissions from livestock systems there is undoubtedly a large nutritional component with much research on the differences between diets in

methane emissions and the use of additives to diets to reduce emissions (Moss *et al.*, 2000 for review). However, little work has been done on the potential role of genetics on emissions, particularly considering the role of genetics in the whole farming system and its interaction with including feeding strategy and management policies (e.g., energy balance, housing periods, fertilisation, and manure management). Robertson and Waghorn (2002) showed a genotype X environment (diet) on the methane emissions from dairy systems with US genotypes producing 8-11% less methane, as a percentage of gross energy (GE) intake, compared to New Zealand genotypes on both pasture and total mixed rations (TMR) diets.

Selection indices have tended to be expressed in terms of a generalised system representative of the “average” dairy farm. However, as shown by Hyslop (2003) there will be a difference in the emissions and economics (not shown) depending on the production systems and the animals used within that system (i.e., an animal of a particular genotype will perform differently on a high input system than on a low input system). The system parameters and relative economics will also differ from production type to production type. For example, recent work has shown that the economics of body tissue mobilisation differs depending on the calving system employed (spring vs. autumn) due to the different costs of feed at grazing opposed to winter feeding (Wall *et al.*, 2007b). There is also likely to be environmental impact differences in traits related to tissue utilisation and wastage depending on system types. In developing environmental indices it will be important to consider the different systems to help farmers consider the long-term environmental impact in their choice of breeding animals, specific to their system of production. For example, in dairy cows is it better in environmental terms to gather and preserve feed for winter feeding or for cows to store some of that energy as body lipid and then use it during the winter? Is it more efficient for the cow to produce milk of low solids content ready for direct consumption or for factories to alter high content milk to suit intended use? The answer to these and other similar questions may dictate the type of dairy cow for the future. Questions such as these may apply across livestock sectors.

A recent study (Moran *et al.*, 2007) has shown the very high value of animal and plant genetics R&D in helping to deliver on likely future policy priorities, including responding to global climate change. This research showed that plant and animal genetic improvement is expected to deliver public good rates of return ranging between 11-61% for the case studies examined, many times higher than the 3.5% recommended Treasury rate of return for public investment.

Conclusions

Overall, the outlook for GHG mitigation in agriculture suggests that there is significant potential. Current initiatives suggest that synergy between climate change policies, sustainable development and improvement of environmental quality will lead the way forward to realise the mitigation potential in the sector. In future, energy costs will rise and the use of nutrients by farmers is likely to be legislated. Nutrient leakage from farming systems will attract costs and so breeding strategies will be tailored to optimise production within nutrient use constraints. Grass/plant breeding and animal breeding will interact. Whole systems of farming that reduce nutrient waste will evolve and may be facilitated by integrated food supply chains. Further modelling work is required at the whole system level to identify sensitive areas and to help policy makers identify methods of encouraging farmers to adopt different production methods over time.

Implications

This study has shown that there is potential to reduce emissions from livestock systems by selection on correlated traits. Selecting on traits that improve the efficiency of the system (e.g., residual feed intake, longevity) will have a favourable effect on the overall emissions from the system. Improvements in system efficiency are also likely to have a favourable impact on the future sustainability of the system. The development of breeding goals that incorporate environmental concerns is possible. However, new measurement techniques for direct and indirect emissions traits will improve the potential to reduce emissions by harnessing genetic selection.

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References

- Amer, P.R., 2006. Approaches to formulating breeding objectives. Proceedings of the 8th World Congress on Genetics Applied to Livestock Production, August 13-18, 2006, Belo Horizonte, Brazil. Abstract No. 31-01.
- Defra, 2001. Third National Communication under the United Nations Framework Convention on Climate Change Published by the Department for Environment, Food and Rural Affairs, 2001.
- De Haan, D., H. Steinfeld, H. Blackburn. Livestock and the environment: Finding a balance. Report to the World Bank, FAO and USAID. <http://www.fao.org/docrep/x5303e/x5303e00.HTM>
- Désilets, E., 2006. Greenhouse gas mitigation program from Canadian Agriculture. Final Report for the Dairy Farmers of Canada.
- European Union, 2000. First European climate change programme http://ec.europa.eu/environment/climat/home_en.htm
- FAO, 2006. FAO Statistical databases. Rome. [<http://faostat.fao.org>]

Garnsworthy, P.C (2004) The Environmental impact of fertility in dairy cows: a modeling approach to predict methane and ammonia emissions. *Animal Feed Science and Technology* 112; 211-223.

Herarty, R. S., J. P. Goopy, R. M. Herd, and B. McCorkell. 2007. Cattle selection for lower residual feed intake have reduced daily methane production. *J. Anim. Sci.* 85: 1479-1486.

Herd, R.M., Arthur, P.F., Hegarty, R.S. and Archer, J.A., 2002. Potential to reduce greenhouse gas emissions from beef production by selection for reduced residual feed intake. 7th World Congress on Genetics Applied to Livestock Production, August 19-23, 2002, Montpellier, France.

Hyslop, J. 2003. Simulating the greenhouse gas and ammonia emissions from UK suckler beef systems. Report to the Department for Environment, Food and Rural Affairs.

International Panel for Climate Change [IPCC] (2006) 'Chapter 10: Emissions from Livestock and Manure Management' in 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Moran, D., Barnes, A. and McVittie, A. (2007) The rationale for Defra investment in R&D underpinning the genetic improvement of crops and animals (IF0101). Final report to Defra.

Moss, A. R., J-P Jouany, J. Newbold. 2000. Methane production by ruminants: its contribution to global warming. *Ann. Zootech.* 49: 231-252.

Mrode, R.A., C. Smith, and R. Thompson. 1990a. Selection for rate and efficiency of lean gain in Hereford cattle. 1. Selection pressure applied and direct response. *Animal Production* 51:23-34.

Mrode, R.A., C. Smith, and R. Thompson. 1990. Selection for rate and efficiency of lean gain in Hereford cattle. 2. Evaluation of correlated responses. *Animal Production* 51:35-46.

Robertson, L.J. and Waghorn G.C., 2002. Dairy industry perspectives on methane emissions and production from cattle fed pasture or total mixed rations in New Zealand. *Proceedings of the New Zealand Society of Animal Production*, Abstract No. 55. 62: 213-218

Safely, L. M., M. E. Casada, J. W., K. F. Roos. 1992. Global methane emissions from livestock and poultry manure. US Environmental Protection Agency. EPA/4001/1-91/048.

Simm, G., Bünger, L., Villanueva, B. and Hill, W.G. (2004). Limits to yield of farm species: genetic improvement of livestock. *Yields of farmed species. Constraints and opportunities in the 21st century* (eds. R. Sylvester-Bradley and J. Wiseman). Publ. Nottingham University Press, pp. 123-141.

Veerkamp, R. F., G. Simm, and J. D. Oldham. 1995. Genotype by environment interaction—experience from Langhill. Pages 59–66 in *Breeding and Feeding the High Genetic Merit Dairy Cow*. Occas. Publ. 19. T.L.J. Lawrence, F. J. Gordon, and A. Carson, ed. Br. Soc. Anim. Sci., Edinburgh, United Kingdom.

Wall, E., Coffey, M.P. and Brotherstone, S. 2007a. Developing a robustness index for UK dairy cows. *Proceedings of the British Society of Animal Science*, 2007. Abstract No. 52.

Wall, E., Coffey, M.P. and Amer, P.R., 2007b. A theoretical framework for deriving direct economic values for body tissue mobilization traits. *Journal of Dairy Science* (*in press*)

Genetic improvement of forage crops for climate change mitigation

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Introduction

A considerable amount of research has focused on greenhouse gas (GHG) emissions from grasslands: how they are measured and management strategies for mitigation. Similarly, there have been a number of studies on the role of grasslands in terms of carbon sequestration. However, less work has been carried out exploring ways in which genetic improvement of grassland crops can reduce emissions. In this paper we describe how grass and clover plant breeding programmes at IGER are being directed towards this aim. The main species we will consider are the major ones of temperate pastures: perennial ryegrass (*Lolium perenne*), white and red clover (*Trifolium repens* and *T. pratense*), and also birdsfoot trefoil (*Lotus corniculatus*). Mitigation of climate change impacts can result not only from reduced emissions but also enhanced carbon sequestration in grasslands, and we will also describe the potential for genetic improvement of forage in this respect.

The main GHG emissions from grassland-based livestock agriculture are nitrous oxide and methane. Nitrous oxide emission from temperate grasslands are poorly quantified although Mummey and Smith (2000) reported estimates from US grasslands of approx 67Gg nitrous oxide N/yr (based on simulated emissions x area). Gregorich *et al* (2005) found that emissions of nitrous oxide from soils increased linearly with the amount of mineral nitrogen fertiliser applied and because systems containing legumes produce lower annual nitrous oxide emissions, alfalfa and other legume crops should be considered differently when deriving national inventories of GHG from agriculture.

The two major sources of agricultural methane emissions are enteric fermentation in livestock and livestock manures. We will focus on genetic improvement strategies to reduce the former since this is both the most important source and the most amenable to improvement through breeding. However, it should be noted that approaches to alter the composition of livestock diets will also have an effect on manure composition (e.g. C:N ratio) which may affect decomposition rate.

Reducing nitrous oxide emissions

The rapid breakdown of herbage proteins in the rumen and inefficient incorporation of herbage N by the rumen microbial population are major causes of N loss and gaseous emissions. Scarcity of readily available energy during the time of maximal protein degradation restricts microbial protein synthesis. Ammonia accumulates as a waste product and is absorbed from the rumen and excreted as waste nitrogen in urine. When sheep (MacRae and Ulyatt, 1974) and cattle (Ulyatt *et al*, 1988) are given fresh forages they can waste 25-40% of forage protein.

Genetic improvement of the forage grasses and legumes that constitute important components of the ruminant diet has the potential to reduce emissions to air. Two possible strategies of increasing the efficiency of conversion of forage-N to microbial-N have been suggested; (i) increasing the amount of readily available energy accessible during the early part of the fermentation and (ii) providing a level of protection to the forage proteins, and thereby reducing the rate at which their breakdown products are made available to the colonising microbial population. One approach is to develop forage species with a better balance between water soluble carbohydrate (WSC) and crude protein (CP) by increasing the WSC content of the grass or the clover component or reducing the protein content of the legume.

The most advanced of these approaches is the development at IGER of high WSC ryegrasses which are already showing considerable commercial success, particularly in the UK, and for which there is some evidence that increased production is accompanied by reduced emissions (Miller *et al*, 2001). There is also significant variation within white clover and associated material including lower protein content and higher WSC. Unique non fixing inbred genotypes of white clover were used at IGER to demonstrate the principle that material of lower leaf protein content resulted in much slower protein degradation in the silo (Kingston Smith *et al*, 2006). Following this we established that genotypic variation within elite gene pools of white clover is much greater than was previously thought. Interspecific hybrids between white clover and *Trifolium ambiguum* (Kura or Caucasian clover) have a crude protein content 14.2g/kg DM lower than white clover.

A further area where genetic approaches can have an impact is in improving the nitrogen use efficiency (NUE) of crops to allow lower fertiliser application and hence reduce nitrogenous emissions through the soil-plant-animal-soil cycle. NUEs from soil to crop are lower generally on a whole-farm basis for grass-based livestock production as compared with arable crop production, ranging from 10-40% for whole dairy systems compared with 40-80% for arable systems (Neeteson *et al*, 2004). More efficient use of N brings benefits to farmers both with respect to meeting regulatory requirements and in terms of cost savings from reduced fertiliser use.

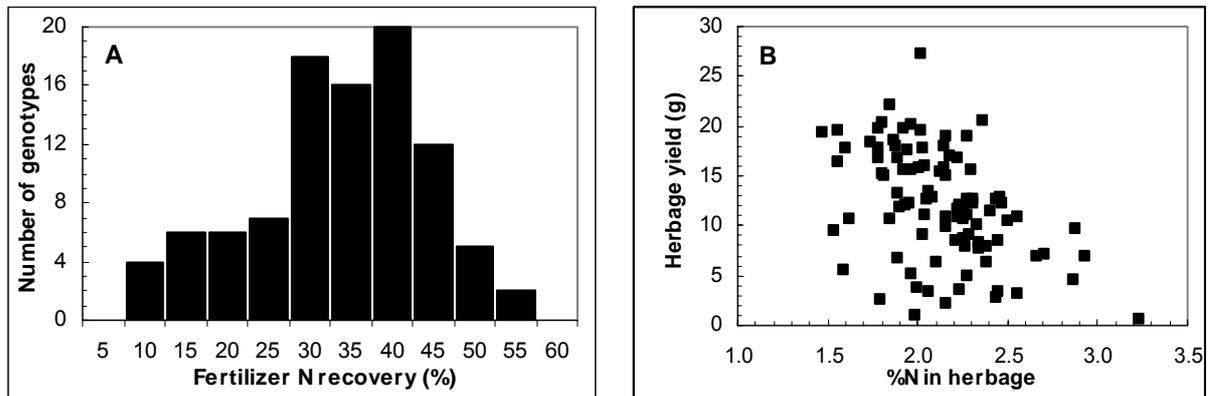


Figure 1 Variation in (A) apparent fertilizer N recoveries (150 kgN/ha application) in herbage of 96 genotypes belonging to IGER's 'amenity x forage' *Lolium perenne* mapping family; and (B) relationship between herbage yields (dry weights) and %N in herbage dry matter. Genotypes were grown as replicate mini-swards (900 cm²) in sand boxes and fertilizer recoveries measured after 6 months.

Recent studies with perennial ryegrass mapping families at IGER have revealed promising variation in fertilizer N recoveries (Figure 1A), little correlation between herbage yield and N content (Figure 1B), and a range of QTLs for components of NUE, including short-term (6 months) N fertilizer recoveries (linkage group 7, LOD= 2.57) and longer term (18 months) recoveries (Linkage group 7, LOD= 3.86).

Reducing methane emissions

An approach of current interest, supported by some promising initial findings, is the use of tannin containing forages and breeding of forage species with enhanced tannin content. Forage legumes such as *Lotus corniculatus* (birdsfoot trefoil) and *L. uliginosus* (greater trefoil) possess secondary metabolites known as condensed tannins (CTs) in their leaves. CTs are flavonoid polymers which complex with soluble proteins and render them insoluble in the rumen yet release them under the acidic conditions found in the small intestine, reducing bloat and increasing amino acid absorption. They are not present in the leaves of white or red clover but are present in the inflorescences. Recent studies have shown that methane production values were lower in sheep fed on red clover and birdsfoot trefoil than on a ryegrass/white clover pasture (Ramirez-Restrepo and Barry, 2005). The extent of variation in CT content between and within varieties of *Lotus corniculatus* and *L. uliginosus* has been recently confirmed (Marley *et al* 2006). Diverse germplasm is also now available at IGER with CT content ranging from 20mg/g DM to >100mg/g DM. These are suitable for experiments to quantify effect of CT content on methane production in combination with other forage species. This will be more feasible using a high throughput CT assay developed at IGER (Marshall *et al*, 2008) which will enable rapid analysis of CT content in the numbers of genotypes required for a breeding programme. Rhizomatous lines of *L. corniculatus* with considerably improved persistence and contribution to mixed swards have been developed at IGER and could form the basis of future varieties.

A significant factor affecting methane emissions is the animal's diet and this is open to modification through breeding strategies particularly where the animal is fed a diet with a significant forage component (grazed or ensiled). Such approaches build on the considerable success that has been achieved in improving quality traits for animal production e.g. ryegrasses with higher water soluble carbohydrate (WSC) content and increased digestibility. Indeed, in many cases it is likely that improvements in quality for animal production will also lead to reduced emissions. This may be the case for the high WSC grasses where more N is partitioned into meat and milk and less is available for nitrogenous emissions through excreta. At the same time of course, other diet based strategies are possible including increasing the amount of fibrous concentrate (Lovett *et al*, 2005). There is also evidence that using clovers and grasses with high WSC in animal diets can directly reduce methane emissions (Lovett *et al*, 2004). It has been demonstrated that increasing the WSC content in perennial ryegrass by 33g/kg reduces methane production *in vitro* by 9%.

Enhancing carbon sequestration in grasslands

The substantial stocks of carbon sequestered in temperate grassland ecosystems are located largely underground in the roots and soil. The roots, senescent leaves, and stems differ in their rate and process of breakdown in the soil (Joffre and Ågren, 2001). However, in a survey of temperate grassland Jobbágy and Jackson (2000) found that only 64% of soil organic carbon existed in the top 40 cm of soil which contained 87% of all roots, the remainder of the carbon is found at greater soil depths probably due to a decreased C turnover at depth in the soil (Jones and Donnelly, 2004).

The key plant traits likely to influence C sequestration (root depth, structure and architecture; litter composition and amount) are reasonably well established and genetic variation is beginning to be characterized for many of them. Whilst the rate of C accumulation is strongly influenced by net primary productivity, genetic improvement may not only enhance short-term rates, for example following conversion of arable to pasture, but also raise the 'quasi-equilibrium' levels of soil C under grassland in the longer term. Some early progress has been made at IGER with regard to mapping of genes in perennial ryegrass for C sequestration, with significant variation in organic matter decomposition rates

(Figure 2A) and C returns in litter (Figure 2B) identified within mapping families, and associated with loci on chromosomes 1 and 5.

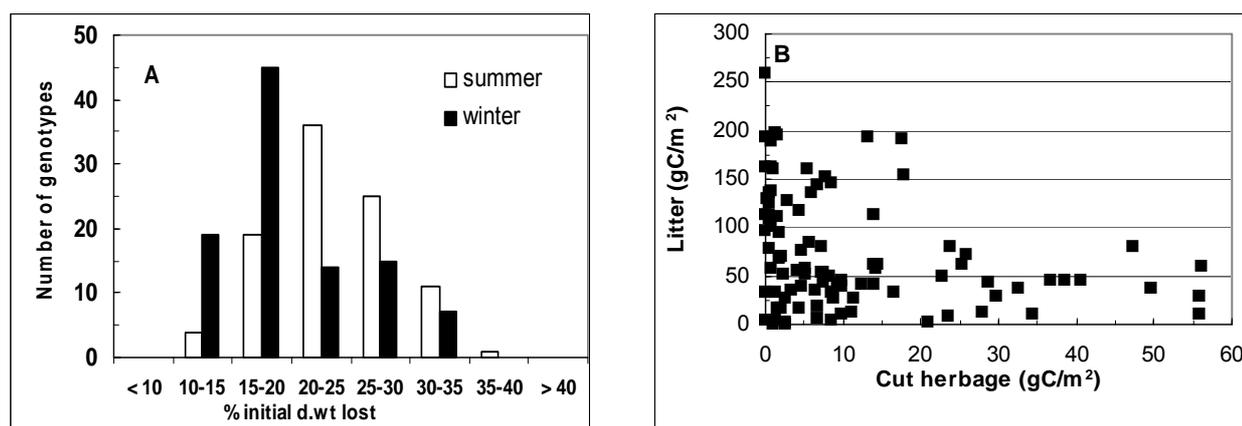


Figure 2 (A) Variation in decomposition of barley straw (litter bags) in the rhizospheres of 96 genotypes of IGER's 'amenity x forage' *Lolium perenne* mapping family grown as mini-swards in sand-boxes, under summer (36 days) and winter (131 days) conditions; and (B) the relationship between the total C content of standing litter (including dead plant shoot material) and live herbage cut at the same time (means of two sand boxes per genotype).

Conclusions

Plant breeding has been successful at increasing the yield, persistency, and stress tolerance of the major grasses and legumes of many grasslands in the world. These same approaches have considerable potential in altering plant traits to enhance the ecological efficiency of grassland agriculture. In respect of reducing methane and nitrous oxide emission and increasing carbon sequestration there are approaches for which the potential is clear but which are not yet fully validated.

Implications

In general, plant breeding approaches are cost effective, accessible to farmers through established routes, and show high rates of uptake in many parts of the world.

Approaches based on plant genetic improvement have the potential to underpin options for reduction in emissions together with other approaches e.g. management, and animal selection. Breeding approaches also have the potential to address multi-functionality and trade offs e.g. maintaining productivity and quality whilst reducing inputs.

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References

- Gregorich, E.G., Rochette, P., VandenBygaart, A.J. and Angers, D. 2005. Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada. *Soil and Tillage Research* 81: 53-72
- Jobbágy, E.G. and Jackson, R.B. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications* 10: 423-436.
- Joffre, R. and Ågren, G.I. 2001. From plant to soil: litter production and decomposition. In: Mooney HA ed. *Terrestrial Global Productivity*. San Diego, CA, USA, Academic Press, 83-89.
- Jones, M.B. and Donnely, A. 2004. Carbon sequestration in temperate grassland ecosystems and the influence of management, climate and elevated CO₂. *New Phytologist* 164: 423-439
- Kingston-Smith, A. H., Bollard, A. L. and Minchin, F. R 2006. The effect of nitrogen status on the regulation of plant-mediated proteolysis in ingested forage; an assessment using non-nodulating white clover *Annals of Applied Biology* 149: 35-42.
- Lovett, D.K., Bortolozzo, A., Conaghan, P., O'Kiely, P. and O'Mara, F.P. 2004. In vitro total and methane gas production as influenced by rate of nitrogen application, season of harvest and perennial ryegrass cultivar. *Grass and Forage Science* 59: 227-232.
- Lovett, D.K., Stack, L.J., Lovell, S., Callan, J., Flynn, B., Hawkins, M. and O'Mara, F.P. 2005. Manipulating enteric methane emissions and animal performance of late lactation dairy cows through concentrate supplementation at pasture. *Journal of Dairy Science* 88: 2836-2842.
- MacRae, J.C. and Ulyatt, M.J. 1974. Quantitative digestion of fresh herbage by sheep. *Journal of Agricultural Science* 82: 309-319.
- Marley, C.L., Fychan, R. and Jones, R. 2006. Yield, persistency and chemical composition of *Lotus* species and varieties (birdsfoot trefoil and greater birdsfoot trefoil) when harvested for silage in the UK. *Grass and Forage Science*. 6: 134-145.

- Marshall, A.H., Bryant, D., Latypova, G., Hauck, B., Olyott, P., Morris, P. and Robbins, M. 2008. A high-throughput method for the quantification of proanthocyanidins in forage crops and its application in assessing variation in condensed tannin content in breeding programmes of *Lotus corniculatus* and *Lotus uliginosus*. *Journal of Agricultural and Food Chemistry* 56: 974-981.
- Miller, L. A., Moorby, J. M., Davies, D. R., Humphreys, M. O., Scollan, N. D., MacRae, J. C. and Theodorou, M. K. 2001. Increased concentration of water-soluble carbohydrate in perennial ryegrass (*Lolium perenne* L.): Milk production from late-lactation dairy cows. *Grass and Forage Science* 56: 383-394.
- Mummey, D.L. and Smith, J.L. 2000. Estimation of nitrous oxide emissions from US grasslands. *Environmental Management* 25: 169-175.
- Neeteson, J.J., Schröder, J.J. and Jakobsson, C. 2004. Drivers towards sustainability: why change? *In: Controlling nitrogen flows and losses*. Eds. DJ Hatch DR *et al.* Wageningen Academic Publishers, The Netherlands. pp. 29-38.
- Ramirez-Restrepo, C.A. and Barry, T.N. 2005. Alternative temperate forages containing secondary compounds for improving sustainable productivity in grazing ruminants. *Animal Feed Science and Technology* 120: 179-201.
- Ulyatt, M.J., Thomson, D., Beever, D.E., Evans, R.T. and Haines, M.J. 1988. The digestion of perennial ryegrass (*Lolium perenne* cv. Melle) and white clover (*Trifolium repens* cv. Blanca) by grazing cattle. *British Journal of Nutrition* 60: 137-149.

Application of greenhouse gas mitigation strategies on New Zealand farms

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Introduction

New Zealand farming is extensive – grazing out of doors all year on temperate ryegrass dominant pastures. Inputs of supplements are low compared with many Northern Hemisphere systems and although grain is very rarely fed, the majority of farmers use some conserved forages (hay/silage) to combat disparities between feed demand and supply. Pastoral grazing has lower greenhouse gas (GHG) emissions associated with production than intensive systems (van der Nagel *et al.*, 2003; Casey and Holden, 2005) where animals are housed for at least part of the year and grain is included in the diet, but equally there are fewer options for mitigation on pasture.

New Zealand comprises 220 000 sq km, with about one third mountainous and another third steep and not able to be cultivated. The human population of 4 million are primarily city/urban dwellers. Our GHG emissions (CO₂ equivalents) comprise about 45% CO₂, 38% CH₄ and 17% N₂O, with agriculture accounting for about half of total emissions (NZ Climate change office; 2003). Within agriculture, virtually all CH₄ arises from rumen (enteric) fermentation and N₂O from excreta and applied fertiliser. Animal numbers (millions) are primarily sheep (40), beef cattle (4.5), dairy cattle (5) and deer (1.5), but the percentages of agricultural GHG (CH₄ and N₂O) from these groups are 38, 22, 37 and 3 respectively (NZ Climate change office, *pers. comm.*) New Zealand has made a significant investment in Tier 2 calculation of GHG inventory for CH₄ and N₂O from agriculture and this has been complemented by researching opportunities for mitigation using animal trials as well as laboratory studies.

Agriculture is not subsidised directly or indirectly and exports (excluding forestry) account for about 50% of export earnings. Our largest company (Fonterra) is the dominant international trader in milk products and the New Zealand economy is dependent on profitable farming and the absence of legislative constraints to animal numbers. Options for GHG mitigation are best if adopted by choice, rather than through enforcement and subsequent monitoring of compliance. To date, there have been no ‘magic bullets’ for GHG mitigation but refinement of farming techniques may lower GHG whilst maintaining or increasing profitability.

This paper presents an overview of opportunities for mitigation and an indication of challenges in lowering agricultural GHG.

Successful mitigation?

New Zealand farmers are well educated, many with tertiary qualifications, and their success in agriculture is due in part to adoption of technologies that are able to increase efficiency (e.g. grazing management, fertilizer application, automatic recording of farm inputs, outputs and individual animal identification). Typical labour inputs to farming are about 1 person for about 1500 sheep or 130 dairy cows. Farmer willingness to consider and adopt new technology provides opportunities but also presents challenges for lowering GHG.

The opportunities include good capability for applying mitigating technologies, facilitated through advisors, discussion groups, and other rural professionals. The down side is that farmers are already achieving a high level of production from pastures, so there are few easy or large changes to farming practice that would be both acceptable and capable of lowering GHG by a significant amount (e.g. 20%).

The scenario presented here embodies many of the challenges faced by governments and administrators in other countries who are charged with lowering GHG emissions from agriculture. In all situations farmers will have to balance costs of production with returns from agriculture. Excessive restrictions and interference in pricing usually reduces production efficiency and lowers employment in the sector. It is also important that legislation doesn't diminish production close to markets, requiring importation from other regions or countries, resulting in a higher overall GHG emission cost.

Honest mitigation of GHG needs to consider the whole picture, covering all GHG and using life cycle analysis. In the New Zealand situation, the absence of subsidies has required farmers to have a clear profit motive. In some European countries regulations could be used to affect changes in GHG production with farm viability maintained by payments through existing support or subsidies. In contrast, less developed regions may seek to increase production and increase GHG production.

Methane mitigation

Because virtually all agricultural methane is derived from rumen fermentation, options for mitigation are confined to feeding, modification of rumen function or selecting animals for low CH₄ production (Table 1). Each potential mitigant has potential costs and benefits and these are discussed below.

Table 1 Potential CH₄ and N₂O mitigants currently available to farmers.

CH ₄	Cost/benefits
Fewer animals; low CH ₄ emitters	Probably unacceptable; little evidence or incentive to select for low emitters
Change forage/ diet	Farmers have already adopted best practice for their region; legumes and condensed tannins can lower CH ₄
Rumen modifiers	Monensin may lower CH ₄ and benefit production; many modifiers are untested or not persistent
N₂O	
Reduce dietary N	An important objective for temperate intensive farming that could maintain profitability; reduce urea, promote legumes
Lower urine N loss	Use dicyandiamide in cool regions; alter diet, acceptable in intensive regions
Strategic fertiliser use	A cost effective option
Soil compaction	Removing animals from pastures in wet conditions will benefit farming

Reducing animal numbers to lower GHG production is unlikely to be acceptable. Changing economics and politics may lead to changes in breeds or species farmed but overall feed production and consumption is unlikely to change. Methane emissions are about 21.0 g/kg pasture DM intake for sheep, cattle and deer (New Zealand Climate Change report, 2003), so animal species have little effect on emissions. Selection of animals that are low CH₄ emitters could be exploited to lower emissions but this would lessen progress for other traits. Farmers are unlikely to select animals for lower methane emissions in preference to conventional traits such as health, robustness or production unless lower CH₄ is linked with other attributes.

Forage species established and managed for grazing are determined by climate, resilience, yield and other factors important to farmers, so changing diets to lower CH₄ will only take place if there are benefits for animal production. Methane arises directly from the diet and digestion of most fresh temperate grasses appear to yield similar amounts of CH₄ (18-24g/kg DM intake) so there are few clear recommendations for dietary changes. Instances of very low emissions have been reported when grain comprises a very high proportion of diets (Johnson and Johnson, 1995) and silages can result in high emissions, but both incur additional GHG costs in production. Minimising grain and silage use will mitigate GHG, but farmers use these supplements to fill gaps in feed supply from pasture.

Legumes inevitably yield less CH₄ during digestion than grasses (12-18 g/kg DM intake (Waghorn and Woodward, 2006) and promote high levels of animal production. They have been an essential component of temperate pastures, but in some situations their role has been diminished by application of urea to boost production, often early or late in the growing season and probably to the detriment of CH₄ emissions. Legumes containing condensed tannin (CT) (e.g. Lotuses) are able to lower methane (g/kg DM intake) by 12 – 15% and can improve animal production as well as prevent bloat and reduce the impact of gastro-intestinal parasites (Waghorn 2008). These benefits merit further research to improve growth of species containing CT, which could make them an attractive option for farmers, especially in regions with low-moderate fertility.

A number of rumen modifiers have been proposed for lowering methane production and sodium monensin (marketed as Rumensin by Elanco Animal Health, A division of Eli Lilly and Company, Greenfield, Indiana, USA) has been effective in several, but not all, trials and can increase cattle production. The dual benefits make monensin an attractive option for farmers, especially as it minimises the incidence of bloat and it is available as either a controlled release capsule (CRC), water additive or premix for feeding with supplements. The availability in a CRC means it can be used in animals under extensive grazing environments. Other modifiers, including probiotics have been purported to lower methane, but all require rigorous proof of efficacy over several months before adoption can be recommended.

Future options for modifying the rumen microflora, especially through vaccine development for reducing methane production (Wright *et al.*, 2004) have good potential for on-farm mitigation because they involve minimal interference to normal farm practice and can be applied to both intensive and extensive farming. It is most important that policy makers are aware that most ruminants are not handled on a daily basis and are fed diets of poor-medium quality. There are few mitigation options that can lower CH₄ under these circumstances.

Nitrous oxide

In grass/clover pastures receiving up to 200kg N/ha per annum about 80% of N₂O is attributed to urine and dung and 20% to fertiliser (de Klein and Ledgard, 2005). The primary source is urine, which is typically deposited in ‘patches’ by grazing animals. Most ruminants stand when urinating and the high concentration of N in many temperate pastures results from intakes that greatly exceed N requirements for production. The net result is a transfer and concentration of N in small areas that are responsible for about 60% of pastoral agricultural emissions in New Zealand. The remaining N₂O originates from fertiliser applied to soils and faeces. Several options are available for mitigating N₂O and lowering costs for farmers, so there are opportunities for lowering this source of GHG.

The use of urea has increased almost exponentially in New Zealand, mainly to stimulate pasture growth in spring and to extend production in autumn. Under present pricing structures, it is cost effective for farmers to apply urea, but associated problems of leaching to ground water, N₂O emissions from both fertiliser and urine patches and animal health issues may bring about a reduction in application. Reduced application of urea would increase white clover and other legume content of pasture, but animal production would decline relative to current levels. The use of urea results in forage N concentrations that greatly exceed ruminant requirements and are probably detrimental to production, but inexpensive urea has provided a financial incentive for its use by farmers.

Another option is application of DCD (dicyandiamide) to soils when temperatures are below about 12°C. The DCD inhibits loss of nitrate to leaching and to N₂O and is potentially able to reduce fertiliser requirements and reduce costs. Future options could include an intra-ruminal slow release product which may have very significant impact on N₂O emissions. Strategic application of fertiliser, on the basis of need could also lessen N₂O emissions and benefit profitability

Emissions of N₂O are exacerbated by wet conditions and by treading (pugging) and compaction of pastures, affecting drainage. Dairy farmers are increasingly removing cattle from pasture under wet conditions, mainly to lessen damage to pasture. This will have a dual benefit by reducing faecal and urine deposition onto saturated soils and lessening compaction. Removing cattle from very wet pasture requires an investment in feed pads and may necessitate feeding conserved forage but it will lower N₂O emissions and maintain pasture quality.

Table 2 Calculated methane emissions per unit of live weight gain from growing lambs fed forages with a range of feeding values (from Waghorn and Clark, 2005).

Diet ME (MJ/kg DM)	Forage	Daily gain (g)	Methane (g/kg DMI)	DMI (kg/kg gain)	CH ₄ Emissions (g/kg gain)
10.0	Ryegrass past.	100	24.0	13.6	330
11.0	Ryegrass past.	150	22.0	9.4	210
12.0	Ryegrass past.	200	21.0	7.5	160
11.5	Lucerne	250	20.0	6.7	130
12.0	Lotus	250	12.0	6.7	70
12.0	Sulla	300	17.5	6.2	110
12.0	White clover	300	16.0	6.2	100

GHG expressed per product

This paper has focused on net emissions of GHG, and shown potential conflict between the need to lower GHG emissions whilst retaining farming profitability. This is especially true for methane, but all extensive farming systems will have limited opportunity for GHG mitigation. However, increased efficiency will lower GHG emissions per unit of product as well as improving profit. An example of breeding efficiency would be to ensure that all animals produce offspring each season, with minimal deaths of new born and twins from sheep and goats. Selecting animals for high growth rates will lower the GHG associated with gain (Table 2) and productive cows have less CH₄/kg milk than those with low production (Waghorn and Clark, 2005). Longevity will lower GHG/product because growing and maintenance are non productive periods of a life cycle. Improved production will not necessarily lower total emissions but more food could be produced whilst retaining profitability

Conclusion

Greenhouse gas (GHG) mitigation options that have been developed in laboratory or research environments may have limited appeal for farmers if they are difficult to implement or lower profitability. Livestock farmers use species, breeds, pastures and practices that ensure a profitable and sustainable outcome in their environment. Immediate options to mitigate GHG from grazed pasture may include use of appropriate diets, rumen modifiers, changes to fertiliser use and drainage, but benefits of any modification to established systems must exceed costs of implementation to be acceptable. Proven technologies are likely to be considered by New Zealand farmers, but there are no subsidies so any investment must be worthwhile. Small reductions in CH₄ and N₂O emissions may be possible in the immediate future, but it will be easier to lower GHG per unit of production through improved farming practice.

Implications

There are options for mitigating N₂O emissions from intensive temperate farming, but fewer opportunities for lowering CH₄ emissions whilst retaining profitability. Future developments may enable rumen CH₄ emissions to be reduced and if vaccines or slow release intra-ruminal devices became available widespread application could be expected. It is important to realise that most ruminants are farmed under extensive conditions and are not subject to daily handling, whereas many mitigation options are best suited to intensive husbandry.

References

- Casey, J. W., and Holden, N. M., 2005. The relationship between greenhouse gas emissions and the intensity of milk production in Ireland. *Journal of Environmental Quality* 34: 429-436.
- de Klein, C. A. M., and Ledgard, S. F., 2005. Nitrous oxide emissions from New Zealand agriculture - key sources and mitigation strategies. *Nutrient Cycling in Agroecosystems* 72: 77-85.

- Johnson, K. A., and Johnson, D. E., 1995. Methane emissions from cattle. *Journal of Animal Science* 73: 2483-2492.
- New Zealand climate change office, National Inventory report. Greenhouse gas inventory 1990-2001, Wellington, New Zealand, 2003, Pp 174
- van der Nagel, L. S., Waghorn, G. C. and Forgie, V. E., 2003. Methane and carbon emissions from conventional pasture and grain based total mixed rations for dairying. *Proceedings of the New Zealand Society of Animal Production* 63: 128-132.
- Wright, A. D. G., Kennedy, P., O'Neill, C. J., Toovey, A. F., Popivski, S., Rea, S. M., Pimm, C. L., Klein, L., 2004. Reducing methane emissions in sheep by immunization against rumen methanogens. *Vaccine* 22: 3976-3985.
- Waghorn, G.C. 2008. Beneficial and detrimental effects of dietary condensed tannins for sustainable sheep and goat production – progress and challenges *Journal of Feed science and Technology*. *Doi:10.1016/j.anifeedsci.2007.09.013*.
- Waghorn, G. C. and Clark, D. A., 2005. Greenhouse gas mitigation opportunities with immediate application to pastoral grazing for ruminants. *International Congress Series* 1293: 107-110.
- Waghorn, G. C. and Woodward S. L., 2006. Ruminant contributions to methane and global warming – a New Zealand perspective. Chapter 12 , pp233-260. In *Climate change and managed ecosystems*. Eds. J.S. Bhatti, R. Lal, M.J. Apps and M.A. Price. CRC Taylor and Francis, Boca Raton.

Adapting livestock production systems to climate change - tropical zones

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Introduction

Responding to the challenges posed by global warming will require a paradigm shift in the practice of agriculture and in the role of livestock within the farming system. Global warming cannot be separated from the future role of the diminishing world supplies of fossil fuel and the impacts on food security of replacing fossil fuels with fuels derived from biomass (bio-fuels).

A holistic approach, which relates to these challenges, is that farming systems should give priority to: (i) maximizing plant biomass production from locally available diversified resources; (ii) processing of the biomass on-farm to provide food, feed and energy; and (iii) recycling of all waste materials. Farmers in developed countries will have the most difficulties in adapting to this strategy because of the impacts of urbanization and their almost complete dependence on products derived from fossil fuels. Developing countries in tropical latitudes, that still have most of the population in rural areas, are better placed for a future when localization will replace globalization as the basis of sustainable life-styles.

Burning of fossil fuels is the major source of greenhouse gas emissions. However, there is an increasing consensus that production and use of alternative bio-fuels will contribute little to mitigation of climate change and may even make it worse. A more appropriate strategy which combines global warming mitigation with alternatives to liquid fuel is the electrification of land transport coupled with decentralization of electricity generation to avoid the losses (and costs) of conventional grid distribution of power and transport of raw materials, at the same time creating employment and entrepreneurial opportunities in rural areas where the biomass is produced.

It appears to be entirely feasible to satisfy global needs for electricity from technologies that use wind, sea currents, direct solar energy and biomass. It is pertinent to note that only recently, admittedly on a windy day, Spain generated more than 40% of its electricity from wind farms (ODAC, 2008). It is about the choice of technologies to use biomass that there is most controversy, which is the subject of this paper.

Biomass as a source of food or fuel? What are the issues?

There are three major issues:

- Should crops normally grown as sources of food / feed be used to make biofuel?
- Is it feasible to produce enough bio-fuel (as ethanol or biodiesel) to replace existing sources of fossil fuel?
- What are the alternatives and what is the role of livestock-based farming systems in developing such alternatives

Sources of bio-fuels

The bio-fuels that are currently receiving most attention (and private investment / Government subsidies) are ethanol and biodiesel. Ethanol from cellulosic biomass is touted as a means of overcoming the disadvantages of using food (starch and sugar) as the feedstock. This paper will endeavour to show that production of hydrogen-rich gas (producer gas) by gasification of fibrous biomass, within an integrated live stock-based farming system is a more appropriate pathway than either ethanol or biodiesel.

Ethanol

Ethanol is produced by yeast fermentation of sugars derived mainly from maize and sugar cane. Cassava roots and other cereal grains, such as wheat and sorghum, may be used according to their availability in a particular region. Conversion rates for these different feedstocks are defined by the stoichiometry of the fermentation process in which one molecule of hexose gives rise to 2 molecules of alcohol:



Thus 182 g of sugars are needed to produce 92 g of ethanol, which translates into the approximate conversion rates shown in Table 1.

Table 1 Conversion of maize, cassava roots and sugar cane stalk into ethanol

Feedstock	kg/litre ethanol
Maize ¹	2.6
Cassava ²	5.45
Sugar cane ²	14

¹ Air-dry basis; ² Fresh basis

These feedstocks are traditionally sources of human food / animal feed, thus their use to produce bio-fuel results in (i) competition in the demand for these goods; and (ii) effects on food / feed prices according to the replacement value of ethanol for gasoline, which in turn is determined by current prices of petroleum. The immediate result of the action of these forces has been major increases in the price of grains and political reprisals around the world (Box 1).

Biodiesel

The major sources of biodiesel are the oils produced from oilseed crops (soybean, rapeseed [canola in North America], sunflower and sesame) and from trees such as the African Oil Palm, *Jatropha curcas* and Castor bean (*Ricinus communis*). Apart from Castor and *Jatropha*, the same problem exists of competition between food and fuel.

Box 1

- 33% Rise since January in price paid by Philippines for rice from Vietnam
 - 3 billion People worldwide who rely on rice as a staple food
 - 40% Rise in rice price in Thailand this year
 - 19.2% Rise in consumer prices in Vietnam last month, against March 2007
 - 8.4% Rise in food prices in the Philippines last month, compared with March 2007
 - 854 million Number of people worldwide who are “food insecure”
 - 1 billion People globally who survive on less than \$1 a day, defined as “absolute poverty
 - Food riots and violence in Egypt
 - Riots in Haiti last week that killed four people
 - Violent protests in Ivory Coast
 - Price riots in Cameroon in February that left 40 people dead
 - Heated demonstrations in Mauritania, Mozambique and Senegal
 - Protests in Uzbekistan, Yemen, Bolivia and Indonesia
- Source: ODAC 2008

The second issue is the degree to which the present programs for bio-fuel production can replace the actual levels of consumption of the transport fuels - gasoline and diesel oil. Data for the USA show that even with the current target of 35 billion gallons of ethanol (which would require 300 million tones of maize - the whole of the US crop - to be converted to ethanol), the potential replacement is only of the order of 20% (Patzel, 2007).

The situation with biodiesel is similar. Despite the rosy projections, the reality is one of uncertainty. Recent reports indicate that in Europe the majority of factories in construction will not be commissioned as their viability is doubtful because of high cost of raw materials, lack of incentives (Government subsidies!!) and even disincentives (proposed Government taxes) (ODAC, 2008). In any event, the potential to replace existing usage of diesel derived from petroleum, with biodiesel derived from vegetative sources, is marginal and mirrors the case of ethanol described earlier. For example it is calculated that if all the cultivable area in the UK was planted with rape seed it would still replace only some 15% of actual usage (Table 2).

Table 2 Potential of biodiesel from rape seed to replace diesel oil in UK (Source: Monbiot, 2004)

Annual diesel oil consumption	37.5 million tonnes
Rape seed yield	3.25 tonnes/ha
Biodiesel from 1 tonne rape seed	415 kg
Area to be planted in rapeseed to replace actual diesel oil consumption	25.9 million ha
Cultivable area available in UK	5.7 million ha

The conclusion by Patzek (2007), and many other analysts, is that the basic error is to pursue alternatives to liquid fuels, at least for ground transportation, as the potential to derive ethanol and biodiesel from biomass is less than 20% of projected needs. In contrast, there is sufficient energy from the sun provided it is captured mainly by solar panels, and from wind and wave power. However, the energy product from these sources is in the form of electricity, hence electrification of the automobile fleet and of mass transit systems appears to be the most logical strategy.

If electricity is the chosen replacement for petroleum, it can be shown that the potential contribution from biomass is much greater when it is converted to a combustible gas in a gasifier than if it is used as feedstock for ethanol. This is because when these gases are used in internal combustion engines (or gas turbines) to produce electricity, there are other major benefits such as:

- localization of the supply (in rural areas where the biomass is produced)
- utilization at source (hence creating employment opportunities and giving comparative advantage to rural areas)
- requires no inputs from fossil fuels
- creates opportunities for carbon sequestration
- no conflict between food and fuel

Fractionation of the biomass

Biomass can be considered to be composed of two groups of compounds; the contents of the cells in the form of sugars, starches, lipids and proteins and the cell walls which serve as physical supporting structures, composed of cellulose and hemicelluloses held together by lignin. The logical use of these two groups of compounds is for the former to be used as food for humans and / or feed for animals, and the latter as fuel or for construction. Fractionation of plants into these two components can be done in a variety of ways, depending on the nature of the plant in question. Physical separation may be needed for crops such as sugar cane. For trees and shrubs, the leaves of which are used as animal feed, the animals themselves can do the separation. All tree crops provide fibrous residues that can be used as feed stock in gasifiers: the stems and branches from coffee, coco and citrus trees; cuttings from bamboo used as construction material; branches from trees grown for timber.

The gasification process

The essence of the gasification process is the conversion of solid carbon-based fuels into carbon monoxide and hydrogen by a thermo-chemical process in an air-sealed, closed chamber, under slight suction. The biomass in the gasifier undergoes three processes; drying, pyrolysis, oxidation and reduction. Pyrolysis is the thermal decomposition of the dry biomass in the absence of oxygen. The products are bio-char (charcoal), liquids (oils) and gaseous products. The products of pyrolysis are then subjected to oxidation the end result of which is a combination of carbon, water and carbon dioxide. The carbon at high temperature reduces the water to hydrogen and the carbon dioxide to carbon monoxide. The final products are a gas the combustible part of which is hydrogen (10-20% by volume), carbon monoxide (15-30%) and methane (2-4%); the remainder is nitrogen and non-reacted carbon dioxide. The outputs from a range of feed-stocks in a gasifier-engine-generator system in Cambodia were relatively similar (Table 3).

Table 3 Gasifier characteristics using coconut shells-husks, cassava stems, mulberry stems and branches of *Cassia stamea* as feedstock (Miech Phalla and Preston 2005)

	Cassia	Cassava	Mulberry	Coconut	SEM	Prob.
Biomass DM, kg/test						
Initial	36.7	32.3	33.7	34.4	1.3	0.21
Final	4.93	1.90	0.00	3.07	2.19	0.49
Consumption	36.9	35.1	40.0	36.4	2.9	0.69
Moisture, %	14.0	13.3	15.7	14.0	1.4	0.69
Density, g/litre	348a	97.0c	273b	128c	10.4	0.001
Duration, hr	3.91	3.67	4.09	4.02	0.328	0.810
Output, kwh	27.4	25.7	28.7	28.2	2.29	0.810
Conversion*	1.23	1.18	1.18	1.11	0.044	0.42
Yield, kwh/kg DM biomass	0.813	0.848	0.850	0.903	0.032	0.400
Efficiency#	0.187	0.204	0.204	0.217	0.0082	0.170
Char, g/kg biomass DM	109	128	109	137	16.5	0.58

* kg dry biomass/kwh

Assumes 15 MJ/kg biomass DM and 3.6 MJ/kwh of electricity

abc Means in the same row without common letter are different at P<0.95

Carbon sequestration – a byproduct of gasification

Recent research indicates that when carbon has been subjected to pyrolysis (as in a gasifier), it acquires specific properties, which when it is returned to the soil render it inert to the normal process of oxidation. Lehman (2007) has estimated that the net withdrawal of carbon from the atmosphere by this process could be as much as 20%. The data in Table 3 indicate that some 10% of the original biomass (DM basis) is produced in the form of bio-char and ash. Assuming that the ash content of this material is about 10% then it can be calculated that for every 1 KWh of electricity produced by gasification there is the potential for a net sequestration of 1 kg of carbon (equivalent to 3.3 kg of carbon dioxide).

Ethanol or producer gas from biomass

Proponents of ethanol argue that the conflict between food and fuel posed current technology will be avoided by use of fibrous, non-edible biomass as feedstock. Apart from the fact that there is as yet no commercially viable system for production of ethanol from fibrous biomass, the results from the pilot facility established by IOGEN in Canada, as analysed by Patzek (2007), are far from encouraging. Patzek (2007) contends that the main problem lies in the characteristics of the final fermentation, as apparently the maximum concentration of ethanol that can be achieved in this process is of the order of 4 to 5%, much less than the concentration of 11 to 12% reached by conventional yeast fermentation of hexose sugars. As a result much more energy is needed in the distillation process to remove the water.

However, the main criticism is that production of ethanol by fermentation of hydrolyzed biomass is much less efficient than gasification, especially when the required end product is electricity (Table 4). When ethanol is the chosen pathway:

- additional energy is needed to grind the biomass and then heat it during the process of separating the lignin from the cellulose and hemicelluloses, and finally to distill the ethanol

- chemicals are needed to separate the lignin
- enzymes are needed for the hydrolysis of the cellulose and hemicelluloses
- genetically modified yeast strains are needed to ferment the C₅ sugars

Table 4 Inputs and outputs when dry biomass is fermented to make ethanol or reacted in a gasifier

System	Ethanol	Gasification
Inputs		
Dry Biomasa, kg	1	1
Extra energy	?	None
Chemicals	?	None
Enzymes	?	None
Outputs		
Ethanol, litres	0.18#	
Electric power, kwh	0.4##	0.83###
Bio-char, kg	None	0.09###
Scale of operation	Large	Localized

From Badger 2002; ## Assumed that 1 litre of ethanol in an IC engine produces 3.5 kwh; ### From Phalla and Preston 2005

By contrast, in the gasification process:

- the transformation energy is provided by the partial oxidation of the biomass
- the system is carbon negative as part of the carbon is returned to the soil as bio-char
- the gasification system can be operated at all levels of scale whereas biomass ethanol is centralized and large scale with considerable costs for the transport of the biomass

Models for small-farm scale production of feed/food and energy

The systems presently being practiced in the TOSOLY ecological farm in Colombia (<http://www.utafoundation.org>) are focused on semi-perennial sugar cane and perennial forage trees with recycling of all wastes. In the sugar cane component of the model, the products are:

- raw sugar cane juice, which is an energy food for pigs and people
- cane tops (leaves and growing point) which are the energy source for cattle and buffaloes
- bagasse which is used as fuel/substrate for the gasifier
- trash (dead leaves) which is returned to the soil as a source of organic matter

The forage tree component comprises a range of trees (*Tithonia diversifolia*, mulberry [*Morus albus*] and *Erythrina poeppigiana*) which are the basal diet of goats and sources of protein for cattle. As indicated in Photo 2, the goats selectively consume the leaves (and in some cases the bark) leaving the woody stems as fuel for the gasifier. The overall farm model achieves both food and energy security with a negative carbon footprint.

Conclusions

- The integrated farming system, using highly productive sources of biomass (sugar cane and tree crops) that are fractionated into food/feed and fuel, are highly appropriate for decentralized, small-scale production of electricity in rural areas without compromising food / feed production.
- The model offers opportunities for sequestration of carbon in the form of biochar - the solid residue remaining after gasification of the fibrous biomass.
- Long distance transport of biomass (as to a conventional distillery or power plant) is avoided, rural employment opportunities are promoted for growing the biomass, and availability of low-cost sources of electricity will facilitate development of rural industry, including access points for charging the batteries of electric vehicles.

Implications

Inexpensive fossil fuel facilitated the intensification of livestock production. The consequences were artificially cheap food, especially of animal origin, pollution because of the accumulation of animal excreta and the almost complete disappearance of small scale "family farms", particularly in rich countries. The imminent decline in availability of this resource should be the signal for a return to small scale farming which will give comparative advantages to the technologies described in this paper.

References

Badger P C 2002 Trends in new crops and new uses, Chapter. Ethanol from Cellulose: A General Review, pp 17 - 21, ASHS Press, Alexandria, VA. <http://www.hort.purdue.edu/newcrop/nenu02/v5-017.html>
 Lehmann J 2007 A handful of carbon. Commentary. Nature Volume 447, 10 May 2007

Miech Phalla and Preston T R 2005. Evaluating selected inedible fibrous crop residues as feedstock for gasification. MSc Thesis. MEKARN-SLU <http://www.mekarn.org/msc2003-05/theses05/phalla1.pdf>

Monbiot G 2004. Feeding Cars, Not People. Guardian, December 12, 2004

ODAC 2008. ODAC News, April 11, 2008 <http://odac-info.org/newsletter/2008/04/11>

Patzek T W 2007. How can we outlive our way of life; Paper prepared for the 20th Round Table on Sustainable Development of Biofuels: Is the Cure Worse than the Disease? OECD Headquarters, Ch[^]ateau de la Muette, Paris, 11-12 September 2007 <http://petroleum.berkeley.edu/papers/Biofuels/OECDSept102007TWPatzek.pdf>

Adapting livestock production systems to climate change – temperate zones

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Introduction

The exact nature of any change in climate remains uncertain but the likeliest scenario may see increased variability, particularly at the extremes, with overall increases in mean temperature and decreases in mean rainfall. What do these changes mean for our livestock and how may our livestock management, feeding and breeding systems adapt? It is impossible to consider the likely effects of climate change on our livestock systems and how they might adapt without noting the parallel impacts of other key changes occurring at this time:

- i) increasing human population
- ii) increasing demand of plant biomass for human food, animal feed and biomass
- iii) the passing of “peak oil” and the increasing oil prices as stocks of fossil oil decline and alternatives are sought
- iv) water resources

Many of these will have been reviewed in the “Scene setting” papers in this conference. As suggested by Preston and Leng (2008) in a companion paper in this conference, “Farmers in developed countries will have the most difficulties in adapting to this strategy because of the impacts of urbanization and their almost complete dependence on products derived from fossil fuels”. By contrast, developing countries in tropical latitudes, that still have a high proportion of the population in rural areas, are perhaps better placed for a future when localization will replace globalization as the basis of sustainable life-styles involving food, feed and fuel production. Globally, things will have to alter: in the last century, inexpensive fossil fuel facilitated the intensification of livestock production. The consequence of this has been artificially cheap food, especially of animal origin, high “food and feed miles” and environmental pollution because of the accumulation of animal excreta. In many countries this has been accompanied by the almost complete disappearance of small scale “family farms”, particularly in developed, temperate countries. The imminent decline in availability of cheap fossil fuel as a major energy input to developed agriculture systems is a major threat to these “developed” agricultural and livestock systems which will have to adapt to survive. So, these activities which have contributed to climate change will need to be considered alongside it when discussing likely adaptations.

Climatic effects on livestock: Direct and/or Indirect

Climate change may have direct or indirect effects on livestock. The quantity and quality of the feed supplied to the animal is a major factor but as well as the direct relationship between the nutrition of the animal and its thermal environment, modifications to the seasonal availability of forage may have implications on animal production systems. For example, altered lambing times may be possible if patterns of spring forage growth change which would have implications for the marketing of finished lamb.

Direct effects

Direct effects of climate result from the normal rules of environmental temperature, along with relative humidity, wind speed etc, on the animal’s climatic physiology. The responses of animals to changes in environmental temperature and emphasises the key difference between our ruminant and non-ruminant species in their comfort zones. Ruminants have wide comfort zones and a high degree of thermal tolerance so it is likely that climate change resulting in an increase of a few degrees is not going to have any major effect on animal performance. The exceptions would be at the extremes. Areas currently characterised by low temperatures and high rainfall may become more favourable and be associated with a reduction in the mortality of calves and lambs. At the other extreme, high summer temperatures may be expected to present the dairy cow with thermal stress and result in reduced intakes and performance. Adaptations to management systems such as increased provision of shade and water should be adequate to counter this. By contrast the non-ruminant species have very narrow comfort zones. This is one of the reasons our pig and poultry enterprises have often been based on intensive, housed systems. Dealing with housed livestock we might expect the direct effects of climate to be small – which is true with two important riders. Higher environmental temperatures in winter may lead to a saving in heating costs for pig and poultry buildings. However in the summer months our existing housing systems may not be able to cope with the increased thermal load. This may lead to an increased requirement for costly air conditioning systems. Additionally, there may be issues associated with the transport of live animals in elevated environmental temperatures. Although the likely direct effects of climate change on the animal are likely to be small, consideration could be given to inclusion of traits associated with temperature tolerance in breeding indices for species/breeds under threat eg genetics of heat stress and G*E interactions.

Indirect effects:

Nutrition

With regards to the supply of feed, central to this consideration is an appreciation of what is currently fed to our farm livestock. Non-ruminant livestock will continue to receive diets consisting largely of cereals and oilseed residues and with least cost ration formulation fairly major changes in ingredient inclusion can be made without altering the nutrient specification. Many diets already include a lot of high quality by-products and imported ingredients and it is unlikely

that climate change would alter the range of ingredients available for ration formulation. A much greater threat is likely to be posed by the food:feed:fuel conflict providing reduced feed supplies, together with issues to do with “feed miles” – the miles travelled by so much of our animal feed raw materials. Ruminant diets differ in that there is a major forage component. In the case of extensive systems this may make up the entire diet whereas in more intensive dairy cattle systems the forage will be balanced by a more concentrated supplement. It is the source, quality and quantity of the forage component of ruminants’ diet which is likely to be affected by climate change. The result may be either effects (advantageous or deleterious) on the existing forage species or a change to forage species not currently grown.

With respect to our existing forage species, low environmental temperature, particularly in spring, is one of the major limitations to higher Dry Matter production. Thus any increase in temperature might be expected to have benefits on early season growth. It is important to note the effect which this might have on the component species of a mixed sward. If mean rainfall were to decline this would lead to soil moisture deficits which would require expenditure on irrigation unless reductions in DM yield were to be accepted. For existing species the stage of maturity at which the crop is cut is a major determinant of quality and in any altered climatic scenario the interplay between increasing quantity and declining quality would continue to be of major importance although the alterations in climate may be favourable to conservation and reduce losses during either ensilage or hay-making. In many hill and upland areas, which are currently characterised by low temperatures and water logged soils, climate changes may be expected to lead to more favourable conditions and result in a shift towards more productive species with accompanying implications to both animal production and the appearance of the countryside.

The other major possibility is that climate change will lead to a shift in the forage species grown. For example, elevated temperatures may lead to an increase in the hectareage of maize grown for silage and of alfalfa for hay. This might be expected to result in improvements in both the quantity and quality of forage for ruminant livestock and could lead us towards the forage component of rations fed to dairy cattle elsewhere.

Nutritional studies have also focused on trying to reduce GHG emissions but whilst some success has been achieved it has often been accompanied by greater use of imported materials with the associated burden of GHG production associated with transport.

It is highly likely that increased attention will focus on the contribution of agriculture, together with the associated contributions from feed transport and livestock housing, to GHG emissions. In turn this will lead to a greater awareness at an individual farm level and a move back towards systems which are more “efficient” in reducing these emissions. Many current evaluations point to the advantages of high yield levels (due to the high animal production levels being associated with a relatively lower proportion of nutrients and losses being associated with maintenance. At present some of this data is incomplete and misleading as it often fails to account for all the contributing off farm factors. This is likely to be remedied in future work to give farmers a clear “steer” towards appropriate systems.

Livestock numbers

Total GHG emissions from livestock are positively related to the numbers of livestock. It is likely that our systems will be under political and social pressure to reduce livestock numbers to reduce the levels of emissions. Additionally, lower numbers of more productive animals will also contribute to more efficiency of production relative to emissions. Globally, one of the main issues relates to numbers of livestock, in particular numbers of livestock for a given level of offtake (animal product). There are large differences between developed and developing countries in this respect. Taking beef cattle as the example, developing countries have twice the numbers of cattle of the developed countries (858 versus 410 million) yet the annual meat offtake is only half (15.2 versus 34.6 million tonnes) giving in excess of a 4 fold difference in efficiency. However, it is important to remember, that in developing countries livestock at often about more than just production! – they have a multi- purpose role. Globally, we are likely see differences in adaptation between developing and developed countries with developed countries perhaps seeing fewer , more productive animals producing quality products for niche local markets. However there remains the requirement to meet the ever increasing global demand for livestock products associated with the combination of increased human population and growing affluence fueling the Livestock Revolution.

Breeding

Many non genetic farm technologies that could help to mitigate emissions require ongoing investment of some sort to maintain the commercial benefit (e.g., dietary manipulation). Genetic improvement on the other hand is effectively a permanent change and does not require additional or continuing resources. Many breeding goals for livestock species include production traits and production efficiency and this helps to reduce emissions. In many cases this can be achieved simply through selection on production traits. Reducing the number of animals required to produce a fixed level of output can also have a favourable effect on methane emissions. For example it has been demonstrated that efficiency of the beef production system was paramount in reducing the GHG emissions/unit output showing that intensive concentrate based systems produce the lowest emissions. Further analyses of the data showed that there was also a significant breed difference suggesting that bigger continental breeds of cattle produced less emissions/unit output than the smaller British type breeds (Hyslop 2008). Selection for fitness traits (lifespan, health, fertility) will help to reduce emissions by reducing wastage of animals. Improving lifespan in dairy cows and maternal line animals (i.e. ewes and beef cows) will reduce wastage by reducing the number of followers. For example, by improving lifespan in

dairy cows from 3.02 to 3.5 lactations will reduce methane emissions by 3%. Also it has been estimated, using modelling, that if cow fertility was restored from the level in 2003 to the level in 1995 that methane emissions from the dairy industry would reduce by 10-15%.

Broader breeding goals have become the norm in many livestock species, usually incorporating production and "fitness" (health, fertility, longevity) traits. Breeding goals can be built in a number of ways including the popular method of weighting traits by their relative economic value (REV). These REVs tend to be calculated by estimating the economic dis/benefit to the system of a unit change in the traits being examined.

Many of the example traits given earlier have been incorporated into indices for particular livestock sectors. However, livestock industries have more recently needed to consider societal views of aspects of farming systems, including issues such as welfare, biodiversity, food safety, health properties and environment. Traits and tools will need to be developed and applied to help livestock industries mitigate emissions using genetic tools. Again, as with the debate on nutrition, the number of animals will be a key issue: reducing the number of non-productive animals will bring the dual benefits of reducing future GHG emissions and provide greater efficiency.

Crop and animal health

A new range of pests and diseases will affect our crop and forage species with effects on the quantity and quality of livestock feeds.

Similarly, we will face new challenges in the field of livestock diseases. Diseases currently thought of as "exotic" may become of importance (eg Bluetongue) (Lancelot 2008) whilst existing diseases eg parasitic gastroenteritis (Skuce *et al* 2008) may become more widespread with increased costs of control and risks of immunity developing.

Bluetongue is a disease of animals affecting all ruminants, including sheep, cattle, deer, goats and camelids (camels, llamas, alpacas, guanaco and vicuña). Horses and pigs are not susceptible species. The disease is caused by a virus spread by certain types of biting midges, *Culicoides oboletus* and *pulicaris* midges carry the disease and can infect animals through a single bite. In the past the insects have been killed by low winter temperatures and the virus cannot replicate below 15 degrees C. However the disease has now become firmly established in mainland NW Europe where farmers are learning to live with the disease. According to DEFRA, in some susceptible breeds of sheep up to 70% of a flock can die from the virus. Animals that survive the disease can suffer long-term damage, such as a reduction in meat and wool production.

The link between climate changes and disease risks from various pathogens has been increasingly recognized. The effect of climatic factors on host-parasite population dynamics is particularly evident in northern latitudes where the occurrence and transmission of parasites are strongly regulated by seasonality-driven changes in environmental temperatures. Shortened winter periods would increase growth potential of many parasite populations (Rogers and Randolph, 2006).

It has also been suggested that the warmer winter temperatures associated with climate change may lead to a greater incidence of vertebrate pests. An example of this is the rabbit. It has been observed that in the UK rabbits have greatly extended their breeding season leading to increased numbers and increased damage to both arable and grass crops

Housing systems

Altered climate may result in altered soil conditions which may result in altered soil conditions which may encourage outdoor systems of poultry and pigs and encourage out wintering of livestock which have previously been housed – not because of the climate having direct effects on the livestock but due to indirect effects via treading. This has possible implications on the type and sophistication of housing systems required.

References

- Hyslop JJ (2008) Simulated global warming potential and ammonia emission figures for a range of suckler herd breeding strategies and beef cattle finishing systems In *Livestock and Global Climate Change. Proceedings of a BSAS Conference 17-20 May 2008, Hammamet, Tunisia*, p 127
- Lancelot R., S de La Rocque and V. Chevalier (2008) Bluetongue and Rift Valley fever in livestock: a climate change perspective with a special reference to Europe, the Middle East and Africa. In *Livestock and Global Climate Change. Proceedings of a BSAS Conference 17-20 May 2008, Hammamet, Tunisia*, p 87
- Preston TR and Leng RA (2008) Adapting livestock production systems to climate change – tropical zones. In *Livestock and Global Climate Change. Proceedings of a BSAS Conference 17-20 May 2008, Hammamet, Tunisia*, p 56
- Rogers DJ and Randolph SE 2006. Climate change and vector-borne diseases. *Advances in Parasitology*, Vol 62 62, 345-381.
- Skuce, PJ, N.D.Sargison, F.Kenyon, F.Jackson and G.B.Mitchell (2008) New challenges for the control of helminth parasites of Scottish livestock in the face of climate change. In *Livestock and Global Climate Change. Proceedings of a BSAS Conference 17-20 May 2008, Hammamet, Tunisia*, p 97

Experiences on mitigation or adaptation needs in Ethiopia and East African rangelands

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Introduction

Pastoralism describes a way of life in which rearing of livestock is the main source of income. Swift (1988) proposed that pastoralists be defined as households or populations where more than 50% household income / consumption is derived from livestock or livestock related activities, either as a result of sales of livestock products or of direct consumption. The pastoralists in eastern Africa are largely nomadic. They live primarily in arid or semi-arid areas and depend on livestock (cattle, sheep, goats and camels) for their livelihoods. Pastoralism is a major livelihood and production system in eastern Africa, with pastoralists found in all the countries of the region.

Contrary to the misconception that pastoralists keep herds in excess of the carrying capacity of the environment thereby promoting environmental degradation, it has been shown that there exists high productivity of pastoral systems that practice “opportunistic stocking rates” in rangeland areas. The large numbers of livestock are kept to operate and survive in the high risk, semi-arid areas, and to insulate their families from adverse effects (mostly climatic). Pastoralists draw on a deep knowledge of herd management. For instance, pastoral herds usually contain very low percentage of unproductive males. Moreover, the number of livestock kept by a pastoral family at any one time is closely linked to the availability of both pasture and family labour.

Pastoral strategies for maintaining production include moving livestock according to vegetation needs and water availability, keeping species-specific herds to take advantage of the heterogeneous nature of the environment, and diversifying economic strategies to include agriculture and wage labor, among others. Indeed, due these strategies, pastoral communities have in the past had the greatest resilience to elements of climate such as droughts, floods among other catastrophes. Pastoralists in the West African Sahel have adapted to cope with rainfall decreases of 25–33% in the twentieth century in the face of changing climate (Adger *et al.*, 2003).

Pastoral communities are however currently constrained on some of the above coping strategies, limitations that have made the people more vulnerable to natural and human-derived perturbations. Rising human populations along with many land tenure and land-use changes have squeezed pastoral livestock onto land areas that are too small to be sustainable for pastoral production. Bearing in mind that climatic shocks in eastern Africa now occur every 2-3 years, and the necessary recovery period from say a 50% TLU⁴ loss is lengthy (10 years for cattle owners; 3 years for small-stock owners & 12 years for camel owners), we now are faced by a situation where livestock populations have tended to be on the decline rather than expanding because of the short recovery periods, disease epidemics and livestock starvation associated with frequently recurring drought. In Ethiopia for instance studies in Afar (Tafessa 2001), show that from 1998 to 1999 the per capita TLU holding decreased from 4.1 to 2.25. The result is a rising human population dependent on a declining livestock population.

Climate change will add burdens to pastoralists who are already poor and vulnerable. The implications for pastoral livelihoods are yet to be fully understood, and indeed two quite different opinions seem to prevail. Some see pastoral groups as the ‘canaries in the coalmine’ of ongoing processes, as rangelands will tend to become drier, and existing water shortages will worsen, thus affecting the overall sustainability of their livelihoods. Others see pastoralists as the most capable to adapt to climate change, since pastoral livelihoods are shaped to deal with scarce and variable natural resources and to tackle difficult and uncertain agro-ecological conditions, and climate change could conceivably lead to the extension of territories where pastoralism could show comparative advantages (Nori and Davies, 2007). This article looks at the risks and challenges confronting pastoral communities of eastern Africa due to climate change, and highlights practices and policies that could help them to adapt.

The Vulnerability of Pastoral Livelihoods

Livestock plays the most significant role in the livelihoods of pastoralists. Vulnerability of pastoral communities to climate change is therefore intimately intertwined to pastoral livestock production. Current livestock holdings in most of the pastoral areas are not adequate to provide livelihood security to individuals while still continuing to drop. Studies show that the nomadic pastoral population owns 4-6 TLU per person. In Ethiopia, Sandford and Habtu (2000) estimated the livestock holdings per pastoralist were 3.98 TLU in Afar, 7.66 in Borena, and 3.39 in Somali Region. Furthermore the ratio of humans to Tropical Livestock Units (TLUs) in Ethiopia has dropped from 4.6 in 1963 to 1.7 in

⁴ TLU= Tropical livestock unit, 1 TLU= 250 kg, LUs were calculated on the following basis: one camel = 1.0 TLU; one head of cattle = 0.7 TLU; one sheep or goat = 0.1 TLU

2004. Bearing in mind that a pastoralist with less than 3TLU / AAME⁵ is famine vulnerable, 3-4 TLU / AAME is livelihood vulnerable and greater than 4 TLU / AAME is livelihood normal, we notice that the majority of pastoral communities in Ethiopia, and indeed most of eastern Africa are famine (and livelihood) vulnerable. Protecting livestock assets has a significant impact on reducing pastoralists' vulnerability to climate change. In some cases livestock owner's livelihoods have been so compromised that rebuilding their livestock assets is no longer appropriate and other alternative livelihood strategies such as safety nets are more applicable. The protection and strengthening of livestock as a key livelihood asset is therefore central to livestock responses in response to changing climatic situations.

Implications and effects of climate change will vary in various regions. Climate analyses suggest that many vulnerable regions are likely to be adversely affected in sub-Saharan Africa. According to Thornton *et al* (2006), many parts of sub-Saharan Africa are likely to experience a decrease in the length of growing period. There are indications that the general trend will be towards marginal areas becoming even more marginal (the arid-semiarid systems) with considerable increase in the spread of arid-semiarid mixed farming systems (as defined by Sere and Steinfeld, 2006) and arid-semiarid rangeland to areas that were previously humid. It is also expected that there will be increased variability of weather, especially of precipitation (effects that are already currently in evidence in the pastoral areas of East Africa) and a concomitant rise in the probability of season failures.

In our own simulations run at the Center for Natural Resource Information Technology at Texas A&M University (Angerer *et al.*, 2004) in a study initiated to examine the effects of climate change on grazing-land in Kenya, results suggested that under all climate change scenarios, areas that were predominantly rangelands experienced decreased cattle forage yields up to 25% in some areas.

Mitigation and Adaptation of Pastoralists

Little attention has so far been paid to adaptation in pastoral areas and much work has been focused on urban areas and highland agricultural areas. Pastoralism arose over 6000 years ago precisely as an adaptation to climate change at that time, and in the future pastoralism might provide important answers to the question of 'adaptability'. Changing environments may provide suitable conditions for expansion of pastoralism, as the flexibility and mobility afforded by pastoralism may increasingly provide a means of providing security where other more sedentary models fail. Pastoralists are the most capable to adapt to climate change, since pastoral livelihoods are shaped to deal with scarce and variable natural resources and to tackle difficult and uncertain agro-ecological conditions, and climate change could conceivably lead to the extension of territories where pastoralism could show comparative advantages.

However, with their current social marginalization, pastoralists' adaptive capacities have been eroded and they may have become more susceptible to climate variability than some other communities. The result of marginalization is that innovation and adaptive strategies are impeded, and constraints are placed on investment, which undermines sustainable development. The threat of Climate Change therefore augments the call for shaping a new societal contract, to enhance learning from the capacities of pastoralists to tackle the challenges of climate change, while enabling herders to innovate and pursue a sustainable process of development (Nori and Davies, 2007).

Pastoral adaptation faces a myriad of challenges, of which climatic change is but one. Indeed, the challenge of climate change seems insignificant to many pastoralists who are faced with extreme political, social and economic marginalization: relax these constraints and pastoral adaptive strategies might enable pastoralists to manage climate change better than many other rural inhabitants. The vulnerability that is associated with climate change in some pastoral environments has its roots in the restriction of tried and tested pastoral coping strategies, including the ability to move through different territories, to access critical livelihood resources, to trade across borders, to benefit from appropriate investments, and to participate in relevant policy decision-making. As is so often the case in developing regions, the main concern for pastoralists is the accessibility, rather than the availability or variability, of resources ((Nori and Davies, 2007).

Current strategies that are already being employed by pastoral communities include enhancing rangeland productivity under an environment of a declining resource base (e.g. use of traditional range enclosures in the Borana rangelands of southern Ethiopia involving semi-private grazing lands used for seasonal grazing by calves and sick/weak animals and particularly to address among others unavailability of pasture during dry seasons for milking animals around sedentary homesteads). Evidence indicates that trends towards set-up of these enclosures is increasing (Angassa and Oba, 2007). In a sample of 245 households on southern Ethiopia, 98% had access to these rangeland enclosures. Other strategies on the increase include diversified livestock holdings; especially keeping of camels. Unlike cattle that largely feed on herbaceous vegetation, camels feed on shrubs and trees that are not only increasing in the environment, but also tend to offer green forage for longer periods during dry seasons. Camels are also a more reliable milk provider than other classes of livestock during dry seasons and drought years. Alternately, the decline in per capita cattle holdings has spurred household-level diversification to include maize cultivation (emergent agro-pastoralism) in some areas, a risky

⁵ AAME- Active Adult Male Equivalent (AAME), a measure of human food energy requirements based on standards established for people | AAME = 1 adult male > 16 yrs; 1.25 adult females > 16 yrs; 1.7 children < 16 years.

strategy that plays to exacerbate the already fragile nature of the pastoral ecology these communities are living in and something which can only help a small portion of pastoralists. On the other hand, some of the communities are also already involving themselves in small-scale economic diversification activities such as petty trade, small savings societies etc.

On the development arena, the last twenty years have seen some important successes in eastern Africa and promising trends in livestock development that would play a significant role in improving the resiliency of pastoral societies in east Africa to climate change. Focus has significantly switched from humanitarian intervention intended just to save lives in time of crisis (focused primarily on food aid), to livelihoods-based intervention targeted at preservation of current livelihoods assets in order to protect and maintain future livelihoods as well as human lives. This strategy is one of the first attempts to address in some way longer term development and resiliency of pastoral systems. Despite some of the above preliminary successes, several challenges remain. Three major areas need to be addressed to enable the consequences of climate change to be adequately analyzed:

Structural Interventions

Structural interventions aim at the rehabilitation of sustainable productive assets through the improvement of processes, institutions or policies that have a direct influence on a target population's assets/liabilities. The principal governance issue has been, and continues to be, resource access and control. Building social capital and bridging relationships between groups and across institutions will be central to forging consensus within rural civil society. In most pastoral areas, community organizations and local non-governmental organizations are very important, especially where they are influential in advocating and influencing user rights to access of resources found in these communities. Pastoral societies have a right (though it may not usually seem so) to utilize local resources that sustains and protects their livestock, a key asset that contributes significantly to the pastoralists' ability to produce food and maintain a standard of living that supports their families. Enabling pastoralists to claim their rights and participate in decision-making at policy level is important because policies and institutions influence the ability of livestock owners to use their assets in support of their livelihoods.

Technology Integration

Science and technology, including climatic adaptation and dissemination of new understandings in rangeland ecology and a holistic understanding of pastoral resource management is still lacking. Successful adaptation will be about the quality of both scientific and local knowledge, local social capital and willingness to act. Communities should have key roles in determining what adaptation strategies they support if these have to succeed. The integration of new technologies into the research and technology transfer systems potentially offers many opportunities to further the development of climate change adaptation strategies. Such tools such as geospatial information and spatial analysis tools, and other decision support tools will continuously play a crucial role in improving our understanding on how climate change will affect livelihoods of pastoral communities. Climate change also offers the opportunity to promote payment to pastoralists for environmental services, as in the case of some livestock keepers in Europe (e.g. Spain, Germany, France and UK). These services could include watershed management, safeguarding biodiversity, landscape management and carbon sequestration.

Production and Market Interventions

Production and market interventions aim at generating food and/or income, and ultimately giving rise to sustainable livelihoods in a changing environment. The promotion of livestock production enterprises to service niche markets is a strategy that holds much promise for pastoral communities. In particular, organic livestock production offers opportunity for improving ecosystem services (e.g., maintaining or improving soil fertility, improving water conservation and quality, preserving natural and agro-biodiversity) on one hand while at the same time, providing price premiums that result in improved household incomes, food security and secondary generation of local employment. Economic integration and diversification will bring positive benefits of spreading risk. Provisions of incentives to diversify production and build community productive infrastructure are crucial to pastoral programmes. Reducing the transaction costs/adding value to livestock products and livestock marketing, which, if done well, offer enormous potential for improving livelihoods in the face of climate change. Mitigation strategies will involve providing these vulnerable pastoral communities with a means to organize themselves into producer groups where they learn improved production and value-added techniques, share the costs of inputs, and carry out joint marketing.

The increased bilateral participation of the state and donor agencies focused on the improvement of social conditions through more holistic programming involving approaches such as large scale social protection systems (safety nets) and weather related insurance schemes to protect farmers and livestock-owners against climatic perturbations will play a significant role in cushioning pastoral communities against negative impacts of climate change. Government or donor integrated risk financing schemes such as the one being piloted in Ethiopia (Hess, 2006) can spread risks and reduce the hardships linked to extreme events. It can also provide incentives for adaptation and risk reduction.

Conclusions

In conclusion, adaptation to climate change has to be built into the core of all development planning and management in pastoral regions. Integrating vulnerability and adaptation to climate change into sustainable development policy planning and implementation will be crucial. It is however, difficult to get governments to act on adaptation. There are

always other priorities that seem more pressing and, at present, the information base on the likely local impacts of climate change is weak. Pastoral communities need effective disaster risk management plans, both to reduce risks and have in place appropriate responses. Good disaster-preparedness (particularly to droughts and at times floods) will form a significant part of adaptation. Without informed scientific knowledge, strong and early mitigation, the difficulty and costs of adaptation will grow rapidly. All adaptation strategies and plans will need to be undertaken with recognition that pastoralists are still the best custodians of dryland environments.

References

- Adger WN, Huq S, Brown K, Conway D, and Hulme D 2003. Adaptation to climate change in the developing world *Progress in Development Studies*, 179 - 195.
- Angassa A and Oba G 2007. Herder perceptions on impacts of range enclosures, crop farming, fire ban and bush encroachment on rangelands of Borana, southern Ethiopia. *Human Ecology* (in press)
- Angerer J, Dyke P, Stuth J and Butt T 2004. Use of splined weather generator coefficients to derive spatially explicit climate data for use in climate change impact studies - an application to Kenya. *Proceedings of AARSE, Nairobi*.
- Hess U 2006. *Integrated Risk Financing To Protect Livelihoods and Foster Development – WFP Discussion Paper*.
- Nori M and Davies J 2007. *Change of Wind or Wind of Change? Climate change, adaptation and pastoralism*. Report to The World Initiative for Sustainable Pastoralism (WISP), 2007 compiled from an E-conference on Climate Change, Adaptation and Pastoralism. 22nd January - 22nd February 2007.
- Sere CO and Steinfeld H 1996. *World Livestock Production Systems: Current Status, Issues and Trends*. FAO Animal Production and Health Paper No 127.
- Swift J 1988. *Major Issues in Pastoral Development with Special Emphasis on Selected African Countries*, Rome, FAO.
- Thornton PK, Jones PG, Owiyo T, Kruska RL, Herrero M, Kristjanson P, Notenbaert A, Bekele N and Omolo A, with contributions from Orindi V, Otiende B, Ochieng A, Bhadwal S, Anantram K, Nair S, Kumar V and Kulkar U 2006. *Mapping climate vulnerability and poverty in Africa*. Report to the Department for International Development. Pp 171.

Climate Change in West Africa: Impact on livestock and strategies of adaptation

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Meteorological data of West Africa indicates that climate, during the past 40-50 years, has shown variations of magnitude and duration similar to those observed elsewhere in the world. Although such changes have a general impact on all types of activities and environmental characteristics, the first and most visible effects in Africa have been observed in agriculture. There are four agro-ecological zones in West Africa, i.e. the arid, sub-arid, sub-humid and humid zones. Livestock farming is practiced differently and on varying scale across the four zones. Traditionally, livestock farming is concentrated in the dry areas whereas crop farming dominates in wetter areas. However, except for the arid zone, livestock is generally integrated with cropping. Rainfall occurring in the various zones is the main factor determining animal movement across zones in search of feed resources. It is therefore expected that climate change will affect the characteristics of livestock farming both in time and space dimensions.

Changes will be presented on observed animal numbers, animal health and livestock management.

FAO data on animal numbers are used to characterize the changes observed in the past few decades across agro-ecological zones. For animal health, the change of glossine-infested areas in Burkina Faso and Mali will serve as an example. Also examples will be presented on the impact of climate change on livestock management in a number of African countries.

With respect to adaptation, we will present certain indigenous strategies that are based on the choice of animal species and the management of land resources that have been discussed in a recent regional workshop, organized by CIRDES in Niger, on the impact of climate change on livestock-environment interaction.

As for the regional study, the countries have been classified using Jankhe's criteria (1982) for defining agro-ecologies, in three zones (the arid and sub-arid zones being merged into one zone). The number of cattle, sheep and goats for each zone was determined for the past 50 years using data from FAO's website. Major demographical events have been noted in relation to rainfall events that occurred in the region.

First and foremost, an analysis of climate change is presented, based on rainfall, main determining factor of agro-climatic conditions.

Climate Change in West Africa

Rainfall changes for three representative countries of the three agro-ecological zones (the Niger for the arid-sub-arid zone, Burkina Faso for the sub-humid zone and Ghana for the humid zone) were determined from data provided by meteorological services of those states. For each country, rainfall data were used based on records from three synoptic stations spread across the country. Changes in rainfall indices for each country indicate substantial decline in rainfall during the 70's and 80's and a significant variation in rainfall amount over the past 40 years.

In addition, an IRD study showed a southward displacement of mean inter-annual isohyets over the two periods 1951-1969 and 1969-1990. This underscores an overall decrease in rainfall since 1970. The most significant rainfall deficits, occurring in the Sahel regions (sub-arid and arid zone) have had consequences both on surface and underground water, and on agricultural activities.

Climate change and livestock numbers

It is noted, that the number of animals, expressed in Tropical Cattle units, generally increased over the forty-year period regardless of agro-ecological zones. But the magnitude of such increase varies according to the zone. Moreover, the increase is regular for the sub-humid and humid zones, in contrast to the arid and sub-arid zone where important drops were observed during the two main drought periods of the early 70's and the early 80's. But no drop was observed in the sub-humid zone in the same period.

Changes in animal numbers differ according to animal species and zones, small ruminants appearing to adapt better to the new climatic conditions of West Africa, as shown by their increased numbers in all zones.

Climate change and distribution of glossines causing animal trypanosomiasis

In Mali, Diarra (2008) notes a significant drop in the spread of glossines linked to drought, the drying up of permanent rivers and to intensive land clearing. A progressive decline of tse-tse flies and of their prevalence rates in Sudan and in Sudan-Guinea regions is also observed.

In Burkina Faso, Guerrini *et al* (2008) used the FAO-Clim database to analyse trends in the distribution of three glossine species: *G. p. gambiensis*, *G. tachinoides* and *G. m. submorsitans*, between two entomological surveys (Küpper *et al.* 1979-1980) and the data available from various research projects at CIRDES between 1999 and 2007 (CIRDES)

for an interpolated mapping of mean decade rainfall for two periods (1970 - 1980) and (1980-1990) from 151 weather stations in Burkina Faso. This has been compared to the northern limit of glossine distribution. While there is a clear trend of isohyets to descend southward, the limits of glossines remain unchanged at the same latitude. These limits seem to be more dependent on microclimatic conditions than on annual rainfall. But such microclimate-sensitive areas are not yet affected by man. This would suggest that where man intervenes because of climate change, the glossine distribution may be changed.

Climate change and livestock management

Boiré (2008) notes that, in the middle region of Bani in Mali, rain deficits during the past few decades have caused a change in the pastoral system of the region, leading to loss of biodiversity and unfavorable genetic changes in forage species, which pushed herders to transhumance.

In the Senegalese groundnut basin, the scarcity of water resources has altered the joint management of lands by farmers and ranchers leading the latter group to adopt new strategies for the management of their flocks (Sarr *et al*, 2008).

Adaptation measures

1) Practical measures

These are coping mechanisms imposed by new environmental conditions or adopted by the producers. Broadly speaking, at the regional, national or local level, the new strategies consist of a displacement of livestock into areas where natural resources are available. Such a displacement may be long or short, and may be more or less sustainable depending on its scale. So, at the regional level, there has been a displacement of flocks from arid and sub-arid zones, mainly to the sub-humid zones. This in fact explains the upward trend in the number of animals migrating from the first zone to the second, rather than the humid zones where the environment is still unfavorable for livestock farming.

There has been also a change in the distribution of reared animal species according to agro-ecological zones. The same changes are observed in a country like Niger; and in the arid country of Mauritania, camel rearing is now the most common livestock activity.

At the local level, new feeding approaches are used, leading to the adoption either of new feeds, or other forms of rangeland management as is the case in Senegal.

2) Institutional measures

There is in Africa, in general and its western part in particular, a number of initiatives of adaptation to climate change on a regional or national scale. Be they regional or national, the strategies proposed by political authorities to respond to climate change have in common the fact that they are not specific to livestock, even in arid and sub-arid countries where livestock is an important part of the economy and very often is the sector most affected by climate change. With regard to regional initiatives, these are at the stage of design and strategy development rather than concrete proposals ready for implementation.

National actions are envisaged by the States under the United Nations Framework Convention on Climate Change. These include the National Communication Programmes for climate change and the National Action Programmes for Adaptation (PANA). In fact under these two frameworks, states have limited their actions to doing a vulnerability analysis and an inventory of measures for adaptation and mitigation without advocating to appropriate actions relevant to national agro-climatic conditions and traditional livestock practices.

Conclusion

The impact of climate change on the livestock sector in West Africa is reflected by a scarcity of feed resources available to animals. This scarcity leads to displacement of livestock from areas most affected to least affected areas. This is just an amplification of seasonal transhumance movements in that the numbers of animals displaced are larger and their stay in transhumance areas becomes longer. But the increased livestock in sub-humid zones can also correspond to a modification of the environment resulting from the changing climate, which enabled livestock development. The change of species distribution across agro-ecological zones may be the result of a natural selection related to a differential adaptation of the various animal species to new environmental conditions, including, for example, the spread of glossines but it may be also the result of specific adaptation strategies by herders. These herders also have other adaptation strategies particularly in the sharing of land with cropping farmers. However, it seems that at national and regional levels, adequate practical provisions have not been made and that a prospective study based on figures is not yet available. The interdependence of countries because of the contiguity of their agro-climatic spaces imposes such a study, to which CIRDES and its national and international partners are committed through the RIPIECISA project.

References

Boiré S. 2008. Presentation at the regional workshop on "impact of climate on livestock-environment interactions" 9-15 February 2008, Niamey 2008. *In press*.

Diarra B., 2008. Presentation at the regional workshop on "impact of climate on livestock-environment interactions" 9-15 February 2008, Niamey 2008. *In press*.

Guerrini L., Coulibaly B., Sidibé I., Gouro. A. S., et Bouyer J., 2008. Presentation at the regional workshop on "impact of climate on livestock-environment interactions" 9-15 February 2008, Niamey 2008. *In press*.

Sarr J., Dakosta H., 2008. Presentation at the regional workshop on "impact of climate on livestock-environment interactions" 9-15 February 2008, Niamey 2008. *In press*.

Winrock International, 1982. Animal Agriculture in Sub-Saharan Africa. XXI + 125 pp. Morrilton, Arkansas, USA : Winrock International for Agricultural Development.

Assessment of global climate changes on agriculture in the Mediterranean countries

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Introduction

It is accepted that one of the most important environmental constraint to agricultural development in the present century is climate change. It will give rise to changes in weather patterns and an increase in the frequency and severity of extreme events such as flooding and drought. In the Mediterranean regions as in the rest of the world, global climate change will reinforce the severity and frequency of heat waves, sea level rise, extreme rainfall and flood events in some regions but increased drought in others.

Climate models predict that warming will be greatest in the Arctic and over land. Models also give a range of temperature predictions based on different emission scenarios. If humans limit greenhouse gas emissions (low growth), then the temperature changes over the next century will be smaller than the changes predicted if humans do not limit emissions (high growth). Most climate change scenarios assume that greenhouse gas concentrations will increase through 2100 with a continued increase in average global temperatures. How much and how quickly the Earth's temperature will increase remains unknown giving, per consequent, the uncertainty of future greenhouse gas, aerosol emissions and the earth's response to changing conditions.

Advancements in model simulations, combined with more data on observed climate changes, have led to increased confidence in projections of future temperature changes. In its 2007 assessment, the Intergovernmental Panel on Climate Change (IPCC) was able to provide best estimates and likely ranges for global average warming under each of its emissions scenarios.

The impact of climate change on agriculture will be translated through changes in temperature, water balance, atmospheric carbon dioxide composition and extreme events (flooding / drought). A number of indirect impacts may also be experienced such as changes in distribution, frequency and severity of pests, disease, fire frequency and weed infestations. Higher levels of carbon dioxide may stimulate plant growth by increasing the efficiency of water use.

As the largest user of water, the agricultural sector is expected to be affected by global climate change more than the other sectors. In this study global climate change and its impact over Mediterranean's agriculture and water resources is assessed.

Materials and methods

Climate is averaged conditions of weather during a long period. Climate system is comprised of the complicated interactions among the atmosphere, the ocean, the cryosphere, the surface lithosphere and the biosphere. Energy from the sun determines the earth's weather and climate; in turn, the earth radiates energy back into space. Atmospheric greenhouse gases (water vapour, carbon dioxide and other gases) trap some of the outgoing energy, retaining heat in a manner similar to the glass panels of a greenhouse. The earth's climate is predicted to change because human activities are altering the chemical composition of the atmosphere through the buildup of greenhouse gases - primarily carbon dioxide, methane and nitrous oxide (Solcomhouse).

The causes of Climate Change

Atmospheric CO₂ has increased from a pre-industrial concentration of about 280 ppm to about 367 ppm at present (ppm = parts per million). CO₂ concentration data before 1958 are from ice core measurements taken in Antarctica and from 1958 onwards are from the Mauna Loa measurement site. It is evident that the rapid increase in CO₂ concentrations has occurred since the onset of industrialization. The increase has closely followed that of CO₂ emissions from fossil fuels (UNEP/GRID). Agricultural sources of greenhouse gases are livestock (fermentation) (CH₄), fertilization, nitrogen fixation N₂O, forest fires (CH₄, N₂O) and rice production (CH₄).

Past, present and future climate

Most climate change scenarios expect that greenhouse gas concentrations will increase through 2100 with a continued increase in average global temperatures (IPCC, AR4, 2007). How much and how quickly the Earth's temperature will increase remain unknown, giving, per consequent, the uncertainty of future greenhouse gas, aerosol emissions and the Earth's response to changing conditions. In addition, natural factors, such as changes in the sun and volcanic activities, may affect future temperature. However, the extent is unknown because the timing and intensity of natural phenomenon occurring cannot be predicted.

Observed changes in climate are:

- Global average surface temperatures increased 0.7°C (IPCC, AR4, 2007)
- Global mean sea-level has risen (1.0 to 2.0 mm/yr, IPCC)
- Arctic sea-ice thickness declined by 79%
- Ozone depletion and its interannual variation have been observed.
- ENSO has been unusual since the mid-1970s;

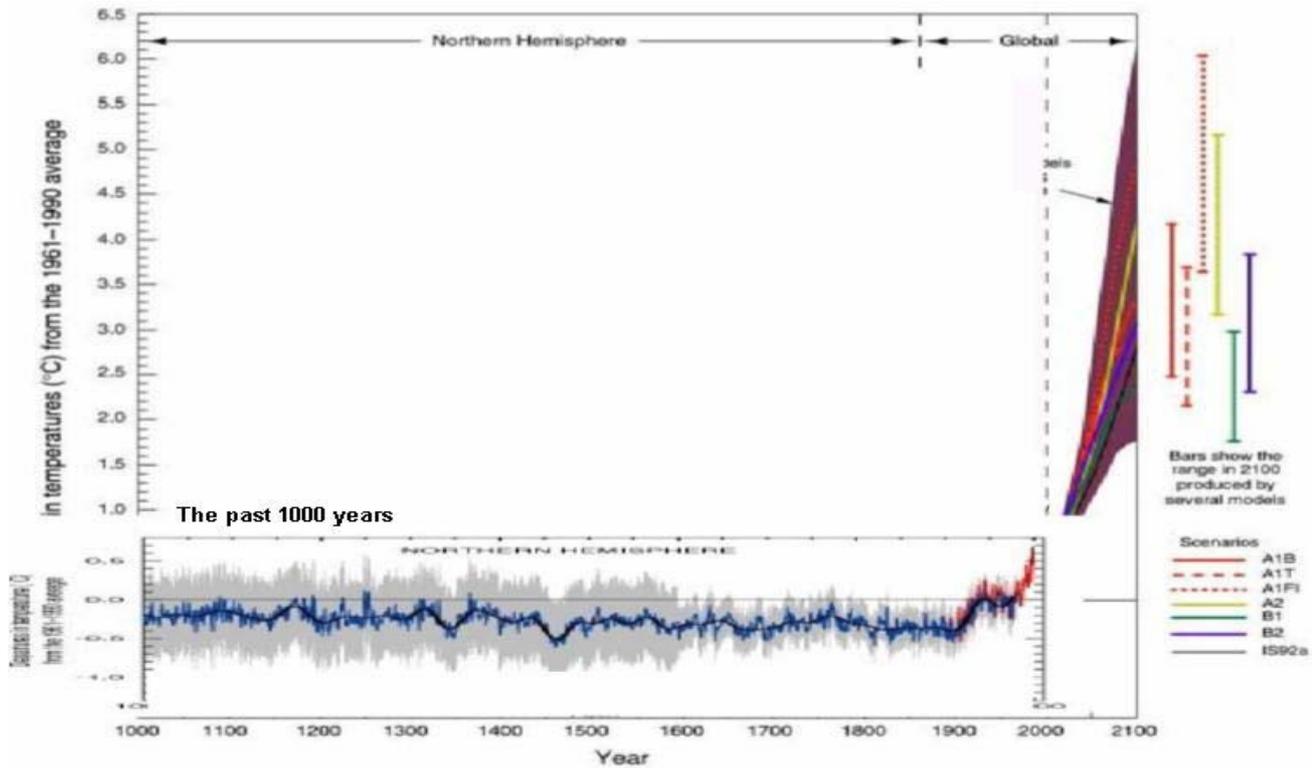


Figure 1 Past, present and future climate. 1000 to 1861, N. Hemisphere, proxy data; 1861 to 2000 Global, instrumental; 2000 to 2100, SRES projections. Data from thermometers, tree ring, corals, ice core and historical resources (IPCC, TAR, 2001).

Expected changes in annual temperature and precipitation

Global warming will not affect the different world countries similarly. Climate models predict that warming will be greatest in the Arctic and over land. Models also give a range of temperature predictions based on different emission scenarios. If humans limit greenhouse gas emissions (low growth), then the temperature change over the next century will be smaller than the change predicted if humans do not limit emissions (high growth). (IPCC, AR4, 2007, WG1). Advancements in model simulations, combined with more data on observed changes in climate, have led to increased confidence in projections of future temperature changes. In its 2007 assessment, the Intergovernmental Panel on Climate Change (IPCC) for the first time was able to provide best estimates and likely ranges for global average warming under each of its emissions scenarios. Based on plausible emission scenarios, the IPCC estimates that average surface temperatures could rise between 2°C and 6°C by the end of the 21st century. Possible benefits of global warming on agriculture are enhancement of CO₂ assimilation, longer growing seasons and increase of precipitation over 40th latitude.

Potential climate changes impact

Scientists expect that the average global surface temperature could rise by 1 to 4.5°F (0.7-2.5°C) in the next fifty years and by 2.2 to 10°F (1.4 - 5.8°C) in the next century with significant regional variation. Evaporation will increase as the temperature increases which will induce that of global precipitation average especially in northern Europe and Canada. Soil moisture is likely to decline in many regions as in Mediterranean and tropics, and intense rainstorms are likely to become more frequent. Sea level is likely to rise in many coastal areas. Climate changes induce health, environment and social problems (Solcomhouse).

Effects of global warming on agriculture

Possible benefits of global warming on agriculture are enhanced CO₂ assimilation, longer growing seasons and precipitation increase over 40th latitude. Possible drawbacks are more frequent and severe drought, heat stress, faster growth, shorter growing periods, shortened lifecycle, sea level rise and flooding and salinisation increase. The impact of climate change on agriculture will be translated through changes in temperature, water balance, atmospheric carbon dioxide composition and extreme events (flooding / drought). A number of indirect impacts may also be experienced such as changes in distribution, frequency and severity of pests, fire frequency, weed infestations and disease. Higher levels of carbon dioxide may stimulate plant growth by increasing the efficiency of water use. Nevertheless, the magnitudes of these effects under field experiment conditions are species dependent. The impact of global warming on crop productivity and yields will depend greatly on the combination of secondary effects. In areas that may receive more precipitation and can adapt to enhanced CO₂ conditions, a greater productivity may be possible as growing seasons will potentially be extended.

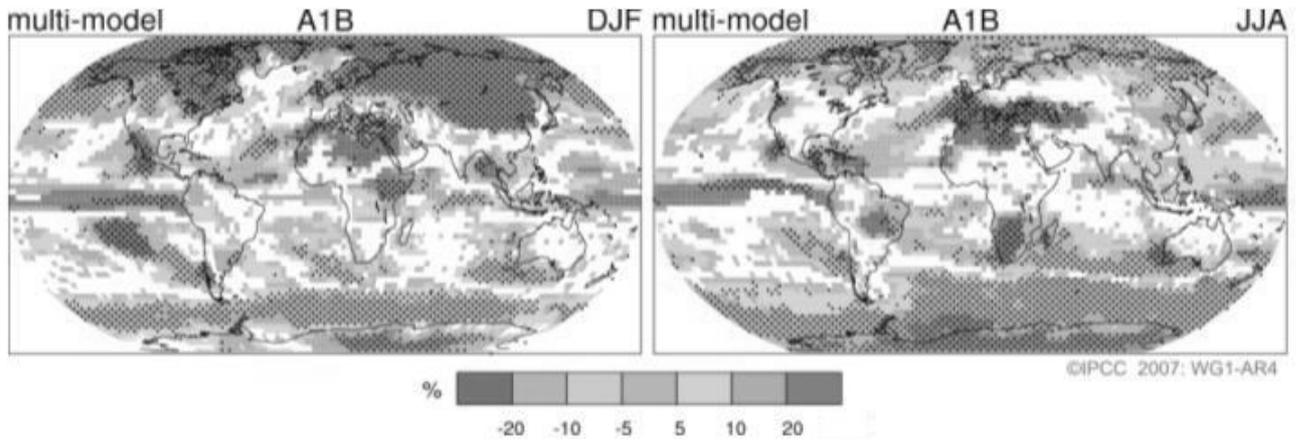


Figure 2 Projected changes in precipitation (IPCC, AR4, 2007, WG1).

Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. Both winter and summer months in the Mediterranean there will be more than 20% decrease in precipitation.

In areas where water is a limiting factor, productivity could potentially be reduced due to the added stress of heat and salinisation (Turkey, Tunisia). According to computer-modeled study by the authors at the NASA Goddard Institute for Space Studies, 2°C increase in temperature will have positive effect on cereal yield but 4°C increase will be negative. Increased CO₂ concentration will increase wheat yield because of the enhanced CO₂ assimilation.

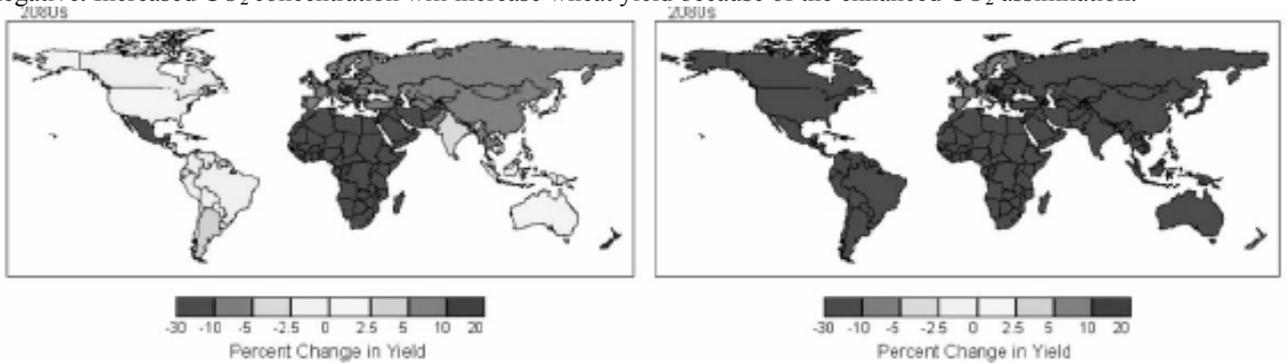


Figure 3 Potential changes (%) in national cereal yields for the 2080s (compared with 1990) under the HadCM3 SRES A1FI with and without CO₂ effects.

A1FI SRES scenario shows reduced cereal yield in the Mediterranean countries (Parry *et al.*, 1999). Growing Season Length (GSL) is the count between first span of at least 6 days with T>5°C. GSL has increased over Turkey except for coastal regions. Projected average increase is 35 days in 100 years. This will have a positive effect on summer agricultural products but some negative affects will be experienced by orchards for example which rely on cold condition which is known as chilling requirements (Sensoy *et al.*, 2007). In the south of Tunisia, Ben Ahmed *et al.* (2007) have stated that temperature average increased by 2.3 °C during the last 20 years, in comparison to that recorded during the period 1952 - 1977.

Climate change impacts and adaptations

Adaptations to climate changes are of three levels. Level 1 included change in crop variety, the planting dates and the amount of water applied to irrigated areas. Level 2 included changes in the type of the cultivated crops, changes in the planting dates and extension of irrigation to non irrigated areas. According to the three GCM scenarios, only developed countries could exploit climate changes grace to their adaptation capacities. Developing countries like Turkey and Tunisia could be negatively affected. Water withdrawal will be increased by 20% to 40% in the Mediterranean basin and by 10% to 20% in the Black Sea while there will be less than 10% withdrawal in the northern Europe.

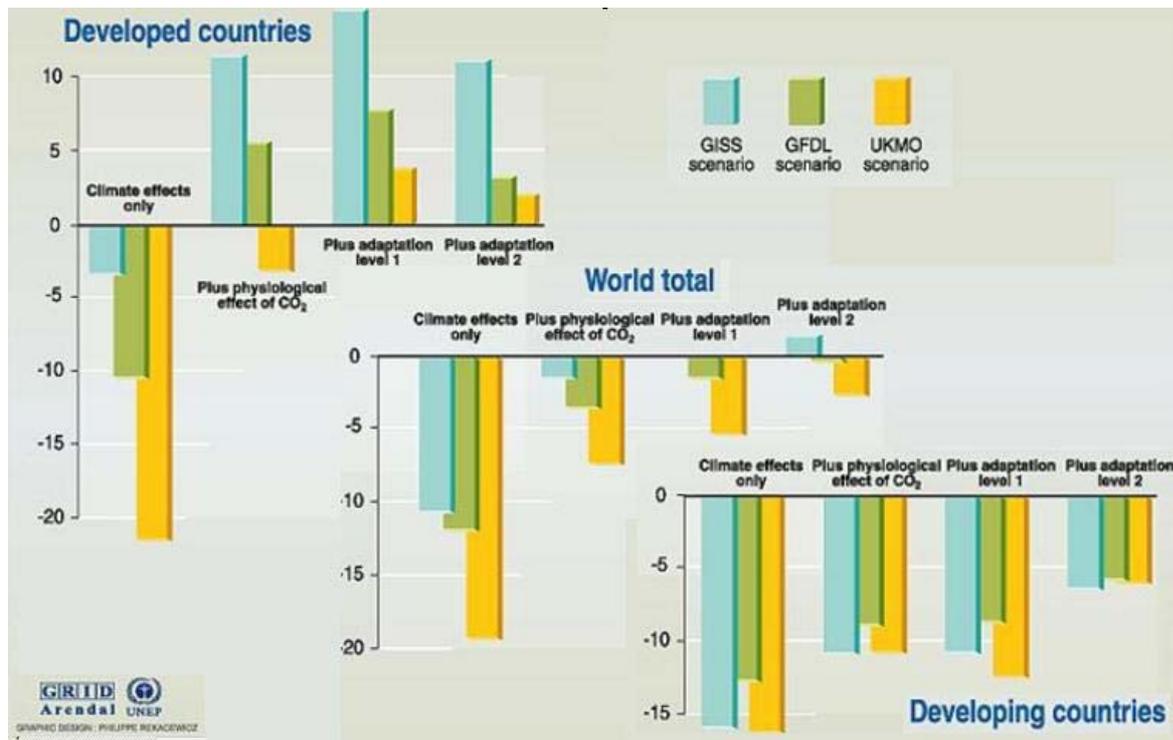


Figure 4 Changes in cereal production under three different GCM equilibrium scenarios in percent from base estimated in 2060. Source: Climate change 1995, Impacts, adaptations and of climate change: scientific technical analyses, contribution of WG2 to the 2nd assessment report of IPCC, UNEP and WMO, Cambridge University Press, 1995.

Conclusion

The earth's climate is predicted to change because human activities are altering the chemical composition of the atmosphere through the buildup of greenhouse gases. Climate changes will lead to changes in weather patterns and an increase in the frequency and severity of extreme events such as flooding and drought. In the Mediterranean as in the rest of the world, global climate change will cause an increase in the severity and frequency of heat waves, sea level rise, and extreme rainfall and flood events in some regions but increased drought in others, in a way that will directly affect living conditions.

Implications

According to various climate models, the Eastern Mediterranean Basin and the subtropical zone which includes Turkey and Tunisia will experience a reduction in rainfall especially in winter, but with changes in the duration and severity of rainfall, both flooding and drought are likely. Both SRES scenarios show reduced cereal yield in the Mediterranean. So, in this areas water will become a limiting factor; productivity could potentially be reduced due to the added stress of heat and salinisation. According to the three GCM scenarios only developed countries could be convert negative climate effects to positive ones grace to their adaptation capacities.

References

- Ben Ahmed Ch., Ben Rouina B., Sensoy S., Mekki Boukhriss M., 2007. A 50 Year Ago of Climate Change in the South of Tunisia: An Assessment for the Future, IUGG Conference, 02-13 July, 2007 Perugia, Italy.
- Crimp S. J., 2000, Department of Natural Resources. (data from Smit, B., L. Ludlow, and M. Brklacich). Possible Benefits. Possible Drawbacks. www.longpaddock.qld.gov.au/ClimateChanges/slides/dnrPI2.html
- EPA, United State Environmental Protection Agency
- IPCC, SAR, 1995, The Intergovernmental Panel on Climate Change, 2nd Assessment Report
- IPCC TAR, 2001, SRES, The Intergovernmental Panel on Climate Change 3rd Assessment Report and Special Report on Emission Scenarios
- IPCC AR4, 2007, The Intergovernmental Panel on Climate Change 4th Assessment Report, www.ipcc.ch/
- Jackson Institute, University College, London
- Mauna Loa Observatory, Hawaii,
- M.L. Parry *et al.* Effects of climate change on global food production under SRES emissions and socio-economic scenarios Global Environmental Change 14 (2004) 53–67
- NASA GISS, Goddard Institute for Space Studies and Earth Observatory,
- NOAA, U.S. National Oceanic and Atmospheric Administration www.noaa.gov/
- Parry, M.L., Fischer, C., Livermore, M., Rosenzweig, C., Iglesias, A., 1999. Climate change and world food security: a new assessment. Global Environmental Change 9, S51–S67.
- R. Nicholls, Middlesex University to the U.K. Met Office, 1997, Climate Change and its impacts: A Global Perspective.

Sensoy, S., Alan, I. Demircan, M., 2007, Trends in Turkey climate extreme indices from 1971-2004, IUGG Conference, 02-13 July, 2007 Perugia, Italy.
Solcomhouse web site: <http://www.solcomhouse.com/climatechange.htm>
The Met Office, U.K., Hadley Centre for Climate Prediction and Research. www.metoffice.gov.uk
UNEP/GRID Arendal, United Nations Environment Program, www.grida.no
UNEP and WMO Climate change 1995, Impacts, adaptations and of climate change: scientific technical analyses, Contribution of WG2 to the 2nd assessment report of IPCC, Cambridge University press, 1995.

Livestock genetic diversity and climate change adaptation

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Introduction

Animal genetic diversity is critical for food security and rural development. It allows farmers to select stocks or develop new breeds in response to environmental change, including climate change, disease, new knowledge of human needs, and changing market conditions, all of which are largely unpredictable. What is predictable, is the future human demand for food. The effects will be most acute in developing countries, where 85% of the increased food demand is expected, and where climate change is projected to have the greatest impact. Climate change will affect the products and services provided by agricultural biodiversity, but this biodiversity has not yet been properly integrated in adaptation and mitigation strategies to climate change, and its role for the resilience of food systems must still be addressed (FAO & Bioversity, 2008). Livestock contributes to and will be affected by climate change (FAO, 2006a).

In its global assessment, *The State of the World's Animal Genetic Resources for Food and Agriculture*, FAO (2007a) found that animal genetic diversity worldwide is under threat. So-called "international transboundary breeds" of the five major species (cattle, sheep, goats, pig, chicken), many of them high output commercial breeds, have spread globally for use in large-scale high external input systems to provide products for the market (FAO, 2003). Local breeds are commonly used in grassland-based pastoral and small-scale mixed crop-livestock systems, where they deliver a wide range of products and services for the local community, with low to medium external inputs. The spread of commercial breeds is due to their perceived economic competitiveness, and has, in some countries, indirectly increased the risk of extinction of local, less productive breeds.

There are many ways in which producers can adapt to climate change. Without judging possible differences in the efficiency of these measures, the paper focuses on animal genetic diversity as one possibility of climate change adaptation. Also, the different trade-offs between mitigation and adaptation measures are not covered. Producers can either adapt their animals' genetics to the changed environment or modify the production environment to suit the genetics. The implications and adaptation strategies will also depend on the public good targeted by various interventions. Facing the complex challenges of climate, ecological, economic and social change, the question is how animal genetic resources (AnGR) can adapt and continue to contribute to food security and rural livelihoods. Contrary to crops or forests, climate change models at the breed level are absent because detailed data on breeds' adaptation traits, including their thermal neutral zone and spatial distribution, are generally not available. Breeds' environmental envelopes overlap and distribution is overlaid by production systems, so breed-level predictions or bio-geographic models for climate change implications are hardly possible. Therefore, instead of trying to predict survival or movement of breeds under climate change, this paper aims to give insight into the likely sensitivity of breed diversity, the production and ecosystems they depend upon, and the goods and services they supply. Direct and indirect effects of climate change are discussed. Because the impact of climate change and ecosystems is described elsewhere, the paper focuses on the response in AnGR management and breeding. Some policy implications are given.

Direct impact of climate change on livestock production and diversity

Catastrophic events

Droughts and floods, or disease epidemics related to climate change may increase. Local and rare breeds thus risk being lost in localized disasters. To secure against such disasters, it is necessary to characterize AnGR and subsequently to build inventories, including spatial information, of breeds and valuable breeding stocks. This may include cryo-conservation of genetic material, or other measures to ensure genetic recovery in the case of a disaster. The role of private versus public genebanks still needs to be defined, but could require genebanks for local breeds and backups for commercial breeds. Operational protocols (e.g. Material transfer agreements) remain to be developed.

Physiological stress and thermoregulatory control

A wealth of literature is available on adaptation differences between Zebu and Taurine cattle (Frisch, 1972; King, 1984; Burns *et al.*, 1997; Prayaga *et al.*, 2006), many of which were done with international breeds. *Bos indicus* is generally more heat resistant than *Bos taurus*. There are fewer studies within cattle species, particularly of local breeds, or in other livestock species. Factors such as properties of the skin and hair, sweating capacity, tissue insulation, and metabolic heat production influence heat loads. High-output breeds originating from temperate regions, such as the Holstein cow, are not well adapted to heat stress (Ravagnolo & Misztal, 2002; St-Pierre *et al.*, 2003).

Many species and local breeds are, however, already adapted to harsh conditions. FAO (2006b) provides a broad overview of breed diversity in drylands, which are among the most extreme environments. Most of these breeds are not well characterized, however, and their adaptation includes not only heat tolerance, but also to their ability to survive, grow and reproduce in the presence of poor seasonal nutrition, parasites and disease. These breeds are rarely covered by structured breeding programmes (FAO, 2007a). Only few countries in the tropics with well-developed breeding

institutions, research, extension and AI service have commercially relevant tropical breeds, both tropically adapted taurine and zebuine (e.g. Brazil, Australia, South Africa, Southern USA) (Madalena, 2007; Prayaga *et al.*, 2006).

A variety of technologies exist in animal husbandry for dealing with short-term heat waves, such as shading or sprinkling to decrease heat loads. Access to such technologies will determine the ability of producers to adapt their herds to the physiological stress of climate change. If climate change exceeds the adaptive capacity of local breeds in extensive or pastoral systems, where the rate of technology adoption is generally low, the risk of breed displacement or loss increases. Intensive livestock production systems have more potential for adaptation through the adoption of technological changes and this may keep the high-output breeds in these production systems. The question is how the “artificial” environment of high-output breeds can be maintained in view of expected higher feed, energy and water prices, and how fast they can genetically adapt to changing environments, including greater disease pressure.

The projections suggest that further selection for breeds with effective thermoregulatory control will be needed. Some reaction norms have been defined as adaptive, meaning that plasticity and robustness are under genetic control, and can be influenced by breeding. Collier *et al* (2008) suggested some opportunity to improve heat tolerance through manipulation of genetic mechanisms at cellular level. Selection for heat tolerance based on rectal temperature measurements and inclusion of a temperature-humidity-index in the genetic evaluation models is promising. However, in dairy cattle, it may be difficult to combine the desirable traits of heat tolerance with high reproduction and production potential (Ravagnolo & Misztal, 2002). In beef cattle, the genetic antagonisms seem to be less, and improved characterization of adaptive traits, use of reproductive technologies and molecular markers, and strategic crossbreeding are elements of programmes underway (Prayaga *et al.*, 2007).

In general, the genetic relationships between adaptation and production traits and potential selection response need further attention. The speed of natural or artificial selection for adaptation depends on many factors. Conventional within-breed selection in species with long generation intervals is given to be insufficiently fast to adapt to the forecast climate change. Assuming that it is faster to select commercial breeds for improved adaptation than to select local breed for higher production (Nardone and Valentini, 2000), there are two options.

- 1) If the industry considers that enough tropically adapted breeds/genes are present in their portfolio and breeding programmes already, they will, as appropriate, undertake targeted and strategic crossbreeding with those adapted breeds, or insert specific genes via biotechnology. Breeding for improved adaptation to heat and harsh conditions, better feed conversion ratio FCR or reduced GHG emissions has become a high-tech exercise. The high throughput-SNP genotyping and the phenotypic characterization and bioinformatics tools needed for their calibration are most likely to be used in developed countries, thereby strengthening the market position of commercial breeds also in developing countries.

This option will continue to preclude characterization and selection within local breeds from developing countries for increased production or even improved adaptation. Problems for the survival of those breeds may occur if climate change is faster than natural selection, or if adapted commercial breeds penetrate into the marginal environments currently occupied by local breeds. Local breeds may remain in “safe zones” in marginal lands, but the bulk of production will be from commercial breeds. Local breeds of ruminants in land-based production systems thus have a better chance of being maintained, but the threat of extinction for local breeds of monogastric species will accelerate (FAO, 2007a). Conservation measures for breeds identified as becoming threatened should be established.

- 2) In view of the unprecedented speed of climate change, it may be difficult to develop breeds that remain productive. If climate change exceeds the adaptive capacity of the currently used genetic portfolio, an increased geneflow and introduction of breeds more adapted to the new environment will occur and the value of those breeds will increase. Currently underutilized species or breeds may become more attractive (e.g. camelids), and species substitution will be an option. This was already observed in the Sahel, where dromedaries replaced cattle and goats replaced sheep following the droughts of the 1980s. Countries will increasingly depend on exotic genetic resources. Countries that happen to host such resources may try to take advantage of this scarcity and control access. Such changes in the species or breed mix in livestock production may lead to a reverse in the current flow of genetics. Tropical breeds may thus become important, however, it can be expected that only well characterized breeds will be used for crossbreeding or gene transfer via biotechnology to increase adaptive traits of high output breeds.

A new species or breed may replace the current one as a single new component in a production system, or may be changed together with other components of agricultural systems, including knowledge systems. In any case, such replacement process may involve considerable costs and substantial investment in learning and gaining experience. The need for improved exchange mechanisms for AnGR and the associated knowledge will thus increase.

Indirect impact of climate change on livestock production and diversity

Ecosystem changes

Ecosystem changes resulting from climate change are relevant for livestock production because of the land dependency of most production systems and the close interaction of livestock genetic resources with other agricultural biodiversity. Water, feed and forage are the most important inputs for livestock production. Their overall and relative availability may be affected by the ecosystem changes, which are accelerated by climate change. Impacts of direct human pressures

such as non-sustainable practices, infrastructure development and fragmentation on rangeland ecosystems currently seem to be greater than those directly attributable to climate change (Easterling & Apps, 2005; Wittig *et al.*, 2007).

Changing host-pathogen interactions and disease challenge

The expected increased and often novel disease pressure related to climate change (Epstein, 2001) will favour genotypes that are resistant or tolerant. FAO (2007a) lists breeds, mainly from developing countries, that were reported to withstand trypanosomiasis, tick burden, tick-borne diseases, internal parasites or foot rot. Many of these are anecdotal evidence rather than scientific studies, and the underlying mechanisms are not well understood. There is, however, a potential for genetic improvement of disease resistance, and commercial breeding programmes already include resistance against helminthosis, ticks, mastitis, *E. coli* or scrapie. The importance of molecular markers and marker assisted selection will increase (Bishop *et al.*, 2002; Prayaga *et al.*, 2006).

Changing terms-of-trade of livestock production inputs compared to other products

Long-term breed survival, in economic terms, depends on the comparative advantage of a breed to provide the desired goods and services in a given environment. The past century has seen a very dynamic development in input and output prices. The non-food sector demand for feed inputs, especially for biofuel and other industrial use, is expected to increase, thereby potentially exacerbating the impact of climate change-induced reduction in feed supply. The predicted shift of C3 to C4 grasslands and increase in shrub cover in grasslands (Christensen *et al.*, 2004) will tend to reduce forage quality. In general, zebrine breeds better deal with low-quality forage than taurine breeds, while taurine have a better feed conversion ratio with high quality feed (Albuquerque *et al.*, 2006). Livestock can compensate for shrub encroachment to a certain extent if the animals are able to select high quality diets from different plant components or species. Some evidence of genetic variability in browsing ability has been reported (Blench 1999; Bester *et al.* 2002).

More research is needed on emission of GHG by livestock. Such studies have been primarily done with cattle, but have generally not considered the overall GHG balance of the full production system (life-cycle analysis) and implications of climate change or management adaptation. Although the model of Williams *et al.* (2006) covers a live-cycle assessment of GHG emissions from cattle, sheep, pig and poultry at different production intensities, it does not consider breed differences or genetic improvement over time. Tropical breeds and feeds have been largely ignored

The implementation of GHG reduction targets may lead to changes in the ranking of species and breeds and regional shifts in market. Depending on the scenario, either the local or commercial breeds could gain importance. The most extreme scenario to reduce GHG emissions would be to produce commercial ruminant meat in-vitro in closed systems, thus threatening those breeds. Commercial breeds are well characterized, however, and the cryo-conserved genetic material used for the normal breeding programme can stock genebanks for these breeds.

The opposite, pro-poor scenario would be to exclude from GHG reduction targets ruminants in marginal rangelands, used for landscape management or those providing the backbone of the livelihoods of the rural poor. This scenario would favour adapted local breeds. If combined with payment for environmental services, the pro-poor investment may increase adaptation and mitigation effects of climate change. Such a scenario, to be both pro-poor and pro-local breeds, would need the inclusion of land-use change in C-trade and the opening of the CDM to grasslands/rangelands. It would decrease livestock numbers, but maintain the breeds and traditional knowledge for those livestock keepers that remain. Possible synergies between plant and animal breeding need to be better developed.

For beef cattle, intensive feedlot systems result in less CH₄ per unit of meat produced than with extensive grazing. Milk protein can be produced with less CH₄ emissions than beef, and high output, low mortality and increased length of utilization of individual animals reduce the emissions per unit production (Williams *et al.*, 2006). If the present increase in feed prices continues, superior FCR will grant monogastrics a comparative advantage to cereal-fed ruminants and commercial breeds will outcompete local breeds. If we combine this trend with an intermediate GHG reduction scenario, intensive dairying might become the major focus of cattle production, while commercial meat may be produced by monogastrics. Commercial breeds of all species selected for FCR, high yield and longevity will dominate.

Breeding has a role in reducing GHG emissions. In addition to selection to increase production per se, any selection that reduces mortality and increases fertility and longevity tends to contribute to reducing the GHG emissions per unit output. Breeding for high performance and improved FCR have significantly reduced the amount of feed per unit of product, particularly in monogastrics and in dairy cattle relative to beef or sheep. For example, FCR in poultry was reduced by about 50% since the 1950s (Flock & Preisinger, 2002). Similar improvements were made for pigs, and future breeding can exploit the genetic variation in digestion parameters for pig and poultry. Alford *et al.* (2006) calculated that CH₄ could be reduced by up to 16% in 25 years if residual feed intake (RFI) was included in beef selection programmes. Initial costs to identify individuals with low RFI are high, however, particularly in grazing animals (Arthur *et al.*, 2004). Contrary to beef cattle, it seems that the genetic determination of CH₄ production is of minor importance in taurine dairy breeds and selection for RFI may not be effective (Muenger & Kreuzer, 2008). Options for selection in ruminants lie in the host components of rumen function, in post-absorption nutrient utilization and in disease resistance.

Implications for AnGR management and policy dimensions

Depending upon the ecosystem changes brought about by climate change and other pressures and the trade-offs between the public goods considered, the portfolio of breeds demanded by society will change. Developed and

developing countries differ in their adaptation capacity and the expected interactions between climate change adaptation and mitigation. Developing countries have a low adaptation capacity, they will therefore have to apply a closer relationship between climate change adaptation and development policy. They also have weak capacity for high-tech breeding programmes to increase their breeds' adaptation. We assume that climate change itself, and the resulting disintegration of the components of (agricultural) ecosystems, together with human migration, will increase the pressure to maintain wide access to AnGR. The associated knowledge for both commercial and local breeds should be transferable together with the genetics as the optimal use of AnGR will increase overall resilience of our global food and agricultural system. For AnGR to adapt to climate change and other pressures and contribute to climate change mitigation, the following actions need to be undertaken:

- Strengthen characterization and evaluation of AnGR, and develop simple methods to characterize adaptive traits,
- Improve national inventories including relevant spatial information and assess future breed distribution,
- Monitor threats to breeds, be they caused by climate change or other pressures (e.g. geneflow), and develop some basic predictive modelling and early warning systems,
- Establish *in vivo* and *in vitro* conservation facilities,
- Facilitate wide access to the genetic resources and the associated knowledge, and share benefit arising from their use;
- Develop methods for live-cycle assessments and include delivery of ecosystem services in the analysis,
- Include C-sequestration from grass/rangelands in the CDM, as this could combine GHG mitigation, poverty reduction and biodiversity conservation targets,
- Develop pro-poor policies and strengthen livestock keepers' adaptation strategies, their ecological knowledge and local institutions,
- Support developing countries in their management of AnGR.

The recent adoption of the *Global Plan of Action for Animal Genetic Resources* and the *Interlaken Declaration* by the international community provide for the first time an internationally agreed framework to promote creating these crucial conditions for the global livestock sector (FAO, 2007b).

References

- Albuquerque, L.G., M.E.Z. Mercadante, J.P. Eler 2006. Recent studies on the genetic basis for selection of *Bos indicus* for beef production. 8th World Congress on Genetics Applied to Livestock Production, August 13-18, 2006, Belo Horizonte, MG, Brasil
- Alford A. R., R. S. Hegarty, P. F. Parnell, O. J. Cacho, R. M. Herd, G. R. Griffith, 2006. Australian J of Experimental Agriculture, 46, 813–820
- Arthur, P.f., J.A. Archer, R.M. Herd, 2004. Australian J of Experimental Agriculture, 44, 361-169
- Bester, J., L.E. Matjuda, J.M. Rust, H.J. Fourie. 2002. The Nguni: A case study. Paper presented to the Symposium on Managing Biodiversity in Agricultural Ecosystems, Montreal, Canada, November 8-10, 2001
- Blench, R. 1999. Traditional livestock breeds: Geographical distribution and dynamics in relation to the ecology of West Africa. ODI working paper 122, 67 pp.
- Burns, B.M., D.J. Reid, J.F. Taylor, 1997. Australian J of Experimental Agriculture, 37, 399-405
- Christensen, L., M.B. Coughenour, J.E. Ellis, Z.Z. Chen, 2004. *Climatic Change* 63: 351–368, 2004.
- Collier, R.J., J.L. Collier, R.P. Rhoads, L.H. Baumgard, 2008. J Dairy Science 91 (2):445–454
- Easterling, W., M. Apps. 2005. *Climatic Change* (2005) 70: 165–189
- Epstein, P.R. 2001. *Microbes and Infection*, 3, 747–754
- FAO, 2003. World agriculture: towards 2015/2030 - An FAO perspective, Ed. by Bruinsma, J., Earthscan, London.
- FAO. 2006a. Livestock's long shadow – environmental issues and options, edited by H. Steinfeld, P. Gerber, T. Wassenaar, V. Castel, M. Rosales & C. de Haan. Rome.
- FAO. 2006 b Breed diversity in dryland ecosystems. CGRFA/WG-AnGR-4/06/Inf. 9.
- FAO. 2007a. The State of the World's Animal Genetic Resources for Food and Agriculture, edited by B. Rischkowsky & D. Pilling. Rome.
- FAO. 2007b. Global Plan of Action for Animal Genetic Resources *and the* Interlaken Declaration. Rome. (http://www.fao.org/ag/againfo/programmes/en/genetics/documents/Interlaken/GPA_en.pdf).
- FAO & Bioversity International, 2008. Synthesis Report. Workshop on Climate Change and Biodiversity for Food and Agriculture, FAO Headquarters, Rome, 13-14 February 2008 organized by FAO, Bioversity International, in partnership with the Platform for Agrobiodiversity Research (PAR) and the Secretariat of the CBD http://www.fao.org/fileadmin/user_upload/foodclimate/presentations/biodiv/Biodiv_Synthesis_Paper.pdf
- Flock D.K. & R. Preisinger, 2002. Breeding plans for poultry with emphasis on sustainability. 7th World Congress on Genetics Applied to Livestock Production, August 19-23, 2002, Montpellier, France
- Frisch, J.E., 1972. Australian J of Experimental Agriculture and Animal Husbandry, 12(56), 231-233
- Hoffmann, I., I. Mohammed (2004): Nomadic Peoples, Vol 8(1), 99-112
- King, J.M., 1983. Livestock water needs in pastoral Africa in relation to climate and forage. Addis Ababa, ILCA Research Report No. 7.
- Madalena, F. E., 2008. Livestock Research for Rural Development, Vol. 20 (2)

Nardone, A., & A. Valentini. 2000. The genetic improvement of dairy cows in warm climates. Proceedings of the ANPA-EAAP-CIHEAM-FAO symposium on Livestock production and climatic uncertainty in the Mediterranean. Agadir, Morocco. EAAP Publication No. 94.

Prayaga, K.C., W. Barendse & H.M. Burrow, 2006. Genetics of tropical adaptation. 8th World Congress on Genetics Applied to Livestock Production, August 13-18, 2006, Belo Horizonte, MG, Brasil

St-Pierre, N.R., B. Cobanov, G. Schnitkey, 2003. J. Dairy Sci. 86:E52–E77

Williams, A.G., Audsley, E. and Sandars, D.L. (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on http://www2.defra.gov.uk/research/project_data/More.asp?I=IS0205&SCOPE=0&M=CFO&V=SRI#Docs

Wittig R, König K, Schmidt M, Szarzynski J (2007): Env Sci Pollut Res 14 (3) 182–189

Riding out the storm: animal genetic resources policy options under climate change

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Introduction

In 2004, the Intergovernmental Technical Working Group on Animal Genetic Resources recommended⁶ the FAO to commission a study to assess how exchange practices regarding AnGR affect the various stakeholders in the livestock sector, and to identify policies and regulatory options that guide the global exchange, use and conservation of AnGR. This paper presents the main climate change-related findings of that study by Hiemstra *et al.* (2006).

A review of the literature related to the predicted impacts of climate change on livestock in 6 regions of the world (Anderson, 2004; AGO, 2004; ABS, 2004; CCCA, 2002; Charron, 2002; FAO, 2000 and undated; Frank *et al.*, undated; MAFF, 2000; IPCC, 2001; Kenny, 2001; Kristjanson *et al.*, 2001; Tisdell, 2003 and WRI, 2000) suggests that climate change can be expected to affect livestock productivity directly by influencing the balance between heat dissipation and heat production (making heat/cold tolerance in breeds attractive), and indirectly through its effect on the availability of feed and fodder, as well as with regard to the presence of disease agents. However, global numbers hide complex spatial patterns of changes. The specific direction of change can only be predicted by considering specific localities.

Regardless of the specific direction of change, these potential impacts suggest that the conservation of both productive and adaptive traits will become increasingly important. The importance of such conservation raises policy issues/concerns which in turn have particular policy implications associated with them. This allows a series of potential policy instruments that could be developed to address such issues to be identified, thereby supporting informed and evidence-based decision-making in international fora relevant to animal genetic resources (AnGR).

Materials and methods

In order to identify and assess potential options, an analysis of the current situation regarding exchange, use and conservation, as well as the elaboration of a range of future change scenarios⁷ and their potential implications, was carried out in Hiemstra *et al.* (2006). The scenario approach was found to be particularly useful as the conditions for animal breeding and conservation of AnGR diversity are changing for a number of reasons. Development of a policy or regulatory framework for AnGR may therefore wish to anticipate future developments. For this reason, four emerging challenges or (potential) future scenarios were developed and used in Hiemstra *et al.*, (2006) to illustrate plausible future developments ('histories of the future'), with the aim of supporting the making of better decisions in the present about issues that have long-term consequences in the future. These future scenarios included: globalization and regionalization; biotechnology development; climate change and environmental degradation; and diseases and disasters. The future scenarios were built on major driving forces, which are not only visible today, but which could have an increasing impact on exchange, use and conservation of AnGR in the future.

The analysis of the implications of these scenarios, should they occur in practice, was carried out through a global assessment of the experiences, interests, objectives and views regarding AnGR policy development of a wide range of stakeholders, including at the global level and in specific case studies in developing and developed countries. Full details of the consultative process that involved more than 200 people from more than 40 countries can be found in Hiemstra *et al.* (2006). The remainder of this section focuses on the drivers, assumptions and impacts underlying the original climate change scenario development.

Climate change scenario development

The main livestock-relevant environmental impacts of climate change (changes in disease challenge, changes in fodder and water availability, land degradation, speed of climate change relative to livestock and forage evolutionary adaptation), together with a series of assumptions can be used to develop four non-climatic scenarios⁸. In turn, these scenarios can be related to a number of potential impacts on AnGR and the policy implications associated with them.

⁶ CGRFA/WG-AnGR-3/04/REPORT, paragraph 24

⁷ A scenario is a coherent, internally consistent, and plausible description of a possible future state of the world. Scenarios commonly are required in climate change impact, adaptation, and vulnerability assessments to provide alternative views of future conditions considered likely to influence a given system or activity (IPCC, 2001, Chapter 3).

⁸ A distinction is made between climate scenarios — which describe the forcing factor of focal interest to the Intergovernmental Panel on Climate Change (IPCC) — and non-climatic scenarios, which provide socioeconomic and environmental "context" within which climate forcing operates (IPCC, 2001, Chapter 3).

We begin by considering that climate change will take place within the context of human population growth⁹, the continuation of urbanisation trends, increasing affluence in the South as a result of the development process¹⁰, and that globalised¹¹ livestock production and marketing will continue to lead to increasing concentration on the use of a limited number of "improved" breeds.

This suggests that:

- the demand for livestock products will continue to increase as part of the "livestock revolution" (Scenario 1 – "livestock product demand increase")
- the portfolio of breeds needed/demanded by society will change as a result of both this increased demand and the environmental impacts of climate change (Scenario 2 – "livestock portfolio change")
- the livestock gene pool will be smaller than it is today because the process of globalisation tends to lead to the use of a limited number of "improved" breeds¹². The speed of climate change which is expected to outpace evolutionary adaptations will also contribute to the reduction in the genepool (Scenario 3 – "gene pool reduction").
- the increase in atmospheric CO₂ and other greenhouse gasses means that livestock methane emission mitigation will be of increasing importance in order to comply with Kyoto and "son of Kyoto" Protocols (Scenario 4 – livestock emissions importance).

Potential Implications

These four scenarios¹³ have a number of inter-related implications and impacts at different levels.

With regard to Scenario 4, it may be expected that the choice of livestock species and feed/agricultural practices will change given the increased importance and value of livestock methane emissions abatement.

At the same time, scenarios 1-3 suggest that

- there will be an increased need for the large-scale movement (i.e. import/export) of livestock breeds in search of more appropriate climatic zones, as a direct result of increased livestock product demand and the change in the portfolio of breeds needed/demanded; and
- that there will be increased demand for the remaining breeds (including for both productive and adaptive traits) not only because of increased livestock product demand and changes in portfolios required, but also because of the existence of a reduced gene pool

Given that these three latter scenarios take place within the context of changed disease challenge, it is possible that stricter zoo-sanitary regulations may impede international germplasm flows. In this case, there are likely to be fewer international policy implications. However, the loss of livestock trade benefits would have significant implications for development, insofar as technical interventions (e.g. better ventilated buildings, improved veterinary interventions) to limit climate change impacts on intensive farm productivity would not be able to fully offset the costs of lost livestock trade.

By contrast, cheaper and more advanced biotechnology¹⁴ may permit compliance with stricter zoo-sanitary regulations thereby facilitating increased international germplasm flows. In this case, it might be expected that demand for both productive and adaptive traits will increase as well as that increased AnGR research will occur as livestock trade becomes more important and biotechnology developments increase the returns to both public and private sector AnGR research. The reduced gene pool and biotechnology developments also make the remaining germplasm more valuable, much of which may in the future be increasingly accessible from *ex situ* and *in situ* conservation programmes. This could well lead to increasing concerns regarding sovereign control of national AnGR.

⁹ It is estimated (medium variant) that there will be 9.1bn people by 2050 compared to 6.5 billion in 2005 (UN Population Division, 2003 and 2004. <http://esa.un.org/unpp>)

¹⁰ IPCC (2001, chapter 3) notes significant uncertainties in developing scenarios of economic development. In the scenarios reviewed in Alcamo *et al.* (1995) and Grübler (1994) per capita GDP growth rates range typically between 0.8 and 2.8% per year over the period 1990-2100. On the basis of an average global per capita income of US\$4000 in 1990, global per capita GDP could range anywhere between about US\$10,000 to about US\$83,000 by 2100. While these figures do not differentiate between "North" and "South", per capita GDP growth rates are expected to be higher for economies which currently have low per capita GDP levels.

¹¹ The "globalization" scenario, its impacts and potential policy implications are described in detail in Hiemstra *et al.* (2006).

¹² Given that, worldwide, over 20% of indigenous livestock breeds are at some degree of risk (FAO, 2007), this scenario is also consistent with a continuation of existing trends.

¹³ Scenarios are meant to be plausible, pertinent, alternative stories about the future, with the objective of permitting an exploration of possibilities rather than predicting the future per se. In this context, scenarios do not have to turn out to be absolutely correct to be useful.

¹⁴ The "biotechnology" scenario, its impacts and potential policy implications are described in detail in Hiemstra *et al.* (2006).

Such concerns may threaten international flows of livestock germplasm and access to AnGR, in a context where such flows and access issues have become more important. At the same time, increased livestock germplasm flows within and between countries will create new opportunities for crossbreeding and introduction of exotics. There will consequently be a need to ensure that any such flows are beneficial and do not threaten remaining livestock diversity.

Results

Policy implications

The specific policy implications of the above analysis are thus that:

- widely accepted standardised material transfer agreements and access/benefit sharing arrangements (including covering the monetary and non-monetary benefits that may occur regardless of any commercialisation process) are developed in order to ensure continued international flows of livestock germplasm and AnGR access; and
- improved understanding of the actual economic benefits of livestock germplasm flows is required, so as to ensure that such flows are not restricted in order to address perceived injustices while simply ending up reducing benefits currently accruing to developing countries.

Potential policy instruments

A range of potential policy instruments that could be applied to address these two types of policy concern can now be identified. Many have in fact already been discussed at a number of international meetings¹⁵, although not necessarily in the context of climate change. These include:

- Developing procedures for access and benefit sharing, including Prior Informed Consent (Bonn Guidelines).
- Regulation of export and import of livestock germplasm, including establishment of protocols for the guidance of donors and NGOs when importing exotic breeds. Development and implementation of "genetic impact assessments" prior to importation and implementation of mitigation mechanisms where appropriate.
- Support for both conservation and improvement of indigenous AnGR. Provision of financial incentives for breeding and raising indigenous breeds.
- Promotion and support for marketing of local breed products; Provision of infrastructure supporting indigenous breed production.
- Establishment of national Biosafety Acts within which any future introduction of AnGR containing genetically modified organisms can be regulated.
- Making special provisions for indigenous AnGR in animal disease acts.
- Acknowledgement of the critical role that local communities play in AnGR conservation (could include "Karen Declaration" type of livestock-keepers rights which involve support for indigenous knowledge remaining in the public domain, excluding AnGR from IPR claims and regimes for research and development).
- Secure land titles or land use rights for indigenous livestock breeding communities.
- Capacity building (education, awareness raising, information¹⁶, use of participatory approaches, recognition of importance of AnGR, etc.).
- Development of a livestock emissions trading mechanism under "son of Kyoto".

Conclusions

Regardless of the specific direction of change, the four potential scenarios identified above (livestock product demand increase, breed portfolio change, gene pool reduction and livestock emissions importance) raise policy issues/concerns and have particular policy implications associated with them. This allows a series of potential policy instruments that could be developed to address such issues to be identified, thereby supporting informed and evidence-based decision-making in existing AnGR policy development fora.

The precise details of the policy instruments identified remain to be defined but the analysis of similar existing instruments, including from other sectors (e.g. EU support for rare breeds under Regulations 1257/99 and 1750/99 on support to Rural Development Plans; standard MTAs used for crop species, etc.), could be undertaken as a next step in their assessing potential viability and impact.

Implications

A review of the literature related to the predicted impacts of climate change on livestock suggests complex spatial patterns of changes that are unlikely to provide a strong basis for international animal genetic resources policy analysis. However, regardless of the specific direction of change, the potential impacts raise policy issues/concerns and have particular policy implications associated with them. This allows a series of potential policy instruments that could be developed to address such issues to be identified, thereby supporting informed and evidence-based decision-making in existing AnGR policy development fora.

¹⁵ In particular, "Community-based Management of Farm AnGR", Mbabane, 2001; "Incentive Measures for Sustainable Use and Conservation of Agro-biodiversity", Lusaka, 2001; "Development of Regional and National Policy"; Luanda, 2002; and "Legal and Regulatory Framework for Farm AnGR", Maputo 2003. Proposed instruments listed below were discussed at Maputo with the exception of livestock emissions trading.

¹⁶ Includes the FAO Global Strategy on Management of Farm AnGR, the State of the World's Animal Genetic Resources for Food and Agriculture, DAD-IS (Domestic Animal Diversity Information System), DAGRIS (Domestic Animal Genetic Resources Information System), etc.

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References

- Anderson, S. 2004. Environmental Effects on AnGR. Thematic Study Paper: Animal Genetic Resources No. 1. CGRFA. FAO.
- Australian Greenhouse Office. 2004. Agricultural Impacts and Adaption. Department of the Environment and Heritage, Australian Government.
<http://www.greenhouse.gov.au/impacts/agriculture.html>
- Australian Bureau of Statistics. 2004. Measures of Australia's Progress.
- CCAA (Climate Change and Agriculture in Africa). 2002. Facts about Africa Agriculture Climate.
http://www.ceepa.co.za/climate_change/index.html
- Charron, D. 2002. Potential impacts of global warming and climate change on the epidemiology of zoonotic diseases in Canada. Canadian Journal of Public Health.
http://www.findarticles.com/p/articles/mi_qa3844/is_200209/ai_n9132821#continue
- FAO. 2007. The State of the World's Animal Genetic Resources for Food and Agriculture. Rome.
- FAO (Food and Agriculture Organisation of the United Nations). 2000. World Watch List for Domestic Animal Diversity, 3rd Ed., FAO, Rome.
- FAO, no date. Extensive pastoral livestock systems: issues and options for the future.
<http://www.fao-kyokai.or.jp/edocuments/docement2.html>
- Frank, K., Mader, T., Harrington, J and Hahn, G. No date. Potential Climate Change Effects on Warm-Season Livestock Production in the Great Plains. Journal Series no. 14462, Agric. Res. Div., University of Nebraska.
- Hiemstra, S.J., Drucker, A.G., Tvedt, M.W, Louwaars, N., Oldenbroek, J.K., Awgichew, K., Abegaz Kebede, S., Bhat, P.N. and da Silva Mariante, A. 2006. Exchange, use and conservation of animal genetic resources: policy and regulatory options. Centre for Genetic Resources, University of Wageningen, The Netherlands and FAO, Rome.
- MAFF (Ministry of Agriculture, Food and Fisheries). 2000. Climate Change and Agriculture in the United Kingdom.
<http://www.defra.gov.uk/enviro/climate/climatechange/index.htm>
- IPCC (International Panel on Climate Change). 2001. Climate change 2001: impacts, adaptation, and vulnerability. CUP.
- IPCC. 2007. Fourth Assessment Report (AR4). Climate Change 2007. CUP.
- Kenny, G. 2001. Climate Change: Likely Impacts on New Zealand Agriculture: A report prepared for the Ministry for the Environment as part of the New Zealand Climate Change Programme.
- Kristjanson, P M.; Thornton, P K.; Kruska, R. L.; Reid, R. S.; Henninger, N.; Williams, T. O.; Tarawali, S.; Niezen, J.; Hiernaux, P. 2001. Mapping livestock systems and changes to 2050: implications for West Africa. Sustainable crop-livestock production for improved livelihoods and natural resource management in West Africa. Proceedings of an international conference.
- Tisdell, C. 2003. Socioeconomic causes of loss of animal diversity genetic: analysis and assessment. Ecological Economics 45 (3), 365 -376.
- WRI (World Resources Institute). 2000. Pilot Analysis of Global Ecosystems: Agroecosystems.

Climate Change: A conceptual approach for assessing health impacts

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Introduction

In order to understand possible linkages between climate (i.e., variability/change) and health impacts one must ask first: Is climate a confounding factor for new and re-emergent human, animal and vegetation diseases and epidemics?

Too often, experts from international organizations and agencies (IPCC, WHO) offer far-reaching conclusions (without uncertainties) and call for a definite climate role on the biosphere and health impacts. It is admitted (without strong scientific evidence) that diseases from food availability and water quality origins, or vector-borne diseases are directly impacted by climate change with human climate-related losses estimated at ~150,000 deaths/year for the 1970-2000 period, globally. These conclusions from doomsayers, are by far too alarmist, particularly when we observe that large death tolls often occur after discrete sanitary crisis. Moreover, uncertainties from the employed analytical and modelling methods are not always clearly presented.

Some climate factors are necessary for diseases' emergence

Climate factors such as rainfall and humidity are often considered as necessary key parameters which modulate the emergence of various human, animal and plants diseases. For example, mosquitoes and other 'vectors' facilitating the transmission and diffusion of diseases such as Rift Valley Fever (RVF), Blue Tongue, Malaria, Dengue Fever and Chikungunya among others, respond to the spatio-temporal distribution of seasonal rainfall. Examples of linkages between rainfall variability associated with the ENSO phenomenon and diseases are given globally:

Rainfall extrema during ENSO (El Niño/Southern Oscillation)

The ENSO phenomenon is associated with variability of the trades in the Pacific Ocean. For example weaker easterlies will contribute to warmer SST in the Central and Eastern tropical Pacific (El Niño). Immediately above the warmer than normal pools of water, atmospheric deep convection is enhanced resulting in heavy rainfall over Peru, Florida, Eastern Africa etc. Conversely Australia and Indonesia are submitted to important drought events. With the El Niña phase (stronger easterlies) opposite patterns are found.

Over Colombia, Peru, Equator, Argentina, Florida (USA) and Kenya, positive rainfall anomalies are measured along with epidemics from vector-borne diseases such as the RVF, Malaria, Dengue Fever, arboviroses, or vibrios-linked diseases including Cholera. On the other hand, over regions with intense and anomalous droughts (Indonesia, Amazonia, South Africa) the main culprit is found to be the re-emergence of respiratory diseases.

The West African drought since the late 60s

The West African drought for the last three decades has favored the geographical extension of Lyme disease (*Borrelia crocidurae*), since the vector *Alectorobius sonrai* has found a 'good environment' within the Sahara and Sahel. The latter disease, after Malaria, is the second vector-borne disease's killer over the Sudan/Sahel regions.

Climate conditions for diseases re-emergence : necessary but not sufficient

A variable and changing climate modulating environmental conditions, seem necessary for impacts on the biosphere/ecosystems impacts and associated health issues. The above ENSO-related examples were taken in order to highlight the different spatio-temporal scales involving climate variability with public health. Indeed the climate system varies and changes (i.e., natural and anthropogenic changes) within a panoply of scales going from intra-seasonal to secular (Tourre and White, 2006). Thus the health impacts can be re-grouped into three main classes associated with:

- i) evolution (trend and low-frequency) of mean climate condition ;
- ii) interannual variability such as ENSO;
- iii) extreme weather events.

1) Low-frequency evolution of mean climate conditions

Low-frequency evolution of temperature and precipitation are going to slowly modify the spatial emergence (re-) of diseases. In particular, biological factors such as habitats, ecosystems, life-expectancy, vectors' reproduction (i.e., mosquitoes, ticks, phlebotomes etc.) and migrating trajectories (migratory birds seen as pathogenic reservoirs) will be affected. The geographical expansion of borreliosis from ticks over West and Central Africa is a good example of impacts for long-lasting droughts there.

2) Interannual climate variability

A classic example is associated with the ENSO phenomenon with a 3- to 8- year spectral-band. Diseases re-appearing on these frequencies/periods have been widely documented.

3) Extreme weather events

The amplitude (and/or frequencies) of extreme weather events such as heat/cold-waves (thermal stresses), droughts/floods, wind storms, have been on the increase. For example the 2003 heat-wave over Western Europe is an example of an extreme health related impact (more than 15, 000 deaths during August 2003, France).

In conclusion, the above three scales must be considered with details, to better understand the mechanisms underlying the climate-health relationships. Physical mechanisms associated to these scales are not independent. They will certainly interact, modulate, amplify each other with non-negligible impacts on the biosphere. If direct climatic factors are thus necessary to modify ecosystems in ways favoring the development of potential diseases, they are not always sufficient for their effective emergences. The latter requires a combination of natural and purely anthropogenic factors (i.e., deforestation, agricultural and industrial expansions, new infrastructures, transportation, dams).

How to quantify climate change impacts on animal health? : the case of the RVF

The multi-factorial climate-health relationships are difficult to assess, from a socio-economical point-of-view, since they imply an integrated and multi-disciplinary approach: i.e., going from biology to socio-economy, including responses from the civil society, political decisions, and degrees of implementation of sentinel and land monitoring networks. A pluri-disciplinary scientific approach is a pre-requisite and must be based upon long-term programming and planning. As of today the approaches are too often seen from the 'epidemiologic side' looking after simple statistical correlations without taking into account the mechanisms at stake.

The case of the Rift Valley Fever

The RVF epidemics are excellent examples on how rainfall might facilitate their emergences, resulting in lethal zoonoses. But this does not explain mechanisms everywhere for RVF epidemics. The spatio-temporal distribution of rainfall is highly heterogeneous, and the statistical correlation with an integrated vegetation index (NDVI) is obtained when using rainfall amount time-series. The deceiving result is that high vegetation indices are correlated with epidemics over East Africa (Linthicum *et al.*, 1999) but not over West Africa (Ndione *et al.*, 2003)! In fact it is found that the mosquitoes' population (carrying the virus) is a function on how the rainfall has been distributed in space and time (which is quite different to integrated rainfall amount over long periods) (Mondet *et al.*, 2005). The above apparent contradictions underline the fact that some links between climate and health, with dynamical processes involved with the diseases' appearance and transmission, are still missing.

A new conceptual approach i) integrating in-situ measurements with products from space, ii) studying the rainfall distribution with ponds' dynamics and RVF emergence has been conducted in the Ferlo region of Senegal. This multi-disciplinary study has included scientists from different backgrounds and disciplines: meteorologists, hydrologists, modellers, biologists, entomologists.

Main results on complex physical mechanisms (including triggering factors) involved are to be discussed for the RVF cases. Brand new products and indices from space, will be presented as well (Lacaux *et al.*, 2007).

Références

- Tourre and White (2006) : *Geophys. Res. Lett.*, 33, L06716, doi:10.1029/2005GL025176.
Linthicum KJ *et al.* (1999) : *Science*, 285, 397-400.
Ndione JA *et al.* (2003) : *Risques et Santé*, 2, 176-181.
Mondet *et al.* (2005) : *J.Vector Ecol.*, 30, 102-106.
Lacaux *et al.* (2007) : *Rem. Sensing of Environ.*, 106, 66-74.

Bluetongue and Rift Valley fever in livestock: a climate change perspective with a special reference to Europe, the Middle East and Africa

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Present situation

Rift Valley fever (RVF)

RVF is a viral, mosquito-borne disease affecting humans and domestic ruminants that causes abortions and neo-natal mortality (Lefèvre *et al.*, 2003). In humans, infection is often unapparent or mild (flu-like syndrome), although more severe forms can be observed, such as retinitis, encephalitis or hemorrhagic fever. In large epidemics, several hundreds of human deaths have been reported (Gubler, 2002).

Many mosquitoes (and other arthropods) are possible RVF vectors, including *Aedes* spp. with possible transovarian transmission and a bio-ecology well adapted to long term dry periods, and *Culex* spp., found in rice fields, irrigation canals, sewers, etc. Humans and ruminants can be infected either through mosquito bites or by direct contact with body fluids of viremic animals, including inhalation of infected aerosols released during abortions or slaughtering. Moreover, viremia duration is long enough to permit long-distance dissemination through cattle movements (transhumance, trade). This is the reason for international trade bans of live animals where RVF occurs. These bans had severe economic consequences for countries like Somalia and Ethiopia after the RVF epidemic in Yemen and Saudi Arabia in 2000 or more recently in the Sudan just before the Hadj festival.

Epidemics occur during the rainy season but temperature also plays an important role: transmission probably stops during the winter, even in irrigated-crop areas where surface water is continuously available.

Bluetongue (BT)

BT is a viral disease of ruminants which does not affect humans (Lefèvre *et al.*, 2003). There are 24 serotypes of the BT virus (BTV), all of which are transmitted by biting midges of the *Culicoides* genus (Ceratopogonidae). There is no trans-ovarian transmission in *Culicoides*. Long-distance dissemination of infected *Culicoides* midges by the wind is possible and was incriminated, for example, in the recent introduction of BTV-8 (BTV, serotype n°8) from Belgium to the UK (Hendrickx *et al.*, 2008).

BT is present on every continent. Until recently, it mostly was confined between 40°N and 35°. Different *Culicoides* species are involved in BTV transmission. In South East Asia, Africa, and the Mediterranean basin, *C. imicola* – a species complex - is considered to be the most important vector. Like other *Culicoides* species, it is sensitive to climatic conditions, particularly water and temperature. Its extension northward was probably a consequence of global warming and was accompanied by BT dissemination in northern Africa and southern Europe. This dissemination, associated with a longer seasonal vector activity, resulted in increased virus persistence during winter, and a higher risk of transmission by indigenous European *Culicoides* species. Therefore, the risk of BTV transmission was expanded over a larger geographical region (Purse *et al.*, 2005). Evidence of this process was the wide dissemination of BTV-8 in 2006 and 2007 in northern and western Europe after an initial outbreak (of unknown origin) in the Maastricht region: *C. imicola* was not involved in this BT epidemic, the largest ever recorded by the European veterinary services (Saegerman *et al.*, 2008). This BTV-8 epidemic continues to cause major restrictions in ruminant trade in Europe, in addition to measures

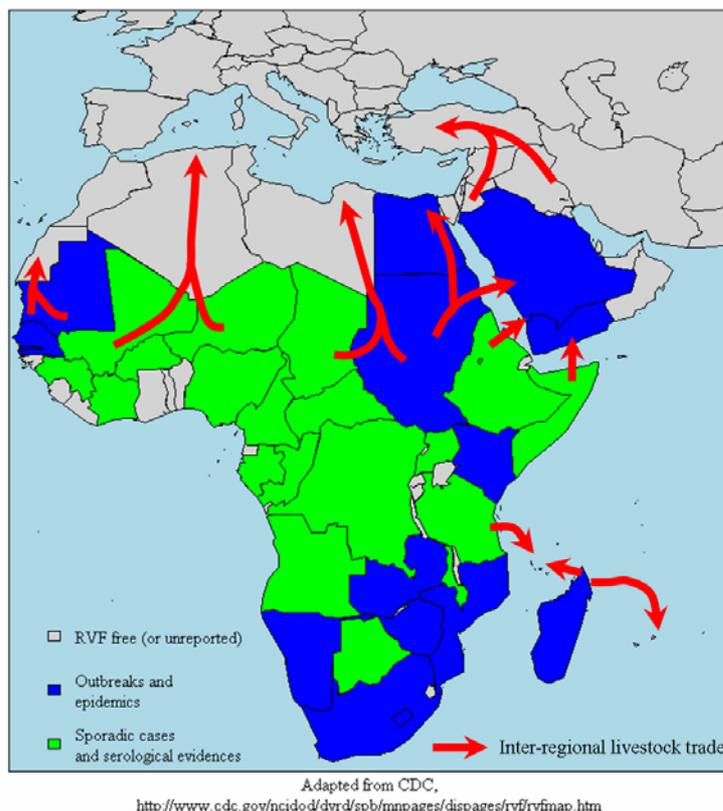


Figure 1 RVF status of African and Middle Eastern countries and inter-regional livestock trade

related to other BT serotypes (Fig. 2). Direct and indirect economic losses amount to hundreds of millions of Euros. For example, in addition to national contributions, the European Commission dedicated € 130 million for BT control measures in 2008.

What can be expected from climate and global change?

Rift Valley fever

On the eastern coast of Africa, RVF epidemics are closely related to *El Niño* events which result in heavy rainfalls (Black, 2005), thus allowing the massive proliferation of RVF vectors. This phenomenon has been recognised for a long time and predictive models have been developed using remotely-sensed surface sea temperature and normalized difference vegetation index (Linthicum *et al.*, 1987). These models are now used in early warning systems (Anyamba *et al.*, 2006), however, their geographical scope is limited and they cannot be used in other African regions (e.g., Sudan, Egypt, Mauritania) where no correlation between excessive rainfall and RVF outbreaks has been demonstrated.

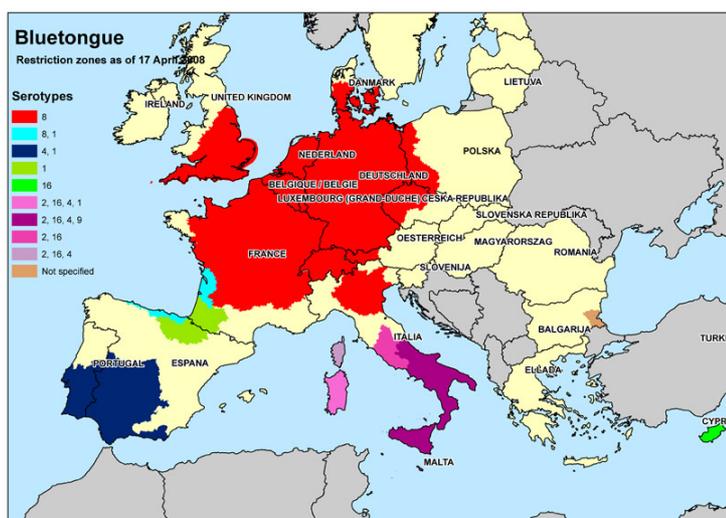


Figure 2 Restriction zones for ruminant movements related to bluetongue infection in Europe as of 17th April 2008

http://ec.europa.eu/food/animal/diseases/controlmeasures/bluetongue_en.htm

Reports of the intergovernmental panel on climate changes (Boko *et al.*, 2007) predict that extreme climatic events such as *El Niño* will become more frequent.

Moreover, deep changes in the African ecosystems are expected with consecutive (i) breaks in the unstable epidemiological equilibriums of many vector-borne diseases, and (ii) more intense livestock movements. These changes probably will result in more frequent RVF epidemics with a wider dissemination. Due to inter-regional livestock trade movements (Fig. 1), northern Africa, the Middle East, and consecutively, Europe will be at a higher risk for RVF.

Trade globalization and the development of international travels also will favour the dissemination of some RVF vectors (see e.g., Reiter and Sprenger, 1987). Higher temperature may increase vector competence of mosquitoes for RVF (Turell, 1989). Climatic and other environmental changes will cause variations in their habitat suitability, both in time and space. Finally, there is an increased risk of RVF introduction into new agro-ecosystems, followed by local virus amplification and installation with vectors of exotic or endemic origins.

Bluetongue

Bluetongue is endemic in sub-Saharan Africa with economic losses limited to countries using exotic sheep breeds (southern Africa). Climate and environmental changes might deeply alter the transmission pattern and disrupt the local epidemiological equilibrium, as is expected for malaria (Boko *et al.*, 2007).

The demographic growth of large cities and more generally, the increase of human populations in northern Africa and the Middle East will result in more intense livestock aggregation around market areas, the merging of populations from different origins, and increased trade from sub-Saharan Africa to these regions. Regarding vector competence and habitat suitability, the same made about RVF apply to BT (Wittman and Baylis, 2000). In the long run, the present European BTV-8 epidemic may only be the first of a series of *Culicoides*-transmitted outbreaks affecting northern Africa, the Middle-East and Europe involving different serotypes of BTV as well as other viruses of major veterinary importance such as African horse sickness.

How to deal with change and uncertainty?

Bluetongue and Rift Valley fever are two examples of emerging; vector-borne livestock diseases with strong economic or public-health consequences. There are many other such diseases and the list may grow with the possible emergence of new pathogens, or the crossing of species barriers by existing pathogens (Mahi and Brown, 2000).

To address this issue, we need to understand and model underlying epidemiological mechanisms at the agro-ecosystem level, and evaluate the impact of climate and environmental changes. An integrated approach must be adopted that combines field and laboratory studies on vector biology and ecology, the collection of veterinary and human public-health data and associated risk factors (including economic and sociological), remote sensing of environmental features (landscape, land cover, and land use), and statistical and mathematical modelling.

The EDEN project (Emerging diseases in a changing European environment) is funded by the European Commission. It is an example of what can be achieved in terms of scientific results, capacity building, networking and innovation

potential (see e.g., Ponçon *et al.*, 2007, Sumilo *et al.*, 2007). Outputs of this research are disease-transmission models, risk maps and catalogues of agro-ecosystems at high disease risk, as well as guidelines to design disease monitoring and early warning systems implemented by public-health agencies.

Based on this kind of knowledge, disease and vector surveillance networks may be implemented or reinforced, including modern laboratory facilities to diagnose and characterise vectors and pathogens, investigate vector competence, etc. Capacity building and maintenance are important issues which must be taken into account, especially in developing countries. Regional and international coordination also is very important to consider.

Finally, public-health policies must be designed or updated using these methods and tools, including integrated surveillance and control strategies, preparedness, and general-audience information. Again, these policies must be designed and shared at a regional and international level, vector-borne diseases being excellent examples of transboundary diseases.

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References

- Anyamba A, Chretien J, Small J, Tucker CJ, Linthicum KJ 2006. Developing global climate anomalies suggest potential disease risks for 2006-2007. *International Journal of Health Geographics* 5: 60 doi:10.1186/1476-072X-5-60.
- Black E 2005. The relationship between Indian Ocean sea-surface temperature and East African rainfall. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences* 363: 43-47.
- Boko M, Niang I, Nyong A, Vogel C, Githeko A, Medany M, Osman-Elasha B, Tabo R, Yanda P 2007. Africa. Climate change 2007: impacts, adaptation and vulnerability *in* Contribution of working group II to the fourth assessment report of the inter-governmental panel on climate change, Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (Eds.), Cambridge University Press, Cambridge UK, 433-467.
- Gubler DJ 2002. The global emergence/resurgence of arboviral diseases as public health problems. *Archives of Medical Research* 33: 330-342.
- Hendrickx G, Gilbert G, Staubach C, Elbers A, Mintiens K, Gerbier G, Ducheyne E 2008. A wind density model to quantify the airborne spread of *Culicoides* species during north-western Europe bluetongue epidemic, 2006. *Preventive Veterinary Medicine*, in press.
- Lefèvre P, Blancou J, Chermette R 2003. Principales maladies infectieuses et parasitaires du bétail: Europe et régions chaudes, Paris, Lavoisier, Tec & Doc.
- Linthicum KJ, Bailey CL, Davies FG, Tucker CJ, 1987. Detection of Rift Valley fever viral activity in Kenya by satellite remote sensing imagery. *Science* 235: 1656-1659.
- Mahy BW, Brown CC 2000. Emerging zoonoses: crossing the species barrier. *Revue Scientifique et Technique* 19: 33-40.
- Ponçon N, Balenghien T, Toty C, Ferré JB, Thomas C, Dervieux A, L'ambert G, Schaffner F, Bardin O, Fontenille D 2007. Effects of local anthropogenic changes on potential malaria vector *Anopheles hyrcanus* and West Nile virus vector *Culex modestus*, Camargue, France. *Emerging Infectious Diseases* 13: 1810-1815.
- Purse BV, Mellor PS, Rogers DJ, Samuel AR, Mertens PPC, Baylis M 2005. Climate change and the recent emergence of bluetongue in Europe. *Nature Reviews Microbiology* 3: 171-181.
- Reiter P, Sprenger D 1987. The used tire trade: a mechanism for the worldwide dispersal of container breeding mosquitoes. *Journal of the American Mosquito Control Association* 3: 494-501.
- Saegerman C, Berkvens D, Mellor P 2008. Bluetongue epidemiology in the European union. *Emerging Infectious Diseases* 14: 539-544.
- Sumilo D, Asokliene L, Bormane A, Vasilenko V, Golovljova I, Randolph S 2007. Climate change cannot explain the upsurge of tick-borne encephalitis in the Baltics. *PloS ONE* 2: e500.
- Turell MJ 1989. Effect of environmental temperature on the vector competence of *Aedes fowleri* for Rift Valley fever virus. *Research in Virology* 140: 147-154.
- Wittmann EJ, Baylis M 2000. Climate change: effects on *Culicoides*-transmitted viruses and implications for the UK. *Veterinary Journal* 160: 107-117.

Distribution of ticks (and tick-borne diseases) in relation to climate change. Illustration with soft and hard ticks

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Introduction

With around 900 described species across the world, ticks (Ixodida) are obligatory hematophagous parasites that are vectors of a wide range of human and livestock diseases, including borreliosis, tick-borne encephalitis, ehrlichiosis, babesiosis, theileriosis, Crimean-Congo haemorrhagic fever, and anaplasmosis (Jongejan and Uilenberg, 2004). In addition, the feeding activities of ticks can cause toxicosis, impair the quality of cattle hides and create wounds that allow entry for other parasites. Ticks are composed of three families, the hard ticks (Ixodidae, ca 700 species), which have thick outer shells, the soft-ticks (Argasidae, ca 200 species) which have a membranous outer surface and the Nuttalliellidae containing only one species. Tick development cycle encompasses 3 stages once eggs have hatched: larvae, nymph and adult. Hard ticks feed on hosts once per stage, for long periods of time (few days), and females lay one batch of eggs before dying. In contrast, soft ticks typically live in crevices and emerge briefly to feed, with several short meals per stage (less than one hour) and several nymphal stages (from 4 to 9) feeding once or twice each. Females lay several batches of eggs. Soft ticks have been the subject of far less studies than hard ticks.

As evidence of global climate changes is accumulating (Intergovernmental Panel on Climate Change, synthesis report 2007 <http://www.ipcc.ch/ipccreports/ar4-syr.htm>), it is predicted to affect human and animal health in many ways, with its nature, magnitude and timing still to be characterized (McMichael *et al.*, 2006). One of the main concerns is the modification of species distribution (geographic range) of vectors, reservoir hosts and pathogens. In this context, scientists are challenged by the detection of distribution changes and the attribution of changes to the effects of anthropogenic climate change (Kovats *et al.*, 2001). Many studies have been conducted on mosquitoes and mosquito-borne diseases (e.g. Epstein, 1998, Hopp, 2001), but ticks and tick-borne diseases are now getting more and more consideration.

The aim of this paper is to give an overview of the knowledge and approaches used to study the link between tick - or tick-borne diseases - distribution and climate changes. We will first depict the criteria that are theoretically required to attribute change in distribution to climate change. Second, we will investigate the biological traits of species that are sensitive to climate that could influence its distribution. Third, we will present the main empirical evidence for shift in distribution and finally we will discuss the different modelling approaches that are used to predict future distribution shift. Ideally, climate effects on vector-borne diseases should take into account the transmission system as a whole, including vectorial capacity, infection rate of vectors, reservoir, and humans (Kovats *et al.*, 2001). However, it is often easier to measure such changes on the vectors, thus, in this paper we will primarily focus on the tick rather than the disease distribution. Examples from hard – mostly European - and soft – mostly African – ticks will be used to illustrate our discussion.

How can change in distribution be attributed to climate change?

The importance of climate has been demonstrated as a limiting factor in the distribution of tick vectors and it is often considered that, on a continental scale, tick distribution is mainly driven by climate (e.g. Ogden *et al.*, 2005). Consequently, it is tempting to attribute observed large-scale distribution change to climate change, but many other factors can affect species or disease distribution. For instance, socio-economical changes that occurred recently in Central European countries significantly increased the exposure of humans to tick bites and thus the incidence of tick-borne encephalitis transmitted by *Ixodes ricinus* (Sumilo *et al.*, 2007). Large-scale reforestation has fostered an explosive growth of deer population, which in turn stimulated the spread of the Lyme disease vector *Ixodes scapularis* in north-eastern USA (Spielman, 1994). As for other biological processes, causal relationship cannot always be deduced from correlation.

Kovats *et al* (2001) suggested three minimum requirements to be met before considering ‘causal’ relationship between climate change and change in human health outcomes (that can be extended to animal diseases): (i) meteorological evidence of climate change based on more than single site of short-time period evidence; (ii) evidence of biological sensitivity to climate, which is usually demonstrated in laboratory; and (iii) evidence of entomological and/or epidemiological change in association with climate change. Factors other than climate that may have an influence on distribution patterns should ideally be tested as well. Rogers and Randolph (2006) highlighted the need to cautiously consider the causal relationship between climate change and any observed change. They suggested that such relationships might reasonably be considered if the climate change has “occurred at the right time, in the right place and in the ‘right’ direction”.

Sensitivity of biological traits to climate that could affect tick distribution

Ticks are adapted to a life that continually swings between feeding and not feeding, thus are dependant on off host survival and questing behaviour. Laboratory studies reveal the relationship between some climatic parameters and tick ability to survive or develop. *Ixodes* spp ticks have been shown to be very sensitive to temperature and humidity (see the summary table in Lindgren and Jaenson, 2006), with a humidity rate of > 85% and temperature above 10°C being optimum for tick development. Winter survival appears to be dependant on winter minimum temperature and duration of exposure to cold (Ogden *et al.*, 2004). In the field, snow cover might provide a protection against extreme low temperature. During host-seeking periods, ticks are very sensitive to humidity as they need to maintain a stable water balance. *I. ricinus* requires a humidity of at least 80-85% at the ground to survive. However, such conditions can be provided by microclimate that is dependant on vegetation (Gray, 1991, Randolph and Storey, 1999).

Temperature and relative humidity also influence the life cycle of the Argasid ticks (Morel, 2003). Regarding development cycle duration and success, high temperatures ranging from 22°C to 32°C and relative humidity up to 75% decrease prefeeding and premoulting durations for all stages, adult oviposition and egg incubation periods. Similarly, mean daily egg production and hatching success are increased with high temperatures and humidity (Loomis, 1961, El Shoura, 1987, Phillips and Adeyeye, 1996). Regarding general survival at all stages, Argasids are xerophilic and can survive in more extreme conditions than hard ticks (relative humidity down to 20% and critical temperature up to 75°C) thanks to the peculiar composition of their oilskin (Morel, 2003). Nevertheless, for most Argasids, the absence of a hard shell and their development optima make them constrained by external conditions. As a consequence, those ticks colonize underground or protected habitats like burrows, dugouts or trenches, caves, litters or nests (endophilic type) (Morel, 2003). Such habitats buffer the external climatic variations and thus delay the influence climate may have on the internal microclimate. This is a critical point to understand climate influence on soft tick distribution.

Climate can also affect tick distribution by indirect effects through a chain of environmental process on habitat and host availability (Jones *et al.*, 1998). Also, climate change may affect tick activity which in turn will modify disease risk. A recent study suggests that increased global warming will probably extend *I. ricinus* activity season more into the winter months and a greater proportion of the tick population may be active at this time than at present (Gray, 2008). Questing *I. ricinus* have frequently been found on open land in Germany in November and December 2006 and again in January 2007, a fact which had not been noted in former years (Süss *et al.*, 2007). In other regions, risk of tick-borne diseases might be diminished with repeated droughts or severe floods. In addition, variations in weather condition influence host behaviour and thus exposure to tick bites.

Soft ticks are generally believed to show regular activity across seasons because their endophily damps out climate variations and because most of them are distributed under cool oceanic climates in the tropics or in the Mediterranean region. However, in Europe, *Argas reflexus* has adapted to strong seasonal variation of climate: oviposition is restricted to the summer months and engorged females enter diapause in winter because eggs cannot successful overwinter (Dautel and Knülle, 1998). Similarly, in Spain, *Ornithodoros erraticus* may colonize pig pens and transmit African Swine Fever by feeding on pigs all year round. However, they do not feed until pig pens reach a temperature of 13-15°C (Oleaga-Pérez *et al.*, 1990). Under global warming, such limiting summer or winter temperatures could change, which in turn may modify pathogen transmission patterns. Finally, even if most soft ticks are largely ubiquitous for hosts as a consequence of their endophily (Morel, 2003), some species like *Argas arboreus* specifically parasitize migratory birds and synchronize their activity with the nesting and breeding season of their avian hosts (Belozarov *et al.*, 2003). Such behaviour may strongly be influenced by changes in bird population abundances, structures or movements related to climate.

Empirical observation of distribution change

The predicted responses to projected global warming are expected to be a northward range expansion (in the north hemisphere) and a higher altitude range of species. Several studies relate these findings, however, other causes of changes are not always ruled out.

I. ricinus is distributed through a large latitudinal range, from 36°N in the Atlas Mountains of Tunisia (Zhioua *et al.*, 1999) to 65°N in Sweden (Talleklint and Jaenson, 1998). Recently, *I. ricinus*, and agent of tick-borne diseases have been found in higher latitudes in Sweden (Lindgren *et al.*, 2000) and altitudes in Central Europe (Daniel *et al.*, 2003, Zeman and Benes, 2004, Danielová *et al.*, 2006). The North American situation is quite different, as the dramatic expansion of *I. scapularis* is primarily attributed to reforestation (Spielman, 1994), but global change could also affect its northern distribution limit (Ogden *et al.*, 2006). Increased incidence of Lyme borreliosis – rather than expansion of its distribution - in some parts of Europe has been detected. In southern Sweden, increased incidence following mild winters and during war, humid summer has been observed (Bennet *et al.*, 2006). Substantial rise in the prevalence of Lyme borreliosis in western Germany over 10 year period were noticed (Kampen *et al.*, 2004). Causes for this increase are still in debate between climate change, ecological conditions, wildlife management, and human behaviour.

Data on soft tick distribution are rare and were mainly collected in the 1940-1960's period (Morel, 2003). However, some recent studies also indicate modification in geographical range linked to global changes. In West Africa, the geographic distribution of the tick-borne relapsing fever (due to the spirochete *Borrelia crocidurae*) has been thought to be typically limited to the Sahel and Saharan regions where the tick vector, *Ornithodoros sonrai*, is distributed.

Examination of burrows infested with ticks and blood samples from small mammal reservoirs has revealed a significant spread of the known areas of distribution of both, the vector and the pathogen. This phenomenon has been linked to the persistence of sub-Saharan drought and the corresponding movement of the 750-mm isohyetal line (i.e. the line joining points of equal precipitation on a map) towards the South, from 1970 to 1992, which allowed the vector to colonize new areas in the Sudan savanna of West Africa (Trape *et al.*, 1996). At the same time, *O. sonrai* distribution has been decreased in the East. Indeed, a correlative approach showed that *O. sonrai* distribution may be linked to small winter rainfall as an indicator of oceanic conditions in West Africa. Now, the abundance and the duration of these rainfalls greatly decreased from 1950 to 1990, and even more so in the eastern part of West Africa where they completely disappeared (Vial, 2005). In some parts of Central Asia, the infection rate of *Ornithodoros tholozani* with *Borrelia persica* strongly decreased although the distribution range of the tick vector did not significantly shrink (except for local variation). This observation may suggest a higher mortality of infected ticks under unfavourable conditions. However, no conclusion has yet been drawn regarding ecological, climatic or human-driven causes (Vasil'eva *et al.*, 1990, 1991).

Prediction of the influence of climate change on tick distribution

Prediction of the influence of climate change on tick (or tick-borne disease) distribution is based on modelling vector and climate data. Advent of geographic information system software has facilitated data mapping. As well, climate data has become increasingly available thanks to ground and satellite-based sensors. The limitation often lies on tick data that derives from a variety of different non standardized sampling methods over a large spatial scale. Monitoring effort is mostly higher where the diseases are most prevalent, making distribution boundaries not as precise (Kovats *et al.*, 2001). Furthermore, a "baseline" distribution before climate change is theoretically needed to detect a change, which is rarely available.

Modelling strategies can be classified into two approaches (Kitron and Mannelli, 1994): (i) pattern-matching (or statistical or associative) models and (ii) process-based (or mechanistic or biological) models. In the first approach, the current observed distribution is matched to current climate variables in a statistical framework, which has its foundation in ecological niche theory. Then, the projected change in climate variables is applied to the distribution by interpolation or extrapolation. The second approach is more biologically based and seeks to describe the processes involved and how they can be affected by climate. The recorded distribution is not used when building the model, but is used to test its validity. Because in process-based models, one needs to know how all parameters are affected by climate, pattern-matching models are usually better when biological knowledge is incomplete (Rogers and Randolph, 2006). In both approaches, the current distribution brings crucial information on the basic distribution of the vector given the actual climatic conditions. The drawback is that the current distribution has often been affected by other things than climate, so that there is no accurate measure of the original geographic extent of the vector distribution. Bearing this in mind, it is still the best available.

Example of pattern-matching models to predict tick distribution

To date, attempts to predict *Ixodes* spp – or tick-borne diseases - distributions in relation to climate change have largely been based on the associative approach. With such an approach, Brownstein *et al* (2005) found that expansion of the northern range of the climatic suitable habitat for *I. scapularis* would significantly occur between 2050s and 2080s. However, some tick-borne pathogen systems might not all benefit from climate change. Randolph and Rogers (2000) found that future rises in temperature and decreases in moisture in the summer, could contract the tick-borne encephalitis virus distribution into higher latitudes and higher altitudes. The reason behind this finding lies in the transmission cycle of the virus that depends on a particular pattern of tick seasonal dynamics. Using a database of African tick occurrences, potential for invasions of 73 species of ticks from Africa to other locations was investigated on the basis of current and projected climatic conditions by Cumming and van Vuuren (2006). They found that habitat suitability for most African tick species increased both within Africa and overall in all scenarios. No tick species extinctions occurred in any models, but three Ixodidae species' habitat suitability decreased in all scenarios. Some of the *Hyalomma* species that are currently in the dry environment of northern Africa are predicted to have the largest increase in suitable habitat. Only two soft tick species were taken into account, *Ornithodoros moubata* and *Otobius megnini*. Both were favoured in all scenarios but their ranges of expansion were very small. For the first species, the correlation between tick presence and climate seemed weak. Indeed, external climate variables may be not well adapted to explain the distribution of this complete endophilic tick. Overall, this study suggests that the tick community might be affected, which in turn will influence food webs dynamics and pathogen-tick interaction (Cumming and Guégan, 2006). Similarly, Olwoch (2007) studied the climate suitability for 30 *Rhipicephalus* species in Africa and found that most of the species showed potential range expansion with also an increase in tick species richness in the south-western regions of the sub-continent.

Prediction of tick distribution based on ecological niche modelling has also been used. In this approach, vegetation indices, such as Normalized Difference Vegetation Index (NDVI), are used in addition to climate data to define habitat. Estrada-Peña and Venzal (2006) studied changes in habitat suitability for *I. ricinus* in Europe between 1900 and 1999. They found that habitat suitability increased because of climate change in specific locations of limited extend, while others decreased. The same authors (2007) sought to develop a definition of climate niche of six species of ticks in the Mediterranean region and tested the sensitivity of the niche to the variations in climate. Increase in temperature and decrease in rainfall resulted in the extension of suitable habitat to the North for 3 species (*Rhipicephalus bursa*,

Rhipicephalus turanicus and *Hyalomma marginatum*). They suggest that the margins of species range are generally more sensitive to climate change than the core.

Example of process-based models to predict tick distribution

Process-based models to test broad-scale predictions about tick response to climate change are still scarce due to the poor knowledge on basic tick ecology, physiology and population dynamics. In addition, the lack of complete phylogeny impairs comparative studies between tick species (Cumming and van Vuuren, 2006). Population dynamic models of *Ixodes* ticks have been mostly developed by Randolph *et al* (2002) and Ogden *et al* (2005). On this basis, Ogden *et al* (2006) investigated the effect of climate change on the range of *I. scapularis* in Canada. They conclude that the geographic range of *I. scapularis* may expand significantly northwards as early as the 2020s.

The prediction of climate effect on diseases can be investigated through the modelling of the basic reproductive number, R_0 , which corresponds to the number of new cases a single infected case will cause in a naïve population. If R_0 lies below 1, the disease will decline, whereas, if R_0 is above 1, the disease will spread. The infection will spread if $R_0 > 1$. This has been mostly applied with mosquito-borne diseases rather than tick-borne diseases (Rogers and Randolph, 2006). The effect of global warming on vector-borne diseases overall can be positive or negative, depending of the climatic dependant variation of each variables used in the models.

Conclusion

There is a high likelihood that climate will change, which in turn will affect to some degree the distribution of ticks and tick-borne diseases. Even small increases in disease distributions may expose new host populations which lack acquired immunity, often resulting in more serious clinical disease. Climate change will also affect tick abundance or seasonal pattern, in a way that will probably vary according to where it occurs. However, for some diseases, climate change effect might be minor compared to changes in risk factors such as translocation of animals, alteration of habitats and ecosystem, or change in production systems (Rogers and Randolph, 2006). Even if at a global scale, many studies point out that although the risk for vector-borne diseases and tick-borne disease in particular may increase, the changes will display great local spatial variation. Thus, we still need to increase our effort in understanding and measuring factors affecting distribution, taking into account also not only the physical environment, but also the economic and sociological environment.

Implications

Understanding the major factors governing tick distribution and being able to predict changes in distribution will help in developing sound, ecological based control measures.

References

- Belozerov VN, Van Niekerk DJ and Butler HJ 2003. Population structure of *Argas arboreus* (Acari: Argasidae) ticks associated with seasonally abandoned mixed heronries, dominated by cattle egrets (*Bubulcus ibis*), in South Africa. Onderstepoort J Vet Res 70, 325-330.
- Bennet L, Halling A and Berglund J 2006. Increased incidence of Lyme borreliosis in southern Sweden following mild winters and during warm, humid summers. European Jnl of Clinical Microbiology and Infectious Diseases 25, 426-432.
- Brownstein JS, Holford TR and Fish D 2005. Effect of climate change on Lyme disease risk in North America. EcoHealth 2, 38-46.
- Cumming GS and Guégan J-F 2006. Food webs and disease: Is pathogen diversity limited by vector diversity? EcoHealth 3, 163-170.
- Cumming GS and van Vuuren DP 2006. Will climate change affect ectoparasite species ranges? Global Ecol Biogeography 15, 486-497.
- Daniel MD, Danielová V, Kříž B, Jirsa A and Nožička J 2003. Shift of the tick *Ixodes ricinus* and tick-borne encephalitis to higher altitudes in Central Europe. European Journal of Clinical Microbiology and Infectious Diseases 22, 327-328.
- Danielová V, Rudenko N, Daniel M, Holubová J, Materna J, Golovchenko M and Schwarzová L 2006. Extension of *Ixodes ricinus* ticks and agents of tick-borne diseases to mountain areas in the Czech Republic. International Journal of Medical Microbiology 296, 48-53.
- Dautel H and Knülle W 1998. Seasonal oviposition and temperature requirements of eggs may limit northern distribution of European *Argas reflexus* (Acari: Argasidae). Journal of Medical Entomology 35, 26-37.
- El Shoura S 1987. Effect of temperature and relative humidity on the life cycle of *Ornithodoros (Pavlovskyella) erraticus* (Ixodida : Argasidae). Journal of Parasitology 73, 1102-1108.
- Epstein PR 1998. Biological and physical signs of climate change: Focus on mosquito-borne diseases. Bulletin of the American Meteorological Society 79, 409-417.
- Estrada-Peña A and Venzal JM 2006. Changes in habitat suitability for the tick *Ixodes ricinus* (Acari: Ixodidae) in Europe (1900–1999). EcoHealth 3, 154-162.
- Estrada-Peña A and Venzal JM 2007. Climate niches of tick species in the Mediterranean region: Modeling of occurrence data, distributional constraints, and impact of climate change. Jnl of Medical Entomology 44, 1130-1138.
- Gray JS 1991. The development and seasonal activity of the tick, *Ixodes ricinus*: a vector of Lyme borreliosis. Review of Medical and Veterinary Entomology 79, 323-333.

- Gray JS 2008. Minireview - *Ixodes ricinus* seasonal activity: Implications of global warming indicated by revisiting tick and weather data. International Journal of Medical Microbiology In Press.
- Hopp MJ 2001. Global-scale relationships between climate and the dengue fever vector, *Aedes aegypti*. Climatic Change 48, 441-463.
- Jones CG, Ostfeld RS, Richard MP, Schaubert EM and Wolff JO 1998. Chain reactions linking acorns to gypsy moth outbreaks and Lyme disease risk. Science 279, 1023-1026.
- Jongejan F and Uilenberg G 2004. The global importance of ticks. Parasitology 129, S3-S14.
- Kampen H, Rotzel DC, Kurtenbach K, Maier WA and Seitz HM 2004. Substantial rise in the prevalence of Lyme borreliosis spirochetes in a region of western Germany over a 10-year period. Applied and Environmental Microbiology 70, 1576-1582.
- Kitron U and Mannelli A 1994. Modeling the ecological dynamics of tick-borne zoonoses. In Ecological dynamics of tick-borne zoonoses (eds. DE Sonenshine and TN Mather), pp. 198-239, Oxford University Press, Oxford.
- Kovats RS, Campbell-Lendrum DH, McMichael AJ, Woodward A and Cox JSH 2001. Early effects of climate change: do they include changes in vector-borne disease? Philosophical Transactions of the Royal Society B: Biological Sciences 356, 1057 - 1068.
- Lindgren E and Jaenson TGT 2006. Lyme borreliosis in Europe: influences of climate and climate change, epidemiology, ecology and adaptation measures. In World Health Organization, Copenhagen.
- Lindgren E, Tälleklint L and Polfeldt T 2000. Impact of climatic change on the northern latitude limit and population density of the disease-transmitting European tick *Ixodes ricinus*. Environmental Health Perspectives 108, 119-123.
- Loomis BC 1961. Life histories of ticks under laboratory conditions (Acarina, Ixodidae and Argasidae). Journal of Parasitology 47.
- McMichael AJ, Woodruff RE and Hales S 2006. Climate change and human health: present and future risks. The Lancet 367, 859-869.
- Morel PC 2003. Ticks from Africa and the Mediterranean Basin in 1969. [French]. Published by CIRAD, CDROM.
- Ogden NH, Lindsay LR, Beauchamp G, Charron D, Maarouf A, O'Callaghan CJ, Waltner-Toews D and Barker IK 2004. Investigation of relationships between temperature and developmental rates of tick *Ixodes scapularis* (Acari : Ixodidae) in the laboratory and field. Journal of Medical Entomology 41, 622-633.
- Ogden NH, Bigras-Poulin M, O'Callaghan CJ, Barker IK, Lindsay LR, Maarouf A, Smoyer-Tomic KE, Waltner-Toews D and Charron D 2005. A dynamic population model to investigate effects of climate on geographic range and seasonality of the tick *Ixodes scapularis*. International Journal for Parasitology 35, 375-339.
- Ogden NH, Maarouf A, Barker IK, Bigras-Poulin M, Lindsay LR, Morshed MG, O'Callaghan CJ, Ramay F, Waltner-Toews D and Charron DF 2006. Climate change and the potential for range expansion of the Lyme disease vector *Ixodes scapularis* in Canada. International Journal for Parasitology 36, 63-70.
- Oleaga-Pérez A, Pérez-Sánchez R and Encinas-Grandes A 1990. Distribution and biology of *Ornithodoros erraticus* in parts of Spain affected by African Swine Fever. Veterinary Record 126, 32-37.
- Olwoch JM 2007. Climate change and the genus *Rhipicephalus* (Acari : Ixodidae) in Africa. Onderstepoort Journal of Veterinary Research 74, 45-72.
- Phillips JS and Adeyeye OA 1996. Reproductive bionomics of the soft tick, *Ornithodoros turicata* (Acari: Argasidae). Experimental and Applied Acarology 20, 369-380.
- Randolph SE and Storey K 1999. Impact of microclimate on immature tick-rodent host interactions (Acari : Ixodidae): Implications for parasite transmission. Journal of Medical Entomology 36, 741-748.
- Randolph SE and Rogers DJ 2000. Fragile transmission cycles of tick-borne encephalitis virus may be disrupted by predicted climate change. Proceedings of the Royal Society B: Biological Sciences 267, 1741-1744
- Randolph SE, Green RM, Hoodless AN and Peacey MF 2002. An empirical quantitative framework for the seasonal population dynamics of the tick *Ixodes ricinus*. International Journal for Parasitology 32, 979-989.
- Rogers DJ and Randolph SE 2006. Climate change and vector-borne diseases. Advances in Parasitology, Vol 62 62, 345-381.
- Spielman A 1994. The emergence of Lyme disease and human babesiosis in a changing environment. Annals of the New York Academy of Sciences 740, 146-156.
- Sumilo, Asokliene L, Bormane A, Vasilenko V, Golovljova I and Randolph SE 2007. Climate change cannot explain the upsurge of tick-borne encephalitis in the Baltics. Plos Biology 2, e500. doi:510.1371/journal.pone.0000500.
- Süss J, Klaus C, Gerstengarbe F-W and Werner PC 2007. What makes ticks tick? Climate change, ticks and tick-borne disease. Journal of Travel Medicine 15, 39-45.
- Tälleklint L and Jaenson TGT 1998. Increasing geographical distribution and density of *Ixodes ricinus* (Acari : Ixodidae) in central and northern Sweden. Journal of Medical Entomology 35, 521-526.
- Trape J, Godeluck B, Diatta G, Rogier C, Legros F, Albergel J, Pépin Y and Duplantier J 1996. The spread of tick-borne borreliosis in West Africa and its relationship to sub-saharan drought. American Journal of Tropical Medicine and Hygiene 54, 289-293.
- Vasil'eva IS, Ershova AS, Mansurov AA, Andrianov VA, Abidov ZI, Ibragimov IUI and Narmatov NN 1991. Changes in the village foci of tick-borne relapsing fever in Uzbekistan over a 10-year period. Parazitologiya 25, 323-329.
- Vasil'eva IS, Ershova AS, Vilisov GM, Khizhinskii PG, Shoismatulloev BSH, Ikbolov A, Nidoev S and Muninshoev M 1990. The current status of foci of tick-borne relapsing fever in the western Pamirs. Med Parazitol (Mosk) 6, 31-34.
- Vial L 2005. Eco-épidémiologie de la borréliose à tiques à *Borrelia crociduræ* en Afrique de l'Ouest. Thèse de Doctorat. Université Montpellier II Sciences et Technologies du Languedoc, France. 236pp.

Zeman P and Benes C 2004. A tick-borne encephalitis ceiling in central Europe has moved upwards during the last 30 years: possible impact of global warming? *International Journal of Medical Microbiology* 293, 48-54.

Zhioua E, Bouattour A, Hu CM, Gharbi M, Aeschlimann A, Ginsberg HS and Gern L 1999. Infection of *Ixodes ricinus* (Acari: Ixodidae) by *Borrelia burgdorferi* sensu lato in North Africa. *Journal of Medical Entomology* 36, 216-218.

Ticks and tick-borne diseases of livestock in North Africa, present state and potential changes in the context of global warming

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In Tunisia, as well as in the other North African countries, ticks are the most important ectoparasites of livestock; they are causing severe economic losses principally due to their ability to transmit pathogenic microorganisms. The North African tick fauna of livestock is mainly formed of 15 species (5 genera) which are showing, all over the region, different patterns of distribution that are related to their requirements for suitable climatic conditions and habitats. On this basis 4 groups of species could be recognised for the dominant tick species found in Tunisia

1. species restricted to humid zones (*Ixodes ricinus*),
2. species encountered in the humid, sub-humid and semi –arid zones (*Boophilus annulatus*, *Rhipicephalus bursa*, *Haemaphysalis punctata*, *Hae. sulcata* and *Hyalomma detritum*),
3. species of the arid zone (*Hyalomma dromedarii* and *Hyalomma impeltatum*),
4. ticks widely distributed (*Hy. m. marginatum*, *Hy. excavatum*, *R. sanguineus* and *R. turanicus*).

In Tunisia, the mean temperature is expected, under the influence of global warming, to attain in 2050, an increase of 2.1°C, and furthermore annual precipitation will decrease by 2030. Consequently, it is expected that aridity will gain both in intensity and in coverage by extending further north to the sub-humid and semi-arid zones. These important climatic changes will certainly affect both the distribution and activity of ticks. It is probable that tick species adapted to drought and able to settle in various bioclimatic conditions will emerge or become gradually more and more important in North Africa, for instance, *Hy. dromedarii* and *Hy impeltatum* might expand northwards. On the other hand, hygrophilic species such as *R. bursa* might face reduced habitat availability. Indeed, recent observations on the exclusive presence of *R. turanicus* in regions where *R. bursa* was previously easily collected might be related to this phenomenon.

Several bacterial, viral and protozoal tick-borne pathogens of livestock are known to occur in North Africa. Among these, piroplasmids (Apicomplexan protozoans) are one of the best examples of non contagious endemic diseases where distribution and incidence are conditioned by the presence and abundance of their vector ticks. Several species of piroplasmids belonging to the genus *Theileria* and *Babesia* are occurring in cattle and small ruminants in Tunisia, some of them like *Theileria annulata*, *Babesia bigemina*, *B. bovis* in cattle, and *B. ovis* in small ruminants are the causes of severe diseases and important economic losses. Global warming will certainly affect, through its effect on ticks, the epidemiology of these infections. However, other climatic driven factors must also be considered in this context, such as:

1. animal migration to northern zones affording better forage potential,
2. effects of malnutrition and micronutrient deficiencies on livestock immunity,
3. modification of herds population structure and dynamics,
4. deviation of financial capacities of stockholders toward animal feeding instead of disease control. Accordingly, the epidemiology of these diseases might face important changes and in particular:
 - i. emergence, in relation to modifications in tick abundance and seasonality, of endemic features to which stockholders are not used,
 - ii. emergence of pathogens in previously non infected regions,
 - iii. changes in transmission patterns and parasite population structures of usual pathogens borne by new tick vectors species.

The extent of losses or benefits that will be experienced by farmers facing these epidemiological stresses will depend on their capacity of adaptation which relies on the level of preparedness of the animal health authorities, emphasizing then the need to include, in addition to transboundary diseases, endemic non contagious diseases in the animal health package considered in mitigation and adaptation strategies coping with global warming.

New challenges for the control of helminth parasites of Scottish livestock in the face of climate change

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Introduction

There is a broad consensus amongst scientists that the global climate is changing. Recent weather in Scotland has consistently been between 1 °C and 4 °C warmer than the mean monthly data collected over a 30 year period between 1961 and 1990, while deviations from the long-term average rainfall have been marked, with unusual periods of both high and low rainfall. Changes have been reported concurrently in the incidence, pattern and geographical distribution of helminth parasitic diseases of Scottish ruminant livestock. It is anticipated that over the next decade, climate change in Scotland will feature greater extremes of weather conditions, with a general trend towards drier and warmer summers and wetter and milder winters. Even intermittent changes in temperature, precipitation, humidity and air movement may result in stable changes to the microclimate inhabited by the free living stages of parasitic helminths and their intermediate hosts. These conditions will have an effect on the survival and development of economically important endemic helminth parasites outside their livestock hosts. Furthermore, climate change could favour the biology of currently unimportant helminth parasites, leading to the emergence of disease, and may afford suitable conditions for the establishment of 'exotic' parasites. These effects could all impact on the health and welfare of Scottish ruminant livestock.

Climate change also influences the pattern of pasture growth, which in turn can influence the protein, energy, macroelement and trace element nutrition of ruminant livestock that graze on it, stocking densities and the length of the grazing period. These factors will compound the direct effects of climate change on helminth parasites.

This study aims to combine surveillance data with clinical observations and case studies on farms to investigate the changing pattern of endemic helminthoses in Scottish livestock in the context of climate change. The effects of climate change on endemic helminth parasites are illustrated by liver fluke infection, caused by the trematode flatworm, *Fasciola hepatica*, and parasitic gastroenteritis (PGE), caused by nematode roundworms, in particular *Nematodirus battus*, *Teladorsagia circumcincta* and *Haemonchus contortus*.

Clinical observations:

Fasciolosis (liver fluke disease)

The pattern of fasciolosis has changed in Scotland and this is widely believed to be as a result of climate change. Consequently, signs of the disease are now often unexpected or unrecognized, leading to substantial loss of production and serious animal suffering.

- (i) There has been a significant increase in the national prevalence of liver fluke infection in both cattle and sheep. Recent Scottish Veterinary Investigation Diagnosis Analysis (VIDA) reports clearly show the incidence of fluke infection has increased several fold, rising from 5% to 13% and 2% to 9% of all diagnosable submissions in cattle and sheep, respectively (<http://www.defra.gov.uk/corporate/vla/science/science-vida-intro.htm>).
- (ii) There has been a west-to-east spread of the disease, which was traditionally limited to the wetter and milder west of Scotland. Sub-acute fasciolosis is now routinely observed in sheep flocks in the east of Scotland, with signs of severe abdominal pain, collapse and death of sheep of all ages (Scott *et al* 2005) and poor reproductive performance in ewes (Sargison 2006), while chronic fasciolosis has become a common cause of ill thrift in both sheep and cattle (Sargison 2005).
- (iii) The seasonal pattern of fasciolosis, whereby subacute disease associated with summer infection of snails was traditionally seen between December and February, has become less defined with subacute fasciolosis now reported in late-summer (Veterinary Laboratories Agency [VLA] Surveillance Reports 2007, 2008).

The observed changes in the incidence, distribution and seasonal pattern of fasciolosis are thought to have arisen primarily as a result of the increased survival over winter and accelerated spring and summer development of the fluke's molluscan intermediate host, the pond snail *Galba (Lymnaea) truncatula*, resulting from a series of exceptionally wet years. Fluke numbers increase greatly during the development of miracidia, through sporocysts and rediae, to cercariae within the intermediate host. Small effects of climate change on the biology of *Galba* spp. snails can, therefore, lead to disproportionately large increases in the numbers of metacercariae available for the infection of ruminant livestock hosts.

Moisture is a pre-requisite for both *Galba* spp. snails and the free living miracidial and cercarial stages of *F. hepatica*, and the prevalence of fasciolosis is greatest following wet seasons. However, even during dry seasons, suitable

microhabitats exist on most Scottish farms for the maintenance of *F. hepatica* and consequent disease in certain cohorts of ruminant livestock. Increases in temperature associated with climate change can have a significant effect not only on *Galba* spp. snail development, but also on the rate of development of the free living stages of *F. hepatica*. Miracidia within the fluke egg only develop when ambient temperatures are above 10 °C. Miracidia hatch approximately 6 weeks after shedding when the average temperature is 15 °C but this can accelerate to 10 days at temperatures above 22 °C (Taylor *et al* 2007).

Parasitic gastroenteritis

- (i) The incidence of parasitic gastroenteritis, caused by gastrointestinal nematodes, has risen significantly in the past 5 years, from 8.8% of diagnosable submissions in 2001 to 15.8% in 2006 (VIDA).
- (ii) Heavy infestations of the brown stomach worm, *T. circumcincta*, are now routinely diagnosed in young lambs in spring in south east Scotland. Historically, spring teladorsagiosis was considered extremely unusual (Connan 1986) because of poor overwinter survival of infective larvae on pasture. *T. circumcincta* infection in lambs would only have been expected later in the summer as a consequence of the periparturient relaxation in immunity of the ewes and autoinfection of lambs (Sargison *et al* 2002).
- (iii) There have been increasing reports over recent years of infection with the highly pathogenic blood-feeding nematode, *H. contortus* occurring on Scottish farms (VLA Surveillance Report, 2008; Wilson and Sargison 2008). Haemonchosis has traditionally been associated with warmer climates and was not believed to survive over winter on Scottish pastures. Previous outbreaks of haemonchosis in Scottish sheep flocks were attributed to the introduction of infected animals from the south of England.
- (iv) The seasonal pattern of infection with the intestinal nematode parasite *N. battus*, traditionally a parasite of young lambs in early summer, has changed such that nematodiosis is now also seen in older lambs into the autumn and winter. *N. battus* is a parasite of arctic origin and has, traditionally, thrived in cold climates, requiring a period of chilling for its eggs to hatch. However, a recent study has shown that this parasite has evolved such that substantial proportions of eggs can hatch without the need for chilling (van Dijk and Morgan, 2008). This evolutionary strategy would aid the parasite's survival and persistence in temperate climates and in response to climate change.

Climate change may influence the incidence of PGE through longer grazing seasons with shedding of nematode eggs by infested ruminant livestock later in the year than previously, and less time for the attrition of L₃ before turnout in the following spring. Furthermore, short periods of exceptionally warm winter weather have enabled nematode egg hatching and development to infective L₃ that did not previously occur. This might explain the appearance of *H. contortus*, a parasite which requires warmer conditions for survival on pasture than the other common nematode parasites of Scottish ruminant livestock. A similar situation has been reported in Sweden (Waller *et al* 2004).

Alternative explanations

The changing pattern of helminth parasitism that has been reported to date in Scottish livestock may have been confounded by a number of factors other than climate change. These may include:

- **Anthelmintic resistance** - in the past, anthelmintic control of helminth parasites of Scottish livestock was relatively straightforward for most farmers. However, despite adherence to basic helminth control principles, farmers are now observing significant detrimental production effects as a result of PGE and fasciolosis. Recent surveys show that anthelmintic resistance is now widespread in Scotland, affecting up to 80 % of lowland farms (Bartley *et al* 2003) and numerous cases of multi-drug resistance have been identified (Sargison *et al* 2007). There are also reports of emerging resistance to triclabendazole, the drug of choice to treat fluke infections, in the west of Scotland (Mitchell *et al* 1998).
- **Parasite evolution** – typically, helminth parasites have enormous biotic potential and are inherently genetically diverse. This provides them the ability to adapt rapidly to exploit new niches, which may occur as a result of environmental change. For example, parasite evolution has been proposed as the mechanism underlying the changes observed in *N. battus* (see above).
- **Farm management practices** – changes in subsidy support and low economic returns from livestock farming have generally resulted in reduced manpower and increasing flock sizes and inadequate handling facilities on farms.
- **Animal movements** – this has the potential to introduce parasitic diseases that are endemic to other areas as has been seen with certain outbreaks of *H. contortus* introduced to Scotland from the south of England, for example.

Future Work/Planned studies

The combination of clinical and surveillance observational data clearly shows that the incidence, distribution and seasonality of helminth parasites of Scottish livestock are clearly changing. However, at present we have no baseline data on species prevalences, population genetic structure or anthelmintic resistance status for the major helminth species. We aim to undertake a survey of UK sheep farms to identify the species present on each farm and the management practices in place. We also intend to apply state-of-the-art molecular genetic techniques to investigate the population structure and anthelmintic resistance status of the major parasitic helminths in Scottish livestock. This will provide the required baseline data in order to begin to monitor the changing situation with time. Moreover, the outcome

will enable some of the confounding effects of climate change, livestock management and parasite evolution that have been described to be unraveled.

Implications

We have observed changes in the incidence, distribution and seasonality of the helminth parasites affecting UK livestock. We aim to undertake a survey to provide baseline data on the parasite species prevalence, population structure and anthelmintic resistance status of UK farms. The data will be used to ensure that we provide informed advice to farmers concerning 'best practice' for effective parasite control and to allow us to gain a better understanding of the respective influences on the populations of these important pathogens in the face of climate change.

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References

- Bartley, D.J., Jackson, E., Johnston, K., Coop, R.L., Mitchell, G.B., Sales, J. and Jackson, F. 2003. A survey of anthelmintic resistant nematode parasites in Scottish sheep flocks. *Veterinary Parasitology* 117, 61-71.
- Connan, R.M. 1986. Ostertagiasis in young lambs in spring. *Veterinary Record* 119, 359-360.
- Mitchell, G.B., Maris, L. and Bonniwell, M.A. 1998. Triclabendazole-resistant liver fluke in Scottish sheep. *The Veterinary Record* 143, 399.
- Sargison, N.D. 2005. Chronic liver fluke. *UK Vet* 10, 60-63.
- Sargison, N.D. 2006. Investigation of poor scanning results. *UK Vet* 11, 52-56.
- Sargison, N.D., Jackson, F. and Scott, P.R. 2002. Teladorsagiosis in young lambs and extended post-parturient susceptibility in moxidectin-treated ewes grazing heavily contaminated pastures. *Veterinary Record* 151, 353-355.
- Sargison, N.D, Jackson, F., Bartley, D.J., Wilson, D.J., Stenhouse L.J. and Penny C.D. 2007b. Observations on the emergence of multiple anthelmintic resistance in sheep flocks in the south-east of Scotland. *Veterinary Parasitology* 145, 65-76.
- Scott, P.R., Sargison, N.D., Macrae, A.I. and Rhind, S.R. 2005 An outbreak of subacute fasciolosis in Soay sheep: ultrasonographic, biochemical and histological studies. *Veterinary Journal* 170, 325-331.
- Taylor, M.A., Coop, R.L. and Wall, R.L. 2007. *Fasciola hepatica*. In: *Veterinary Parasitology*. Eds: M.A. Taylor, R.L. Coop and R.L. Wall, Blackwell Publishing, Oxford, 201-208.
- Waller, P.J., Rudby-Martin, L., Ljungstrom, B.L. and Rydzik, A. 2004. The epidemiology of abomasal nematodes of sheep in Sweden, with particular reference to over-winter survival strategies. *Veterinary Parasitology* 122, 207-220.
- Wilson, D.M. and Sargison, N.D. 2008. The changing pattern of haemonchosis in Scotland. *Proceedings of the Sheep Veterinary Society* 30, In Press.
- van Dijk, J. and Morgan, E.R. 2008. The influence of temperature on the development, hatching and survival of *Nematodirus battus* larvae. *Parasitology* 135, 269-283.
- Veterinary Laboratories Agency Surveillance Reports 2007. *The Veterinary Record*, August 25, 249-252.
- Veterinary Laboratories Agency Surveillance Reports 2008. *The Veterinary Record*, February 9, 169 – 172.

Identification of QTL for tick resistance using a bovine F2 population in tropical area

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Introduction

In tropical regions, animal infestation by ticks (*Rhipicephalus (Boophilus) microplus*) causes a yield reduction and even the death of the most susceptible animals. Around a billion bovines, mainly located in tropical regions, could have their performance affected by various tick species, blood-feeding ectoparasites, that affects their hosts both directly and as a vector of viral, bacterial and protozoal diseases, with significant loss in production systems (Pegram *et al.*, 1991). In most Latin American countries the predominant species of bovine ticks is *Rhipicephalus (Boophilus) microplus*. In Brazil, Furlong *et al.* (1996) found that ½ Gyr: ½ Holstein cows showed a 23% milk production loss when they had an individual average of 105 ticks. A loss of 26% (526 kg) in milk production per lactation was estimated when Holstein cows were not treated against ticks (Teodoro *et al.*, 1998), besides an annual loss to the cattle industry of about 390 million kg of meat (US\$ 600 million) and 4 billion liters of milk (US\$ 700 million). Moreover, tick infestation causes a loss in leather quality - only 8% of the production is sold as high quality product.

Most tick control is routinely accomplished by the use of acaricides, however long term treatment has generated tick resistance to agrochemicals. The use of acaricides, besides representing an additional cost to farmers, leaves chemical residues that contaminate meat, milk and the environment. Vaccines have not been successful in solving the problem of tick infestation (Frish, 1999). Another alternative could be the use of naturally resistant animals in tropical regions so contributing to better sustainability of animal production systems. Genetic variation related to tick resistance between *Bos taurus* and *Bos indicus* breeds could be useful to identify genetically superior animals in order to reduce the costs of chemical treatments. The new tools provided by molecular genetics facilitate the identification of quantitative trait loci (QTL) for tick resistance for marker-assisted selection (MAS).

The objective of this study was to identify QTL associated with tick resistance/susceptibility in a bovine F2 population derived from the Gyr (*Bos indicus*) x Holstein (*Bos taurus*) crossing.

Material and methods

A F2 segregating population of 332 animals from a Gyr x Holstein crossing was produced by mating F1 females (50% Gyr: 50% Holstein) with F1 sires of the same genetic composition. The F1 animals were produced by embryo transfer of 27 Gyr cows and four Holstein sires resulting in a total of 150 F1 animals (males and females). Of those, only five F1 sires and 67 F1 females were used in the subsequent embryo transfer, avoiding inbreeding. The crosses were carried out in 1995 at the Embrapa Dairy Cattle Research Center, located on the State of Minas Gerais, Brazil.

To evaluate tick resistance, artificial infestations were made on the F2 animals in two seasons: wet season characterized by warm temperatures (season 1) and dry season characterized by cool temperatures (season 2). A total of 10,000 *Rhipicephalus (Boophilus) microplus* larvae were used to challenge each animal. Animals were grouped by age ranging from 13 to 15 months during experimental challenges. The number of female ticks, whose diameter ranged from 4.5 to 8 mm, was counted at the 21st day after infestation (Utech *et al.*, 1978).

Blood samples from the parental, F1 and F2 generations were collected. DNA was extracted from leukocytes using a modified phenol/chloroform method. Quality and concentration of DNA were determined with the Gene Quant Pro spectrophotometer (Habersham Biosciences). A total of 24 micro satellite markers were selected to cover chromosomes 15, 16, 17 and 27, with a marker interval of 20 cam. Markers were selected from the consensus map available at MARC/USDA (Meat Animal Research Center/ United States Department of Agriculture) database - <http://www.marc.usda.gov/genome/genome.html>. Markers were chosen based on their position in the map, multi-allelism and minimum of 50% heterozygosity. Microsatellite marker alleles were detected by capillary electrophoresis in the MegaBACE 1000 DNA sequencer (Amersham Biosciences). Primer combinations based on the range of the different alleles and on the fluorescent dyes were multiplexed and injected with volumes ranging from 0.5 to 4 µL depending on the primer signal intensity. ET-ROX 400 internal size standard (Amersham Biosciences) was added to each sample. Allele genotypes were analyzed with Fragment Profiler software (Amersham Biosciences) and data were exported to an Excel datasheet (Microsoft Corporation).

Analysis of variance (ANOVA) for tick resistance was performed using the PROC GLM function of SAS (SAS Institute, Cary, NC) employing the general model: $y = Xb + e$, where y is the dependent variable, X is the incidence matrix of the fixed effects of sex, coat color, infestation order, season, year/group and , as a covariate, age at counting. Tick counts were normalized using logarithmic transformation: $\log(\text{count of ticks} + 1)$.

QTL were identified by means of the regression analysis using the option for F2 data analysis available in the QTL Express software (Seaton *et al.*, 2002). The algorithm assumes Holstein and Gyr as lines one and two, respectively. F

was calculated to test the hypothesis of QTL segregation using a restricted model including year/group and coat color as fixed effects. A 95% and 90% significance level for the chromosome wise threshold was computed on the basis of 10,000 permutations. The statistical power of detecting QTL segregation is affected by sample size, genetic distance between markers and QTL, and QTL effect (Israel & Weller, 2002). Because neither QTL location nor effect is known a priori, rejecting putative QTL at a too stringent significance level defeats the purpose of a preliminary scan. Therefore, we have settled on the significance levels of 5% chromosomewise and 10% chromosomewise.

Results

From 2001 to 2007, a total of 332 F2 animals were evaluated in 18 age groups and counting results ranged from zero to 792 ticks/ animal. Mean value of tick count was 36.3 ± 62.2 . Estimated heritability of this trait in the F2 population was 0.21 ± 0.12 for the log of tick count +1. Analysis of variance found the effect of year/group and coat color on the log of tick count +1 (Table 1). Animals with whiter coat color showed less ticks than the dark ones. The effect of the season was significant ($P < .05$). The heat stress faced during the warm season can affect the immune response of the animal and therefore change the pattern of parasite resistance. The effects of sex, infestation order and age of animal at tick counting were not significant ($P > .05$).

Table 1 Analysis of variance indicating degrees of freedom (DF), F value and the level of significance for the log of tick count +1.

Effect	DF [#]	F value	P
Sex	1	1.77	0.1840
Coat color	2	13.93	<.0001
Infest	1	1.73	0.1894
Season	1	3.98	0.0466
Year/Group	26	9.38	<.0001
Age	1	0.34	0.5604

[#] Degrees of freedom

The association studies identified QTL regions for tick resistance. Interval mapping analysis indicated the presence of a QTL with additive effect in dry season ($P < .05$) for tick resistance on chromosome 27 that explains 4.8% of the total phenotypic variation. One putative QTL ($P < 0.10$) were also found on chromosome 15 for the dry season which explained 2.26% of the total phenotypic variation. The significant QTL are presented in detail in Figures 1 and 2.

Additional chromosomes are currently under investigation in order to cover the whole bovine genome. The fine mapping objective includes additional markers in regions where the QTL for tick resistance were detected could increase the level of significance for QTL as well as decrease the confidence interval. Thus, the viability of marker-assisted selection greatly increases because of the lower probability of a crossing over between marker and QTL, since the range will be shorter.

The future steps after QTL mapping involve validation of these results in commercial herds of dairy and beef cattle and fine QTL mapping favoring the identification of candidate genes involved with tick resistance.

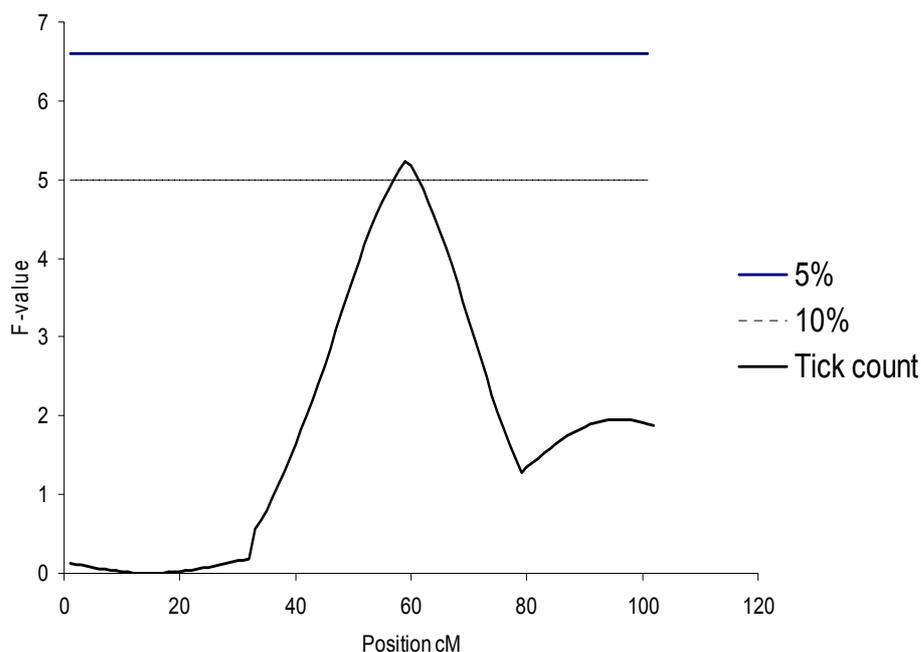


Figure 1 F-statistic profile for BTA15 for season 2. The F-statistic is plotted against the relative position in centimorgans (cM); horizontal solid line represents the 5% chromosomewise threshold for the trait and dashed line is the 10% chromosomewise significance threshold.

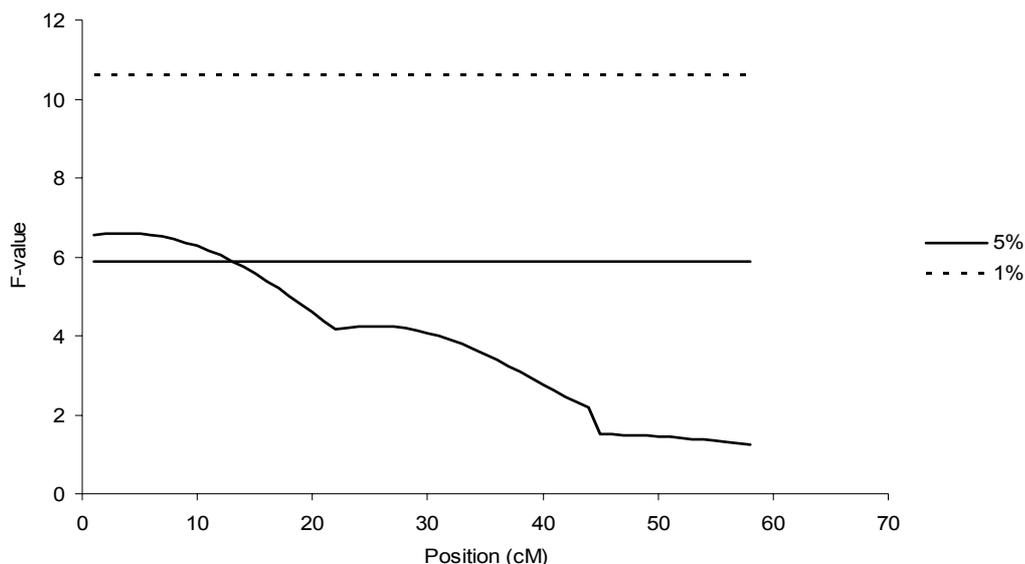


Figure 2 F-statistic profile for BTA27 for season 2. The F-statistic is plotted against the relative position in centimorgans (cM); horizontal solid line represents the 5% chromosomewise threshold for the trait and dashed line is the 1% chromosomewise significance threshold.

Conclusions

In summary, we have identified two new QTL regions on two chromosomes that influence tick resistance in a F2 population. Further investigation of this QTL will promote our understanding on the mechanisms of tick resistance in cattle.

Implications

The highly significant QTL regions affecting tick resistance will be further fine-mapped to shorter map intervals and facilitate the identification of the genes underlying the QTL. Selected genes will be sequence analyzed to look for the phenotype causative mutations. After validation, these haplotypes could be used in marker-assisted selection programs.

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References

- Frisch J.E. 1999, Towards a permanent solution for controlling cattle ticks. *International Journal Parasitology*. 29: 27-71.
- Furlong J., Deresz F., Matos L.L., Balbi M.V. 1996. The effect of cattle tick *Boophilus microplus* (Acari: Ixodidae) infestation on feed intake and milk yield of Holstein x Zebu crossbred cows. In: Congresso Panamericano de Veterinária, XV. Campo Grande 1996, 340.
- Israel, C.; Weller, J.I. 2002. Estimation of quantitative trait loci effects in dairy cattle populations. *J. Dairy Sci.*, 85:1285-1297.
- Pegram, R.G., James, A.D., Oosterwijk, G.P.M., Killorn, K.J., Lemche, J., Ghirotti, M., Tekle, Z., Chizyuka, H.G.B., Mwase, E.T. and Chizhyka, F., 1991. Studies on the economics of tick in Zâmbia. *Experimental Applied Acarology*, 12, 9-26.
- Seaton, G.; Haley, C.S.; Knott, S.A. 2002. QTL Express: mapping quantitative trait loci in simple and complex pedigrees. *Bioinformatics Applications Note*, 18:2, 339-340.
- Teodoro, R.L.; Lemos, A.M.; Madalena, F.E. 1998. Effects of ticks *Boophilus microplus* infestations on milk yield of *Bos taurus/Bos indicus* crosses. In *Proceeding of the 6th World Congress Genetics Applied to Livestock Production* 27, 137-180.
- Teodoro. R.L.; Pires, M.F.A.; Furlong, J.; Prata, M.C.A.; Machado, M.A.; Silva, M.V.G.B.; Célio Freitas, C.; Junqueira, M.M.; Verneque, R.S.; Peixoto, M.G.C.D.; Martinez, M.L. 2006. Estimativas de parâmetros genéticos e fenotípicos para a resistência a carrapatos e bernes em uma população experimental F2 Holandês X Gir. *Proceeding of the 43ª Reunião Anual da Sociedade Brasileira de Zootecnia*.
- Utech K.B.W., Wharton R.H., Kerr J.D. 1978, Resistance to *Boophilus microplus* (Canestreni) in different breeds of cattle. *Australian Journal of Agricultural Research*. 29: 885–895.

The challenge of sustainability to design the future dairy farms

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Introduction

After having sought to increase production, then the quality of products, today agriculture is facing the challenge of sustainability. The deterioration of the quality of water and soils, the loss of biodiversity, global warming and the decrease in nonrenewable natural resources resulting from the intense development of the human activities require reconsidering the ways of production in many sectors, particularly in agriculture. The question of the relationship between animal farming and the environment was recently highlighted by the FAO report "Livestock's Long Shadow" (Steinfeld *et al.*, 2006) which shows that livestock production, including very extensive systems, impacts the environment. Simultaneously, the increase in the population on earth and its standard of living tends to increase the demand for animal products. The challenge thus consists in solving this dilemma.

Today, a great diversity exists in dairy systems, not only between continents, but also within countries. This great diversity attests the economic viability of different strategies in dairy production, which is much less true in other livestock productions. This observation suggests that many evolutions are possible to find answers to the environmental issues without disturbing the economic profitability of these systems. However, complications arise due to the fact that dairy farms, generally located in temperate regions, will face climate changes. If in certain areas the climate change can be favourable to the growth of plants, others will likely be exposed to more difficult situations. The access to water resources will be reduced in many areas. The thermal stress will impact both animal and plant productions, in regions generally saved up today. The costs of energy and inputs will increase. This article discusses the new challenges of research to predict the evolutions of dairy systems and attempts a prospective exercise of probable scenarios for the dairy farms.

Future: How to integrate sustainability to design dairy farms?

To achieve this goal, the scientific processes must initially work out means to study, observe and describe dairy farms, then build indicators and methodologies to evaluate them and finally develop innovating strategies to improve these systems.

Developing a systemic approach to study the dairy systems

The first challenge for research consists in developing a systemic approach of the production systems. Establishing the most relevant frontiers of the system to be evaluated is a key issue. The recent evolution of livestock production consisted in a specialization of the animals, with better performance either in milk or in meat production. The underlying assumption was that increasing the animal productivity increases the profitability of the whole system. In dairy production the relation between milk production per cow and the economic and environmental performances of the farm is not obvious. In addition, historically, livestock had agronomic roles (manure, animal draught). The specialization of the systems of production partly made lose sight of the importance of these complementarities which must be recovered either within farm or with farm cooperation (Courdier *et al.* 2002, Andersson *et al.* 2005). It is thus necessary to develop a multidisciplinary approach to study livestock farms, at the farm scale but also probably at a larger scale (network of farms, watershed, region...).

Three different approaches are possible to study these dairy farms. The first one consists in observing the diversity of farming systems, surveying large sets of farms during several years with the same methodology (Institut de l'élevage 2005, Schils *et al.*, 2006). Such networks make it possible to evaluate the differences between the main types of farming systems but comprise significant biases related to the interactions between structures and systems of production. Moreover, they offer only a limited number of descriptors of the state of the system, very seldom with a dynamic approach. Finally these large databases are useful to get a good picture of farms, but are difficult to maintain and remain very expensive. The second approach consists in evaluating farming systems using experimentation. It is a good way to evaluate the interactions within a system, which will become essential to understand the behaviour and the performance of the systems studied. However, it requires measuring continuously a large set of parameters. This method is thus very expensive and can be used for a very limited number of experimental farms (Aarts *et al.*, 1992). Modelling constitutes a third way which makes it possible to study the behaviour of a large number of virtual systems, providing dynamic information on many variables difficult to measure for technical or economical reasons. Systems can be studied on long time scales, which is very difficult with experiments. Moreover, it is also possible to aggregate several entities to understand the impact of different individual behaviours on a territory. Several dairy farms models have been developed recently to evaluate economical and/or environmental performances: IFSM (Rotz and Coiner 2005), FASSET (Berntsen *et al.* 2003), MELODIE (Chardon *et al.*, 2007). The development of models should be connected with the system experiments described above. Models can be improved thanks to experiments, and can pinpoint the knowledge gaps to investigate.

Build new indicators adapted to the evaluation of these systems

To interpret the variables measured on production systems, it is essential to build powerful multicriteria indicators to evaluate sustainability (Girardin *et al.*, 1999). The construction of these indicators raises two major difficulties, on the one hand the frequent dilemmas opposing the various impacts and on the other hand the multiple productions of a dairy farm.

The complexity of multicriteria evaluations generally lies in the impossibility to find a common unit to balance the different indicators. Defining thresholds for each indicator, as well as aggregation rules (possibly based on fuzzy logics) to derive synthetic criteria is a way to overcome this. The approaches on environmental evaluation are often made difficult because there are strong tensions between the various stakes. It is not easy to conciliate economic and environmental aspects, but these tensions also exist between the different environmental stakes. There is very often a strong dilemma between the emissions to water or to the air, or between the aerobic and anaerobic processes which both increase the emissions of two green house gases: N₂O and CH₄. In more general terms, should we increase land use with a limited production and impact per hectare, or should we intensify the production in some areas while preserving natural spaces on the spared areas? It is clear that the answers to these questions are not universal. They will depend primarily on the territorial context which can bring to adapt the thresholds of emissions acceptability.

The environmental indicators generally represent impacts per unit of area or of product. This is particularly true with the life cycle assessment (LCA). If the impacts are often difficult to calculate and draw most of the attention, the choice of the denominator unit is essential (Bastianoni and Marchettini, 2000). It is generally admitted that calculating impacts per unit of area is more suitable for local impacts and impacts per unit of product for global impacts. But what products should be considered? For example, a dairy farm produces milk but also meat and often cereals in proportions varying according to the type of farm. Is it better to enter the sum of the various products in money value, in nutritional value (protein or energy) or to isolate the effect of dairy production by including the LCA results of beef production systems in the dairy systems? These different options change many conclusions on the impacts of the various systems (Cederberg and Stadig, 2003).

Large research orientations to improve the sustainability of the dairy systems

The efficiency of conversion of inputs to products is a major area of improvement in the search for more sustainable dairy systems. As far as dairy cows are concerned, the conversion rates of carbon or nitrogen in milk and meat are weak, respectively lower than 20% and 25% considering the whole life of the animal. This means that most of the carbon and nitrogen fed, nearly 80%, are excreted and that an improvement of the use of these elements will have little consequences on the amount excreted, but tends to decrease losses in urine. The efficiency of minerals is higher and it is possible to reduce considerably the excretion by a good control of supplies. The efficiency can be improved by an increase in milk yield or a reduction of the nonproductive periods, which means an increased longevity (Rotz *et al.*, 2005), an early first calving and a good persistency of lactation.

The second research area consists in optimizing the organisation of nutrient flows to reduce the risks on the environment and health. The low feed conversion of animals can be compensated at the farm scale. First, the efficiency of use of the wastes should be optimized. In many situations, a better utilization of manure requires both optimal conditions (weather, technique of application, type of manure) and moderate application rates. Secondly, optimizing the interactions between forage and crop production can help to avoid losses to the environment and to maintain the organic matter capital of soils. The use of legumes in roughage production is a way to regulate the nitrogen inputs. The presence of grassland in temperate regions, more favourable to biodiversity, conservation of soils and carbon storage than annual crops, must be encouraged in spite of the difficulty in managing this dynamic resource (Bassett-Mens *et al.*, 2007). It is also important to organize land use and to plan the agricultural activities in this landscape to take into account the heterogeneity of natural environment using possible benefit of naturalresources of landscape (Tenail and Baudry, 2005). Finally, the circuits of the animals indoors and outdoors, as those of the wastes, must be organized to reduce the risks of diseases (Faye *et al.*, 1999).

The third area of research has to reconsider the current orientations on the choice of the type of cows in the dairy herds of tomorrow. The very high specialization of dairy cows during the last decades resulted in forsaking other criteria of breeding and could handicap the dairy systems in the long term. The orientation towards very different dairy systems further evoked clearly encourages the selection of optimal cows for each specific system (Bryant *et al.*, 2005). The place of dual purpose cows can be re-examined in particular for economic and environmental reasons.

Some scenarios for future dairy farms

This exercise of futurology is difficult and must in no making forget that the choices of the systems of production in breeding are very dependent on the territorial context, on politic decisions, but also on farmers and their representation of their activity. Considering the diversity of contexts, it is likely that several types of dairy farms will exist. In this paper, four of them are proposed and discussed considering economical efficiency with different options in the environmental dilemmas mentioned above.

The high technology landless dairy farm

In this landless system, dairy specialization is maximal with very high yielding dairy cows, lengthened lactations, and optimized food. The rations are complex mixes of forages produced without irrigation and of by-products of the food and biofuel industries. Many additives are required to meet the complex needs of the very high yielding dairy cows. The wastes are totally collected and treated in a methanisation system to reduce the losses of methane and odours. The feed production and the waste applications are managed optimally by a cropping farm coupled with the dairy farm. The high consumption of energy is compensated by renewable forms of energy (solar panels, methane, wind generator). The productivity per labour unit is very high but the production costs as well (automation, machinery, dairy sheds). This system is sparing on areas but does not support biodiversity and can be criticized on aspects of animal welfare, in spite of a pasture dedicated to exercise around the buildings. The risks for water quality are partly controlled by optimal management of organic manures. The impacts on the air per kg of milk are rather good, thanks to the air control systems filtering ammonia. Capitalization is very high and the transmissibility can become difficult. The dairy industry will support this type of dairy farms able to deliver a constant product and volume all year long.

The improved mixed crop-dairy farming systems

The search of self-sufficiency in mixed farms is the driving force of this system. The basic concepts are similar to organic farms. The cropping system is based on a long crop rotation with low level of fertilization, mixing temporary pastures and crops with a significant proportion of legumes. The cows graze when possible in order to minimize the costs of food and waste applications, but the crops provide high quality conserved feed. Dual purpose cows are used, with good qualities of breeding. These systems are both technically and environmentally efficient but they require more land and their development are limited by the low consideration for these systems today (learning, research) and the land price.

The specialized grazing systems

This system should be considered as an evolution of the New-Zealand dairy farming system with slight improvements in the management of nitrogen and methane to reach the best results possible with LCA (BassetMens *et al*, 2007). The system is highly specialized in dairy production. It is based on intensive grazing, and the inputs are very low in spite of the high milk production per unit of area. Milk production is synchronized with grass growth with grouped calving although the seasonality of milk delivery is a constraint for the dairy industry. The animals are always outside and the dairy sheds are reduced to a minimum in order to face the land investment. These systems are confined to areas with oceanic climate favourable to grass growth and where the animals can stay outside in winter.

The "terroir" dairy farms

These farms are located in natural areas with nice landscape and great biodiversity, resulting in both added value and constraints to agriculture. These farms are dedicated to the production of specific local products with high added value related to their typical features (special cheese, butter or cream, yogurt with local fruits or aromatic plants...) and to their image. They play a role in the development of regions with low agricultural productivity and prevent the closing of landscapes by forest. The farm participates to the transformation and the marketing of a certain number of typical products. These dairy farms are in charge of maintaining local breeds. Husbandries take into account the environmental constraints; the stocking rate is weak and optimal for biodiversity (Jouven and Baumont, 2008). The maintenance of landscape represents an agricultural activity financed by the local or national government and by the activities of service. They also play an important role of service for townsmen in search of rurality and agriculture is only a part of their total activity.

Conclusion

The aim of this futuristic exercise is not to forecast tomorrow but to draw attention about the large variety of possible sustainable dairy systems. The difficulty to balance the different dimensions of sustainability is central for research. Each of these systems is consistent but can be improved to optimize income, labour and environmental impact. The systemic approach and new indicators adapted to dairy farms could be helpful to reach this goal. The social dimension of farmer's job, not considered in this review, must also be considered to understand the evolution of dairy farms.

References

- Aarts, H. F. M., E. E. Biewinga, and H. Vankeulen. 1992. Dairy Farming Systems Based on Efficient Nutrient Management. *Netherlands Journal of Agricultural Science* 40:285-299.
- Basset-Mens, C., S. Ledgard, and M. Boyes. 2008. Eco-efficiency of intensification scenarios for milk production in New Zealand. *Ecological Economics*. In Press, Corrected Proof.
- Bastianoni, S. and N. Marchettini. 2000. The problem of co-production in environmental accounting by energy analysis. *Ecological Modelling* 129:187-193.
- Berntsen, J., B. M. Petersen, B. H. Jacobsen, J. E. Olesen, and N. J. Hutchings. 2003. Evaluating nitrogen taxation scenarios using the dynamic whole farm simulation model FASSET. *Agricultural Systems* 76:817-839.
- Bouwman, A. F., K. W. Van der Hoek, B. Eickhout, and I. Soenario. 2005. Exploring changes in world ruminant production systems. *Agricultural Systems* 84:121-153.
- Bryant, J., N. Lopez-Villalobos, C. Holmes, and J. Pryce. 2005. Simulation modelling of dairy cattle performance based on knowledge of genotype, environment and genotype by environment interactions: current status. *Agricultural Systems* 86:121-143.

- Cederberg, C. and M. Stadig. 2003. System expansion and allocation in life cycle assessment of milk and beef production. *International Journal of Life Cycle Assessment* 8:350-356.
- Chardon, X.; C. Rigolot; C. Baratte; A. Le Gall; S. Espagnol; R. Martin-Clouaire; J.P. Rellier; C. Raison; J.C. Poupa and Faverdin, P. (2007) MELODIE : a whole-farm model to study the dynamics of nutrients in integrated dairy and pig farms. In Oxley, L. and Kulasiri, D. (eds) MODSIM 2007 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2007, pp. 1638-1645. ISBN : 978-0-9758400-4-7.
- Courcier, R., F. Guerrin, F. H. Andriamasinoro, and J. M. Paillat. 2002. Agent-based simulation of complex systems: application to collective management of animal wastes. *Jasss-the Journal of Artificial Societies and Social Simulation* 5.
- Faye, B., D. Waltner-Toews, and J. McDermott. 1999. From 'ecopathology' to 'agroecosystem health'. *Preventive Veterinary Medicine* 39:111-128.
- Girardin, P., C. Bockstaller, and H. Van der Werf. 1999. Indicators: Tools to evaluate the environmental impacts of farming systems. *Journal of Sustainable Agriculture* 13:5-21.
- Institut de l'élevage, 2005. The french experience of « Farm network ». http://www.inst-elevage.asso.fr/html1/IMG/pdf/reseau_Anglais-2.pdf
- Jouven, M. and R. Baumont. 2008. Simulating grassland utilization in beef suckler systems to investigate the trade-offs between production and floristic diversity. *Agricultural Systems* 96:260-272.
- Rotz, C.A., Coiner, C.U., 2005. The Integrated Farm System Model Reference Manual. Online. URL: <http://www.ars.usda.gov/Main/docs.htm?docid=8519>.
- Rotz, C. A., D. L. Zartman, and K. L. Crandall. 2005. Economic and environmental feasibility of a perennial cow dairy farm. *Journal of Dairy Science* 88:3009-3019.
- Russelle, M. P., M. H. Entz, and A. J. Franzluebbers. 2007. Reconsidering integrated crop-livestock systems in north America. *Agronomy Journal* 99:325-334.
- Schils, R. L. M., A. Verhagen, H. F. M. Aarts, P. J. Kuikman, and L. B. J. Sebek. 2006. Effect of improved nitrogen management on greenhouse gas emissions from intensive dairy systems in the Netherlands. *Global Change Biology* 12:382-391.
- Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales, and C. de Haan. 2006. *Livestock Long Shadow, environmental issues and options*. FAO Rome, ISBN 978-92-5-105571-7, 390 pp.
- Thenail, C. and J. Baudry. 2005. Farm riparian land use and management: Driving factors and tensions between technical and ecological functions. *Environmental Management* 36:640-653.

Management practices for adapting sheep production systems in the WANA region to climate change

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Introduction

The recent climate change scenarios show that most of the Near East region will face a decrease in water availability of up to 40 mm on an annual basis. Crop water availability is expressed as runoff – the difference between rainfall and the sum of evapotranspiration. It takes into account both rainfall and temperature patterns, including the effect of increased temperatures on increased evapotranspiration. The number of dry days is expected to increase everywhere in the region, with the exception of some central-Saharan areas, while the number of frost days should decrease everywhere. The length of growing seasons should decrease once temperatures increases reach 3 or 4°C. Yields of the key crops across Africa and Western Asia may fall by 15 to 35 % or 5 to 20 %, depending on whether there is weak or high carbon fertilization (FAO, 2008 based on IPCC 2007).

The expected additional stresses from climate change in most of the region will increase the already evident vulnerability to climatic fluctuations in the West Asia and North Africa (WANA) region. An analysis of the coefficient of variation of the maximum Normalized Difference Vegetation Index (NDVI) for the period 1982-2000 carried out by Celis *et al.* (2007) showed that there is already ample evidence of hotspots of response and vulnerability to climatic fluctuations in the region. Among the fairly well defined hotspots are the grain belts of north-eastern Syria and northern Iraq. Thus, these parts of the drylands are already facing conditions as predicted from climate change (drier, hotter, erratic rainfalls, and fragile water supply).

The expected impact of climate change on agriculture has to be seen also on the background of other trends shaping the agricultural environment in general, such as already high and growing populations, persistent reliance on income from agriculture, unstable off-farm income due to political and socioeconomic factors discouraging investment into industry and services, and dwindling water resources due to overuse and lack of policies to protect or use them efficiently (Thomas *et al.*, 2007). Other important additional trends interacting with the impact of climate change in particular for livestock production include those associated with the status of the natural resources, in particular with the processes of land desertification, decreasing productivity of rangelands and the reduction of land devoted to livestock production or production of fodder.

The increasing demand for animal products results in increasing interactions of small scale livestock producers with markets. At present small ruminant producers in the region are targeting local markets for dairy and meat products and regional markets (e.g. the Gulf region) for meat. However, the share of the WANA region in meat supply to the Gulf market is decreasing. This is apparently the consequence of health-related trade restrictions for small ruminants, poor market infrastructure, and lack of information about export markets and policies to effectively respond to export market requirements (Aw-Hassan *et al.*, 2005). The incidence and control of zoonotic diseases have received little attention in the region. Also at the region's markets urban consumers are becoming more demanding with regard to food quality while retailers demanding homogenous, reliable and safe supplies are increasing. Market structures often lack transparency that limits farmers in their attempt to capitalize market opportunities. Thus, issues of product quality and safety are turning so important that they may restrict smallholders from accessing markets.

Another important trend in the region is the decreasing contribution of rangelands to the small ruminant diets. A survey in the Syrian steppe showed that depending on the mobility of the livestock producers, rangelands contributed only 22 to 36 % to the sheep diets in 2004, an average rainfall year (Dutilly-Diane *et al.*, 2006).

It is suggested that Syria can be considered a representative example of the WANA region and the complex problems that will become reality or aggravate in the areas predicted to be negatively affected by climate change. Thus, strategies developed by ICARDA's small ruminant programme in Syria to reduce the vulnerability of small scale livestock keepers and strengthen their adaptive capacity and the resilience of their production systems will be highly relevant. ICARDA has been working on appropriate (adequate) management practices for traditional and newly emerging and intensifying small scale production systems through:

- characterizing small ruminant breeds;
- making adjustments in management practices such as feeding, husbandry, breeding, rangeland management, etc.;
- diversifying income and employment to withstand climate shocks and seasonal effects;
- strengthening or developing extension systems that respond to the changes; and
- institutional strengthening and improved decision-making capacities of the national system.

This paper presents the results from a range of research projects conducted in Syria with NARS and other partners over the last eight years that included on-station and on-farm experiments.

Management elements to support mitigation and adaptation to dryland conditions

Matching breed and production environment

The WANA region is one of the main centres of domestication for sheep and goats known as the “Fertile Crescent”. ICARDA has been documenting the status of the diversity and phenotypic characteristics of the sheep and goat breeds in the WANA region jointly with NARs partners (Iñiguez, 2005). Many breeds are shared across the region and have important adaptive traits to dryland conditions. In Syria there is only one sheep breed, the Awassi, and three goat breeds, the Shami, Jabali (mountain) and Baladi (local), of which the latter two breeds are poorly characterized. A characterization of the Jabali goat population at the phenotypic level and of their production systems has been carried out (Wurzinger *et al.*, 2008) and now is expanding to the genetic characterization of all goat breeds of Syria. The study explores relatedness among the three breeds but also specific features of subpopulations and potential for niche products.

The Awassi, a coarse wool fat-tailed sheep, is very closely associated with the barley production cycle. Thus, it is well adapted to the high temperatures during stubble field grazing in summer which coincides with the mating period. It is also adapted to very variable feed quantity and quality supplied by grazing the steppe rangelands in spring and stubble field in summer. However, an intensification of dairy sheep production resulting in a higher proportion of concentrates in the diet has been observed in last decades, in particular in the relatively higher rainfall zones in Syria (Rischkowsky *et al.*, 2004). As meat from Awassi sheep is preferred and highly valued in the Gulf region, introducing another dairy sheep breed would jeopardize the value of the lambs. In response to farmers’ needs of dairy sheep that respond to the higher level of concentrates in the diet, ICARDA initiated a genotype comparison by crossing two Awassi genotypes in 1999. A line produced at the Al-Kraim breeding plan under the Syrian Ministry of Agriculture in Salamieh (S) and sheep produced at Ceylanpinar program of Turkey (T) were crossed. The average milk yields of TS and T ewes were 13 % and 30 % higher than that of S, and the lactation lengths 8 % and 23 % longer, respectively, than of the S ewes. While the fat percentage did not differ among genotypes, protein and solid non fat (SNF) contents were significantly different but the magnitude of these differences had no practical implications (Iñiguez and Hilali, forthcoming). Thus, making use of the breeding progress achieved in neighbouring countries proved to be a successful way to raise milk production without losing the breed characteristics.

Replacing high cost concentrates in the diets

Most fattening and milk producing systems in Syria use concentrates for critical periods based on grains, cotton seed cake and wheat bran. In view of expected rising prices and decreasing availability of grains in response to climate change but also due to the increased use of cropland for biofuel production, alternative feeding options are of high importance for livestock producers. ICARDA researchers tested and developed multi-nutrient feed blocks from non-conventional and cheap agro-industrial by-products for supplementation in dry areas. These included the utilization of widely available by-products such as molasses, crude olive cake, sugar beet pulp and tomato pulp (Rihawi, 2005) and the mixing of Atriplex leaves with Molasses. Although many by-products can be used, a constraint is that often their production levels do not reach significant volumes to cover the large demand. Thus, multi-nutrient feed blocks with molasses and urea for lamb and milk production and for fattening were tested more intensively with the aim to replace barley in the diets. In some cases the feed blocks were combined with urea treated straw. Urea-molasses feed blocks were tested on farm for strategic supplementation of ewes during critical periods in the production cycle, namely early mating, late pregnancy and lactation (Rihawi *et al.*, 2007). In seven flocks located in three villages each farmer divided his flock into two groups, one group was fed according to traditional practices (control) and the other one was supplemented with molasses-urea feed blocks adjusted to the ewes’ nutritional demands in the three supplementation periods. Strategic supplementation reduced the mating period, and produced more lambs with higher body weights at weaning: twinning rate increased from 11 % (control) to 32 %; the lambs of the improved group (18.3 kg) were heavier at weaning than in the control group (16.7 kg). Lactation length was extended by two weeks and total milk yield was 31% higher. Although the ewes were supplemented for a longer period than animals under the control diet, the total feeding costs (US\$41.6/ewe) were nearly similar to that of the control (US\$39.4/ewe). The cost-benefit analysis accounting for the gains in yogurt production and the weight of weaned lambs showed that the net benefit for strategic supplementation was 18.7 US\$ per ewe higher than that of the control.

Alternative feeding options are also of high importance for lamb fattening systems that have become an important income generation activity for smallholders (ICARDA, 2007). In the control diet, Awassi lambs grazed green barley, supplemented with an expensive concentrate (barley grain 60 %, cotton seed meal 10 %, soybean cake 10 %, broken wheat bran 15 % and barley straw 5 %). The two alternative diets were (1) semi-intensive feeding based on vetch grazing with minor supplementation with a low cost diet and (2) intensive feeding, based exclusively on feeding with the same low-cost concentrate used in the semi-intensive diet (molasses 20 %, barley grain 30 %, cotton seed meal 10 %, wheat bran 15 %, broken wheat 20 % and barley straw 5 %). Although the intensive and semi-intensive regimes used the same supplement, the semi-intensive required only one-fifth the amount of supplement per animal and day. The intensive and semi-intensive diets were 16 % and 12 % cheaper, and promoted similar or even better growth than the traditional diet. The semi-intensive diet (with molasses and vetch) required much less purchased feed and gave the highest growth rates. Vetch provided green fodder for up to 90 days, with the added benefit of improved soil fertility. However, vetch is not suitable for very dry conditions (Rihawi *et al.*, 2006; Iñiguez *et al.*, 2007). The use of agricultural and industrial by-products has been widely investigated not only by ICARDA but also by national agricultural research centres. However, the delivery of these products and their access by farmers pose difficulties which require due efforts

in private sector participation and policy development. It is expected that the value of these options for livestock may increase under conditions reflecting higher prices for grains.

Alternative management options for more milk or targeting higher market prices

It is estimated that about 25 % of the milk yield of a dairy Awassi ewe is produced during the first 65 days of lactation (Al Jassim *et al.*, 1999). Thus, early weaning through creep feeding of lambs is an interesting option to increase the milk offtake and lamb weights at weaning. In an on-station experiment raising twenty lambs by their mothers with access to supplemental creep feeding was compared to raising twenty lambs only by their mothers (control). Creep feeding (25 %crushed barley, 25 %wheat bran, 25 % crushed soybean and 25 % hay) was offered to the lambs from two weeks of age onwards. The creep fed lambs were 6.6 kg heavier than the control lambs at weaning age of 60 days. The weight of lambs with creep feeding at 45 days (19.3 kg) was within the range of weights at the normal weaning time of 56 days at ICARDA's flock (mean 19.5 kg). This would offer the possibility to wean the lambs already at an age of 45 days (Rihawi *et al.*, 2008).

At experimental level it was shown that milk production out-of season to capture higher market prices is possible. Although representing additional costs, producing out-of season can bring extra benefits to farmers allowing them to recover costs and make a profit because of the better prices of milk products. At experimental level the extra profit per ewe that could be obtained by producing during an unconventional time, in spite of feeding costs, amounted to 23US\$. It is interesting to note that many farmers are already moving into this type of specialized production by their own initiative.

Adding value to products increasing food hygiene, safety and quality

In Syria national reports have shown that the amount of milk sold as fresh milk has dropped, as a result of the progressive replacement of fresh sheep milk with cow milk (Iñiguez and Aw-Hassan, 2004). This trend has apparently triggered an increase in the number of more intensive dairy production systems which process their own milk, particularly yoghurt, rather than selling it as fresh milk at a low price. Improving quality, shelf-life and marketability of dairy products is critical for farmers to respond to the market demands of food safety and hygiene. The traditional way of making yoghurt is very prone to contamination. Farmers reported that the yogurt was often sour, had a poor texture, crumbled, and had a yeast flavour. All these lowered the quality and market value of the yogurt. Another problem was that the yogurt was not firm and collapsed when transported. ICARDA researchers and livestock extension worked with Syrian farmers that depended on sheep milk processing for 48% of their income to improve the quality of their products. Workshops and training (on milk hygiene, improved yoghurt processing and culture management) were held involving women. For example, the use of industrial starters in making yoghurt with improved firmness allowed farmers to transport without collapsing. This provided additional 5 Syrian pounds per kg compared to yoghurt traditionally prepared. The participatory approach helped farmers to improve their processing skills and marketing of dairy products (Hilali *et al.*, 2006). Such simple capacity building activities would improve competitiveness of smallholders in the market and help them to mitigate the effect of climate change through improved income and better shelf-life of their products.

Improving animal health

ICARDA scientists in collaboration with ILRI have been studying the current animal health situation in the NENA (Near East-North Africa) region. The project aimed to contribute to livelihoods of the poor farmers in the region by increasing productivity and enhancing their access to local, national and international markets through improving small ruminant health (Majok *et al.*, 2005). Studies involved marketing constraints (policies, reducing transaction costs including transportation and taxes), and decreasing the threat of market exclusion or disruptions due to the occurrence of small ruminant diseases. Changes in the equilibrium of the ecosystems during climate change could contribute to epidemiological changes, in particular concerning diseases transmittable to humans that need to be anticipated by further research investments in this important area.

Improving contribution of feeds from rangelands

Vast rangeland areas suffer from poor soil fertility, and varying levels of degradation. As a result of overgrazing, severe cutting of trees and removal of vegetation, valuable species are being replaced by less valuable species unpalatable to livestock. Several shrubs and drought tolerant species have been introduced or used in the WANA region. This includes widely known *Atriplex* and *Acacia* species and cactus. These plants have been found useful to rehabilitate rangelands, alone, in alley cropping, or as ingredients of feed blocks. The plantation and grazing of these shrubs is faced with the inherent difficulties associated with land communally owned. The inconsistencies and lack of policies in relation to communal use of ranges and resources leave the communities with little motivation to conserve rangelands, and hinders the development of efficient management strategies to conserve and regenerate them. Numerous other measures are available: reseeding, water harvesting, increasing water use efficiency, enhancing soil fertility, and policy reform on land tenure. The challenge is to implement some or all of these measures in poor dryland communities (El Dessougi, 2006).

Implications for livestock research and development

It should be emphasized that a one-size-fits-all solution is not feasible to cope with the challenges of climate change. There is a clear need to stratify the region according to level of vulnerability and opportunity for success. Well defined scenarios of climate change at local levels would help to work on production systems related management options. Some key needs in R&D in relation to climate change in this context include:

- Geo-stratified characterisation (phenotypic and molecular genetic) of local sheep and goat breeds to identify most appropriate breeds for future climates,
- Setting up efficient breeding programs that will allow the access by farmers to improve animals for key production traits considering adaptive traits, in particular higher heat tolerance
- Linking up disadvantaged breeds to markets, adding value to their products
- Improving sheep and goat health (e.g. focus on transboundary and zoonotic diseases that limit trade)
- Increasing fertility of some of the local breeds
- Sustainable rangeland improvement and management including institutional solutions for rangeland access
- Water harvesting and distribution of water delivery points in rangelands
- Revisiting the research on by-products, straw treatment, feed blocks, etc.
- Well focused program for production of highly water productive forages under rainfed conditions
- Biotechnological interventions to developing drought-tolerant cereal and forage species and varieties
- Development of fodder banks (e.g. for cactus and shrubs)
- Safety of animal products through developing effective disease control, carcass inspections and milk quality
- More efficient pathways for outscaling technologies successfully tested with smallholders.
- Models for outscaling technology options to farmers plus more effective private sector involvement

References

- Aw-Hassan, A., Shomo, F., Iñiguez, L., 2005. *Caravan* 22: 14-17.
- Al Jassim, R.A.M, Aziz, D.I., Zorah, K., Black, J.L., 1999. *Animal Science* 69: 441-446.
- Celis, D., De Pauw, E., Geerken, R., 2007. ICARDA, Aleppo, Syria, 69 pp.
- Dutilly-Diane, C., Saint-Macary, C., Tiedeman, J., Arab, G., Batikha, N., Ghassali, F., Khoudary, E., 2006. 2ème séminaire du réseau méditerranéen élevage. 'Les productions de l'élevage méditerranéen: défis et atouts'. Saragossa, Spain, 18-20 Mai 2006.
- El Dessougi, H., 2006. *Caravan* 23: 23-25.
- FAO, 2008. Twenty-ninth FAO Regional Conference for the Near East, Cairo, Egypt, 1-5 March 2008. 15 pp.
- Hilali, M., Iñiguez, L., Zaklouta, M. 2006. Proceedings 57th Annual Meeting of the European Association for Animal Production, Antalya, pp. 207.
- ICARDA, 2007. ICARDA Annual Report 2006. ICARDA, Aleppo, Syria, pp. 77-80.
- Iñiguez, L. (ed.), 2005. Vol. 1. West Asia and Vol. 2. North Africa. ICARDA, Aleppo, Syria, 462 and 196 pp.
- Iñiguez, L., Aw-Hassan, A., 2004. Proceedings of the Symposium on the Future of the Sheep and Goat Dairy Sectors, Zaragoza, Spain, 28-30 October 2004. IDF/CIHEAM, Zaragoza, Spain.
- Iñiguez, L., Hilali, M. *Livestock Production*. (forthcoming).
- Iñiguez, L., Rihawi, S., Wurzinger, M., Knaus, W., 2007. *Caravan* 24: 44-46.
- IPCC, 2007. Inter-governmental Panel on Climate Change Special Report on Emissions Scenarios. web: <http://www.grida.no/climate/ipcc/emission/076.htm> retrieved 24 March 2008.
- Majok, A., Jabbar, M., Aw-Hassan, A., 2005. *Caravan* 24: 26-27.
- Rihawi, S. 2005. *Caravan* 22: 28-30.
- Rihawi, S., Iñiguez, L., Wurzinger, M., Knaus, W., Larbi, A., Hilali, M., Zaklouta, M., 2006. Proc. 57th Annual Meeting of the European Association for Animal Production, Antalya, Turkey, 17-20 September 2006, pp. 91.
- Rihawi, S., Iñiguez, L., Knaus, W.F., 2008. Proceedings ICARDA/Boku workshop, Small ruminant production diversification and genetic diversity, ICARDA, Aleppo, Syria, 29 February-1 March 2008.
- Rihawi, S., Iñiguez, L., Rischkowsky, B.A., 2007. First International Conference on Food Safety of Animal Products. Amman, Jordan, 12-14 November 2007.
- Rischkowsky, B., Thomson E.F., Shnayien, R., King, J.M., 2004. *Experimental Agriculture*, 40(1): 109-126.
- Thomas, R.J., De Pauw, E., Qadir, M., Amri, A., Pala, M., Yahyaoui, A., El-Bouhssini, M., Baum, M., Iñiguez, L., Shideed, K., 2007. *J. of Semi-Arid Tropical Agricultural Research* 4(1): 1-37.
- Wurzinger, M., Iñiguez, L., Zaklouta M., Hilali, M., Soelkner, J., 2008. *J. of Arid Environments* 72: 384-391.

Trade-offs among enteric methane production, non-milk nitrogen and performance in dairy cows during the winter feeding period

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Introduction

Quantification of the pollutant gases like methane (CH₄) in dairy cattle production is a subject of great interest because large emissions occur from enteric fermentation in cows and also from anaerobic storage of manures (Hensen *et al.*, 2006). Understanding the impact of different production systems on enteric methane production is important not only for dairy productivity but also for developing mitigation strategies for the contribution of agricultural activities to anthropogenic greenhouse gas (GHG) emissions (Weiske *et al.*, 2006). However dairy production is not only responsible for the production of GHG. Nitrates coming from dairy cattle represent the feed nitrogen component that is not utilised by cows and potentially can pollute through runoff, volatilisation and leaching (Tamminga, 2003; Jonker, *et al.*, 2002). In this regard, achieving a better understanding of the interactions in the production of polluting agents in different dairy systems is an important step in developing holistic strategies to mitigate the polluting aspects of the modern dairy cow. The objective of the current analysis was to investigate whether dairy cows in production systems that have high enteric methane production also have high nitrogen losses

Materials and methods

Data were obtained for the winter feeding period from a herd of Holstein Friesian cows, which are on a long-term 2 x 2 factorial, genotype x management system project based at the SAC Dairy Research Centre, Dumfries, Scotland. Two contrasting approaches to dairy herd management systems were practiced. The two management systems were a high forage system (HF) and low forage system (LF). In HF system, the cows grazing when sufficient herbage was available and fed a complete diet containing between 70% and 75% forage in the dry matter when grass heights fell below set values and housed in the winter months. Typically, the winter feeding period was from November of one year to March of the following year. In the LF system, the cows were housed throughout the year and had access to a roofed loafing area for approximately eight hours per day during the summer months. The cows in the LF system were fed a complete diet containing between 45% and 50% forage dry matter (DM). Milk yields of individual cows were recorded at each milking and individual cow milk samples taken weekly for analysis of fat, protein and somatic cell contents. The feed intake was recorded on 3 days out of six using Hoko gates (Insentec BV, Marknesse, The Netherlands). The chemical compositions of the silages and concentrate were determined at the SAC Analytical Lab, Edinburgh, Scotland. A summary of the feed composition for the feed offered to the two groups is presented in Table 1.

Table 1 A summary of the feed composition for the feed offered to the two groups during the study period on dry matter (DM) basis

Feed constituent	Group					
	Low Forage			High Forage		
	Average	Min	Max	Average	Min	Max
ME (MJ/kg DM)	12.3	12.1	12.5	11.5	11.3	11.7
Crude Protein (g/kg DM)	185	180	190	180	175	185
Oil (g/kg DM)	60	55	665	50	45	55
Starch (g/kg DM)	180	160	200	130	110	150
Sugar (g/kg DM)	70	60	80	50	40	60
NDF (g/kg DM)	345	330	360	390	360	420
NDF from forage (g/kg DM)		240			270	
Dry matter (%)		45			30	

Each management system consisted of cows that belonged to one of the two genetic lines (Select and Control) based on merit for kilograms milk fat plus protein. The Select group cows were sired by bulls with high predicted transmitting abilities (PTA) for fat plus protein yield, whereas the Control cows were sired by bulls of UK average merit for fat plus protein (Pryce *et al.*, 1999). The PTA values for the Select sires whose daughters were included in the current study were 936.7 (sd = 231.2) kg for milk yield, 34.3 (sd = 5.38) kg for fat yield, and 31.1 (sd = 3.76) kg for protein yield. The PTAs for the Control sires were 262.7 (sd = 185.3) kg for milk yield, 2.77 (sd = 6.81) kg for fat yield, and 5.40 (sd = 5.35) kg for protein yield. Approximately equal numbers of cows formed the Select line-low forage (LFS), Select line-high forage (HFS), Control line-low forage (LFC), and Control line-high forage (HFC) groups.

Enteric methane production per cow per day was calculated using three different equations. The first equation predominantly uses total DM intake, DM intake from concentrate component of the feed (CDMI), and the neutral detergent fibre (NDF) in the feed (Yates, *et al.*, 2000) i.e. CH₄ (MJ/day) = 1.36 + 1.21 x DMI - 0.825 x CDMI + 12.8 x NDF. The second equation uses metabolisable energy intake (Mills, *et al.*, 2003). The equation by Mills, *et al.* (2003) is, CH₄ (MJ/day) = 8.25 + 0.07 x ME intake (MJ/d). The third equation uses DM intake, feed characteristics and milk

characteristics i.e. Methane energy (% gross energy) = $2.898 - 0.0631 \times \text{milk yield (kg/d)} + 0.297 \times \text{milk fat (\%)} - 1.587 \times \text{milk protein (\%)} + 0.0891 \times \text{CP (\%DMI)} + 0.1010 \times \text{forage ADF (\%DMI)} + 0.102 \times \text{DMI (kg/d)} - 0.131 \times \text{fat (\%DMI)} + 0.116 \times \text{DM digestibility(\%)} - 0.0737 \times \text{CP digestibility (\%)}$ (Holter and Young, 1992). In all cases, the methane energy output was initially converted to grams of methane per cow per day and further to grams of methane per kg of milk. In terms of pollution into the ground water resources, non-milk nitrogen was calculated. Non-milk N represented the amount of N that did not get into milk and might have been lost as faecal and urine N. In adult cows, only about 2% of the non-milk N is retained in the cows' body tissue (Tamminga, 1992) and hence non-milk N was calculated as the difference between N intake and milk N. Since the great majority of non-milk N ends up as either faecal or urine N, the predominant mode of pollution for non-milk N is through runoff, volatilisation and leaching (Tamminga, 2003; Jonker, *et al.*, 2002). The unit of comparison for non-milk N, therefore, was the unit of land allocated to each cow. The amount of land allocated to each cow was a quotient of dry matter forage intake per cow and dry matter forage production per hectare of land. The proportion of DM forage in the TMR for the different groups was corrected for to determine the individual cow forage dry matter intake. On average the land area per cow was 0.31, 0.49, 0.28 and 0.46 ha for LFS, HFS, LFC, and HFC, respectively. In the final analysis non-milk N was expressed in g/m^2 .

Data were analysed using a univariate mixed model which included the following fixed factors: production system, parity, days in milk, year of production, and days in milk. The individual cow within parity and random residual were included as random effects. Cows in any parity higher than three were combined with those in parity three. Analysis was undertaken using restricted maximum likelihood (REML) methodology implemented by the MIXED procedure of SAS version 8.2 (SAS Inst. Inc., 2001). Least square means for DIM were used to generate profiles for methane and manure N over the first part of the lactation

Results

Production systems (genotype x feeding system) had highly significant effects ($p < 0.001$) on enteric methane production, non milk nitrogen and performance of dairy cows during the winter feeding period. Similarly, days in milk and year of production, had significant effects ($p < 0.001$) on enteric methane production, non milk nitrogen and cow performance. Parity of the cow did not have significant effect on either enteric methane production estimated using the method by Holter and Young (1992) or on body energy content of the cows. Least square means of CH_4 (g/kg milk), non-milk N (g/cow/day), ECM (kg/d) and EC (MJ) for the systematic factors, parity, production system and year of production, are presented in Table 2. Sensitivity results for the enteric methane estimates using the three equations indicated that the estimates were closely related.

Results from all the three methods used to estimate enteric methane emissions from the cows indicated a decrease in enteric methane per kg milk with increase in parity. For example, enteric methane decreased by 10.7% from parity one to parity three using the enteric methane estimation method by Yates, *et al.* (2000). Non-milk Nitrogen per area of land decreased with increase in parity while energy corrected milk yield increased with increase in parity. For example, Non-milk Nitrogen per area of land decreased by 24.0% from parity one to parity three while ECM increased by 28.0% from parity one to parity three. Among the production systems, the high genetic merit cows on a low forage diet (LFS) had the lowest enteric CH_4 emissions/kg milk while the control genetic merit group on high forage diet (HFC) had the highest enteric CH_4 emissions/kg milk (e.g. 12.2g/kg milk vs. 18.5g/kg milk using Yates, *et al.* (2000) method. The trend of these results was the same using the other two methods for enteric methane estimation. Using Yates, *et al.* (2000) method, HFS had higher enteric methane emission than LFC (16.4g/kg vs. 13.5g/kg, indicating generally higher CH_4 emission from the high forage groups than the low forage groups. In the other two methods (Mills, *et al.*, 2003 and Holter and Young, 1992) HFS and LFC groups did not give substantially different values of enteric CH_4 emissions/kg milk. Non-milk N was higher in low forage groups than in high forage groups (51.1 and 53.4 g/m^2 for LFS and LFC, respectively vs. 31.2 and 29.3 g/m^2 for HFS and HFC, respectively) suggesting higher potential N pollution to the environment from low forage systems than higher forage systems. From a production perspective, LFS had the highest performance with the energy corrected milk yield of 33.3kg/d while HFC had the lowest energy corrected milk yield of 23.4kg/d, representing a 42.3% difference.

Table 2 Estimates (least square means) and SEM for Methane (CH₄) using three different methods and Non-milk Nitrogen (Nnm) for cows in different production systems

Factor	Effect	CH ₄ g/kg milk (² method 1)		CH ₄ g/kg milk (method 2)		CH ₄ g/kg milk (method 3)		Nnm g/m ²	
		lsmean	SEM	lsmean	SEM	lsmean	SEM	lsmean	SEM
Parity	1	15.9	0.14	16.1	0.15	23.0	0.37	45.8	0.66
	2	15.0	0.21	15.2	0.21	22.6	0.54	43.1	0.95
	3	14.2	0.34	14.8	0.35	21.8	0.86	34.8	1.55
System ¹	LFS	12.2	0.25	14.3	0.25	20.8	0.60	51.1	1.08
	HFS	16.4	0.24	14.9	0.24	22.1	0.58	31.2	1.12
	LFC	13.5	0.23	15.8	0.23	22.8	0.57	53.4	1.06
	HFC	18.5	0.26	16.6	0.25	24.3	0.63	29.3	1.13
Year	2003	16.6	0.30	17.8	0.29	28.1	1.03	34.1	0.71
	2004	13.7	0.20	14.6	0.20	19.2	0.55	42.4	0.66
	2005	14.5	0.15	14.7	0.15	20.8	0.39	43.9	0.65
	2006	15.4	0.14	14.7	0.14	21.9	0.35	44.6	0.64

¹LFS = low forage, high genetic merit group; HFS = High forage, high genetic merit group; LFC = Low forage, low genetic merit group; HFC = High forage, low genetic merit group. ²Method 1 = Yates, *et al.*, 2000; Method 2 = Mills *et al.*, 2003, Method 3 = Holter and Young, 1992

CH₄/cow/d = Methane (kg), N₂O, Nnm = Non-milk Nitrogen

Generally, high forage systems had higher methane production per kg of milk than low forage groups. However, low forage groups had higher nitrogen loss per land area than high forage groups. Hence, cows with increased productivity in terms of milk yield were associated with a decrease in methane production per kg of milk but an increase in nitrogen loss per area of land. The results highlight the importance of the need to incorporate the dynamics of emission burden and pollution potential of different dairy systems in characterising different dairy systems. By including the environmental issues in calculations of cow productivity for dairy systems, production should be improved without compromising the environment.

This seeming trade-off for two different environmental-impact traits raises an issue on how efficiency should be defined in relation to the environmental impact of dairy farming. Dairy efficiency is normally defined as yield of milk per unit of dietary DM consumed (Britt, *et al.*, 2003) and hence, milk yield used as a functional unit in dairy production (Casey and Holden, 2005). Since methane emissions like the other greenhouse gases are a global issue in terms of the pollution mechanism, it is not logical that the environmental impact of enteric methane production be expressed per unit milk yield. It makes more ecological sense than not to express N loss in relation to land area which is allocated to each cow because most of it ends up as nitrates that get into the local ground water system (Brink *et al.*, 2001). As indicated in the ADAS report (ADAS, 2007) the estimated high readily available manure N efficiency in England and Wales is 25% of the total N applied. Reported values for N₂O losses range from 1.25 to 4.2 % of total manure N (IPCC, 1997; Molodovskaya *et al.*, 2005) while those for ammonia losses are about 24% (Paul *et al.*, 1998). The above reports show that a substantial proportion of manure N ends up in the local soil and ground water system. However, agronomic management plays a vital part in influencing N losses and N utilization (Salazar, *et al.*, 2005). In this regard, a common 'currency' for comparing cow efficiency where environmental impact is concerned should be developed. This could be units of a pollutant per litre of milk per hectare of land.

Conclusion

This study demonstrated that the various dairy systems had different environmental impact during the winter feeding period. The efficiency of N utilization and methane production were highly variable amongst the different dairy systems. Generally, an increase in production efficiency in terms of milk yield was associated with a decrease in enteric methane emissions per litre of milk. However, non-milk N increased in the more production efficient systems. The importance of the pollution cost of dairy production on the environment suggests that more research is needed to incorporate these issues in dairy systems analysis.

Implications

In order to reduce the contribution of methane emissions from dairy cows efficiency of dairy production is promoted. Efficient cows have lower methane pollution relative to the amount of milk produced. However, the current study has shown that cows with low enteric methane production per kg milk have high non-milk nitrogen loss per unit of land. The consequences of this trade-off may mainly be relevant to dairy farms in the nitrate vulnerable zones where diffuse pollution is an important issue.

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References

- ADAS 2007. ADAS report to Defra – supporting paper D1 for the consultation on implementation of the Nitrates Directive in England.
- Brink C, Kroeze K and Klimont Z 2001. *Atmospheric Environment*. 35 (36), 6313–6325.
- Britt JS, Thomas RC, Speer NC and Hall MB 2003. *Journal of Dairy Science* 86, 3796-3801.
- Casey JW and Holden NM 2005. *Journal of Environmental Quality* 34, 429-436.
- Hensen A, Groot TT, van der Bulk WCM, Vermeulen AT, Olesen JE and Schelde K 2006. *Agriculture Ecosystem and Environment* 112, 146-152.
- Holter JB and Young AJ 1992. *Journal of Dairy Science* 75, 2165-2175.
- Intergovernmental Panel on Climate Change (IPCC) 2007. *Climate Change 2007: http://ipcc-wg1.ucar.edu/wg1/docs/WG1AR4_SPM_Approved_05Feb.pdf*
- Jonker JS, Kohn RA and High J 2002. *Journal of Dairy Science* 85, 1218-1226.
- Mills, J. A. N., E. Kebreab, C. M. Yates, L. A. Crompton, S. B. Cammell, M. S. Dhanoa, R. E. Agnew and J. France. 2003. *Journal of Animal Science* 81, 3141–3150.
- Molodovskaya MS, Singurindy O, Richards BK, Giri SK and Steenhuis TS 2005. American Geophysical Union, Fall Meeting 2005, abstract #B51A-0181.
- Mulvanny P 1977. *Animal Production* 24, 157-158.
- Salazar FJ, Chadwick D, Pain BF, Hatch D and Owen, E 2005. *Bioresource Technology* 96, 235- 245.
- SAS Institute Inc., 2001 SAS Institute Inc., Cary, NC, USA
- Tamminga S 2003. *Livestock Production Science* 84, 101– 111.
- Tamminga S 1992. *Journal of Dairy Science* 75, 345-357.
- Pryce JE, Nielsen BL, Veerkamp RF and Simm G (1999). *Livestock Production Science*, 57(3), 193-201.
- Weiske A, Vabitsch A, Olesen JE, Schelde K, Michel J, Friedrich R and Kaltschmitt M 2006. *Agriculture Ecosystem and Environment* 112, 221-232.
- Yates CM, Cammell SB, France J, Beever DE, (2000). *Proceeding of the British Society of Animal Science* 2000, 94.

Physiological and behavioural parameters of crossbred heifers in single *Brachiaria decumbens* pasture and in silvopastoral system

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Introduction

The increasing concern with the thermal comfort of the animal is justifiable mostly in countries situated in the tropical zone of the planet, where high air temperatures, in view of the high solar radiation incident, predominate. Therefore, knowledge of the functional relationships between animal and the environment, contribute to the adoption of procedures that elevate the efficiency of milk production. (Damasceno and Targa, 1998). When environmental variables, such as, temperature, humidity, air movement and solar radiation reach values superior to the limit considered as thermal comfort for dairy cattle, they can exercise negative influence on the performance of these animals (milk production, reproduction, growth etc), resulting in a process known as heat stress. The animal capacity of resisting severities of heat stress has been evaluated physiologically by alterations in the rectal temperature, in the respiratory frequency (Osório, 1997) and in the animal behaviour (Pires *et al.*, 1998). Management strategies can attenuate the effects of the heat stress, among them, it is considered a main one, the physical modification of the environment, aiming to reduce the radiation incident via shade provision, reducing the heat load received by the animal (Buffington *et al.*, 1983). In this context, a new approach has been studied, which consists in the implementation of silvopastoral systems, characterized by the cultivation of arboreal species in association with pastures. The trees, besides improving the production, quality and sustainability of the pastures (Castro and Paciullo, 2007), contribute to animal comfort, by provision of shade, attenuation of extreme temperatures, decrease the rainfall and wind impact whilst serving as shelter for the animals (Salla, 2003). Within this approach, Leme *et al.* (2005), concluded that the silvopastoral system brings great benefits to animal comfort, specially in the summer. This way, the objective of the present work was to evaluate the thermal comfort of Holstein x Zebu crossbred heifers, kept on a single *Brachiaria decumbens* pasture or in a silvopastoral system

Material and methods

The research was conducted in the research station of Embrapa Dairy Cattle, in Coronel Pacheco, Minas Gerais State, Brazil. The climate of the region is classified as having alternating dry (May to October) and rainy periods (November to April), with average temperatures of 22 °C in the summer (rainfalls period) and 16.8 °C in the winter (dry period). Twenty Holstein x Zebu crossbred heifers with initial weight between 150 and 200 kg were used, distributed in two treatments: T1 - animals kept in grazing systems of single *Brachiaria decumbens* fertilized with P and K and T2 - animals kept in silvopastoral system (pasture of *Brachiaria decumbens* associated with *Stylosanthes guianensis*, fertilized with P and K, and trees bands). The experimental design adopted was entirely random in which each treatment had two replicates making a total area of 8 ha (four ha/ replicate). Each replicate had eight paddocks. For this study four of those paddocks were selected, being two of each treatment (one for repetition). The experiment duration was nine months, embracing the different seasons (fall, winter, spring and summer). In each season, the heifers (five/paddock) were observed always on the same paddock in a rotational grazing system. Each period consisted of a 7 day paddock occupation, and a rest period of 35 and 49 days, in the rainfall and in the dry times, respectively. The animals were monitored two days (in the first and in the seventh grazing day) in each season, at 6:00 am and at 6:00 pm. The measures of the behavioural standards were accomplished by instantaneous observation, at 10 minutes intervals, in which was identified, for each animal, one of the following behaviours: Position, whether standing or laid down; grazing, ruminating or idle. Concomitantly, at 9:00 am and 3:00 pm, were taken the temperature of corporeal surface (TCS) in °C (using a digital infrared thermometer) and the respiratory frequency (RF) measured by the number of respiratory movements per minute (mov/min) by visualization of flank movements of the animal. In the afternoon period, after the collection of these data, the animals were sent for a trunk located close to the paddock to measure sweating rate (ST) using the cobalt chloride method modified by Schleger and Turner (1965). The temperatures of the dry bulb, of the humid bulb and temperature of the black globe were taken every hour, during the data collection period. These data were used to calculate the Black Globe Humidity Index (BGHI) and the radiant heat load (RHL). The physiological data and those referring to the animals behaviour were submitted for analysis of variance, using the procedure SAS (Statistical Analysis System) version 8.0, adopting a level of 5% of probability. For comparison between treatments averages the test SNK was used, to the level of 5% of probability.

Results

The air temperature variations, regarding the seasons, were those usually observed in the region, with smaller values in the winter, intermediary in the fall and larger in the spring/summer (Table 1). In shade, a small attenuation of air temperature was verified when compared with values under full sun. In general, RHL values were smaller under the tree canopy than for full sun, evidencing that the shade supply in the pasture is an efficient method to reduce the radiation incident on the animal, improving animal thermal comfort (Table 1). According to Morais (2002), RHL represents the total of thermal energy exchanged between an individual and the environment and should be as small as possible to obtain thermal comfort. Therefore, the values obtained in this experiment, between 6669 to 801.4, were considered high

by the authors. It was observed, that all the values obtained under shade were below the inferior limit mentioned by Morais (2002), which highlights the importance of providing shade for grazing animals. In conditions of full solar radiation, at least 50% of the values were in the critical value interval, as considered by the author, which indicates that the heifers would not be in the zone of thermal comfort. The BGHI an index closely related to thermal comfort, was influenced by the presence of trees on pastures (Table 1), therefore supplying shade allowed reduction of BGHI values, making them closer to those considered a comfortable environment (up to 74). Bunffington *et al.* (1983) obtained higher correlations between BGHI and physiological parameters of animals than between physiological parameters and the climatic elements alone This confirms that BGHI is the most accurate term to characterise environmental thermal comfort. On the other hand, although the ambient temperatures, taken in the hottest period of the day (3 pm), indicate a microclimate more pleasant under the tree canopy, it showed that shade was not enough to keep the temperatures in the thermoneutral interval established for *Bos taurus*, in the spring and in the summer.

Table 1 Average ambient temperature, radiant heat load, Black Globe Humidity Index in the silvopastoral system and in *B. decumbens* pasture, registered at 9:00 am and 3 pm.

	Systems					
	Silvopastoral				<i>Brachiaria decumbens</i>	
	Shade		Sun		Sun	
	9:00hs.	15:00hs	9:00hs	15:00hs	9:00 hs	15:00 hs
Seasons	Air temperature (°C)					
Fall	20,0	26,2	20,0	27,2	20,0	27,2
Winter	17,7	26,5	19,6	27,2	19,6	27,2
Spring	24,4	29,5	25,0	31,5	25,0	31,5
Summer	22,5	27,5	23,0	28,4	23,0	28,3
Seasons	Radiant Heat Load ($W.m^2$)					
Fall	456,9	504,6	524,7	694,8	667,8	703,6
Winter	467,9	499,7	623,6	724,7	685,3	817,8
Spring	507,1	527,2	623,5	633,3	669,6	689,6
Summer	475,9	533,5	567,0	630,1	554,3	615,7
Seasons	Black Globe Humidity Index					
Fall	70,1	74,2	75,2	80,8	84,8	90,7
Winter	68,6	73,7	77,7	89,0	80,8	84,8
Spring	74,4	80,0	82,3	84,6	79,4	85,5
Summer	71,1	78,7	76,8	87,8	75,5	81,0

In both treatments, RF for the heifers, observed in the morning period was lower than that observed in the afternoon period (Table 2), and it remained in normal values (60 mov/min). A lower RF value in the morning could have been a consequence of favourable climatological conditions in this period of the day. However, the animals in the shaded paddocks, presented normal RF values, even in the afternoon, which was considered the hottest period of the day (Table 1). Hahn (1999) comments that with a respiratory frequency of around 60 mov/min, the animal presents no or a minimum level of heat stress. Shade in pastures contributed to the reduction of RF ($P < 0,05$), probably for supplying an environment with better thermal comfort. This reduction in RF indicates that the animals employed lower thermal regulator mechanisms. This can make better use of dietary energy towards the growth of the animal. These results are in agreement with Carvalho and Olivo (1996), which concluded that absence of shade affected animals' RF, presenting thus, higher values when compared with shaded systems.

Table 2 Average of rectal temperature and respiratory frequency for dairy heifers managed in the silvopastoral system and in the single *Brachiaria decumbens* paddocks.

Seasons	SYSTEMS									
	Silvopastoral					<i>Brachiaria decumbens</i>				
	RFM ¹	RFA ²	TCSM ³	TCSA ⁴	ST ⁵	RFM ¹	RFA ²	TCSM ³	TCSA ⁴	ST ⁵
Fall	44aA	55aB	26,1bB	23,5bB	111aB	40bA	65aA	31,6bA	30,1bcA	188aA
Winter	38bB	53aB	27,0bB	25,8bB	185bA	46aA	60aA	34,3aA	32,4abA	221aA
Spring	39bB	43bA	29,8aA	30,0aA	199bA	45abA	51bA	31,8bA	29,3cA	212aA
Summer	40abB	54aB	29,7aB	28,8aB	295cB	45abA	67aA	34,0aA	33,7aA	354bA
Averages	40,25	51,25	28,2	27,0	197,50	43,5	60,75	32,9	31,4	243,75

¹RFM (mov/min): Respiratory frequency in the morning (9 am); ²RFA (mov/min): Respiratory frequency in the afternoon (3 pm); ³TCSM (°C): Temperature of the corporeal surface in the morning; ⁴TCSA (°C): Temperature of the corporeal surface in the afternoon; ⁵ST (g/cm²/h): Sweting rate. Averages followed by equal miniscule letters in the column and capital letters in the line for a same variable do not differ to each other by the Test t (to=5%).

The effects of the RHL, BGHI and of the ambient temperature in the system without shade (Table 1) could have contributed to the higher average values for corporeal surface temperature (CST) of the animals in this system, in the morning (32.93°C) as well as in the afternoon (31.37°C), compared to the CST of the animals managed in the

silvopastoral system : 28.16°C in the morning and 27.04°C in the afternoon (Table 2). In all seasons, except spring, a larger heating of the corporeal surface in the animals that did not have shade was observed ($P < 0,05$) because they were more exposed to the solar radiation. It is opportune to emphasise that, in the spring, the animals in the silvopastoral system spent most of the time in activities under the sun, which probably contributed to the result. For the animals that were managed in paddocks without shade CST was higher in the winter and in the summer. This effect observed in the winter was due to, probably, the smaller cloud cover in this season. Morais (2002) also observed higher surface temperatures in periods of time with lower humidity due to the largest quantity of solar radiation that reaches the animals. The highest sweating rate ($P < 0,05$) was observed in the heifers managed in paddocks without shade, during the summer (Table 2). Also, there was a trend for higher average sweating rate (SR) for animals in pastures without shade (243,75 g/cm²/h) when compared with heifers in silvopastoral system (175,50 g/cm²/h). Independent of grazing system (with or without shade) the highest SR ($P < 0,05$) was observed in the summer (Table 2). Morais (2002) also found higher values of sweating rate ($P < 0,05$) in crossbred Holstein-Zebu bovines on pasture in the hottest period of the year, 346.4 against 174.9 g/cm²/h for the winter's period. However, Azevedo (2005) did not find any difference in SR of crossbred cows in lactation during the winter and summer seasons. This difference probably was due to a combination of factors such as measurement location, animal management, animal category and climatic conditions. The high CST obtained in the summer can be considered, according to Silva (2000), as one of the responsible factors for SR being more elevated in this season.

Comparing the systems, the shade effect was verified for fall and winter seasons in which longer grazing times were observed (Table 3). The effect of higher RHL and of BGHI in the afternoon period, in this season, could have contributed to the difference among systems in the behaviour of the animals, just in the fall and winter. Considering that the forage availability in the pastures and its nutritional value have been similar in the two treatments, it can be inferred that the shade supply in the silvopastoral system contributed to the thermal comfort of the animals, since time of grazing was larger in the arboreous paddocks, when compared with that observed in single *Brachiaria decumbens* pasture under full sun. Viegas *et al.* (2002) found similar results indicating that the environment can interfere in the search for food.

Table 3 Average time in minutes spent by crossbred heifers in grazing activities, rumination and idleness in silvopastoral system and single *Brachiaria decumbens* pasture

Behaviour	Systems							
	Silvopastoral system				Single <i>Brachiaria decumbens</i>			
	Seasons				Seasons			
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
Grazing	475aA	480aA	507aA	375bA	407bcB	432bB	511aA	384cA
Rumination	161aA	81bA	103bA	170aA	102bB	77bA	89bA	146bA
Idleness	95bB	169aB	120bA	184aA	222aA	221aA	130bA	200aA

Averages followed by equal, minuscule letters in the line, do not differ ($P > 0,05$) among seasons inside system and capital letters among seasons between systems.

The time spent by the heifers ruminating on single *Brachiaria decumbens* pasture was smaller ($P < 0,05$) than that in the silvopastoral system, in the fall and winter seasons (Table 3). On the other hand, time of idleness was larger ($P < 0,05$) under full sun than in the silvopastoral system, indicating that the animals without shade reduced the time dedicated to ingestion activities (grazing and rumination), in an attempt to decrease the production of metabolic heat, spending more time idle. Leme *et al.* (2005) also verified change in behaviour of non-lactating cows in an attempt to reduce the production of endogenous heat and thus reduce heat stress. Shade can reduce by 30% or more the load of radiant heat allowing the animals to maintain their normal behaviour. The beneficial effect of the shade on animal performance was verified by Blackshaw & Blackshaw (1994). In the two other seasons (summer and spring) there was no effect ($P > 0,05$) of the system on the ingestive behaviour of the animals (Table 3). Thus, contradicting the expectations, in the seasons in which the ambient temperatures tended to be more elevated, shade did not favour grazing activity, probably because of the reduced RHL in those seasons (Table 1). When comparing the animals behaviour within the systems, it is verified that, in the summer, the animals decreased time spent grazing, during this period of abundant forage, thus spending less time searching for forage and increasing other activities, as also verified by Pires *et al.* (1998).

Conclusions

The silvopastoral system proved to be efficient in providing thermal comfort to the animals, by showing an increase in time spent for grazing and rumination activities, conditions in which high RHL occurs

Implications

The adoption of silvopastoral systems by dairy cattle farmers, besides offering improved thermal comfort for the animals, contributes to sustainability of the activity, to the landscape beauty and aggregates value to the business through the timber.

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References

- Azevedo, M.; Pires, M. F. A.; Saturnino, H. M.; Lana, A. M. Q.; Sampaio, I. V. M.; Monteiro, J. B. N.; Morato, L. E. 2005. Estimativa de níveis de críticos superiores do índice de temperatura e umidade para vacas leiteiras $\frac{1}{2}$, $\frac{3}{4}$ e $\frac{7}{8}$ Holandês-Zebu em lactação. Revista Bras. Zootec., v. 34, n. 6. p. 2000-2008.
- Blackshaw, J. K. e. Blackshaw, A. W. 1994. Heat stress in cattle and effect of shade on production and behaviour: a review. Aust. J. of Experimental Agriculture. 34:285-295.
- Buffington, D. E., Collier, R. J., Canton, G.H. 1983. Shade management Systems have reduce heat stress is dairy cows in hot humid climates. Trans. ASAE, v. 26, p. 1798-1802.
- Castro, C. R. T. and Paciullo, D. S. C. 2007. Sistemas Silvopastoriles . In: Martins, P. C., Diniz, F. H., Moreira, M. S. P., Netto, V. N. (Ed). Conocimientos y technological strategies of leche in regiones tropical. Juiz de Fora. Embrapa Gado de Leite. 2007. v.1, p. 211-236.
- Damasceno, J.C., Targa, L. A. 1998. Definição de variáveis climáticas na determinação das respostas de vacas Holandesas em um sistema “free-stall”. Engenharia da Agricultura, v.12:, p. 34-43.
- Hahn, G.L 1999. Dynamic responses of cattle have thermal heat loads Journal of Animal Science, v.77, supplement 2, p.10-20.
- Leme, T.M.S.P, Pires, M.F.A., Verneque, R.S., Alvim, M.J., Aroeira, L. J. M 2005 . Comportamento de vacas mestiças Holandês x Zebu em pastagem de *brachiaria decumbens* em sistema silvipastoril. Ciência Agrotécnica, v. 29, p. 668-675.
- Morais, D. A. E. F. 2002. Variação de características do pelame, níveis de hormônios tireoideanos e produção de vacas leiteiras em ambiente quente e seco. 2002. 123 f. Tese (Doutorado) – Faculdade de Ciências Agrárias e Veterinárias, UNESP, Jabotical
- Osorio, M. M. 1997. Rectal temperature rhythms of cattle in tropics In: Livestock Environment, 5, 1997, Bloomington. Proceedings.. Bloomington: American Society of Agricultural Engineers, 1997. P. 803-808
- Pires, M.F.A, Vilela,D,Verneque R.S, Teodoro, R.L 1998. . Reflexos do estresse térmico no comportamento de vacas em lactação. In: Simposio Brasileiro de Ambeencia na Producao de Leite, 1., 1998, Piracicaba. Anais... Piracicaba: [s. n.], 1998. p. 68-99.
- Silva, R. G. Introdução à bioclimatologia animal. São Paulo: Nobel, 2000. 286 p.
- Schleger, A.V.& Turner, H.G 1965. Sweating rates of cattle in the field and their reaction to diurnal and seasonal changes. Australian Journal of Agricultural Research, v. 16, p. 92-106.
- Viegas, J.; Schwendler, S. E.; Everling, D. M.; Elgelman, A. L.; Santos, R. M.; D. Filho, E. H.; Carvalho, N. M.; Ziech, M. F.; Charão, P. S.; Pereira, M. A. Atividades Diárias Desenvolvidas por Vacas da Raça Holandês em Pastagem de Milheto com e sem Sombra. In: Reuniao Anual da Sociedade Brasileira de Zootecnia, 39., 2002, Recife. Anais... Recife: Macromédia, 2002. 1 CD-ROM.

Agroforestry and livestock: adaptation/mitigation strategies in agro-pastoral farming systems of Eastern Africa

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Introduction

In the mid-1980s the landscape of Shinyanga region in Western Tanzania was declared the desert of Tanzania by the late President Mwl. Julius K Nyerere due to severe deforestation and degradation. The region covers 5.4% of the total land area in Tanzania and carries over 20% of the ruminant national herd making it the most overstocked region in the country (MLD 2005). The inhabitants mainly of the Wasukuma ethnic group are agro-pastoralists and over 80% of the population derive their livelihoods from livestock kept on extensive grazing systems. The region is semi-arid with erratic unimodal rainfall of 600 to 800mm.

The severity of the land degradation problem brought national and international development agencies to implement a long term natural resource management programme, which was launched in 1986 with a major thrust on afforestation and agroforestry. Successes have been recorded and the biggest of them was in blending local knowledge and modern science to reclaim degraded land and generate various socio-economic and environmental benefits (Monela 2004). Revival of *Ngitili* the traditional land use system in which large areas of land are set aside by communities and individuals to ensure that forage is available in the dry season was used to rest the land and introduce interventions that increased tree density, vegetation cover, soil productivity and consequently more biomass production (Barrow and Mulenge 2003; Monela 2004).

In 2002 these initiatives received international recognition by the UN Equator Prize 2002 for the outstanding local efforts for poverty reduction and environment conservation. A major criticism has been lack of baseline data for a more objective assessment of the impact. Furthermore emerging global challenges of climate vulnerability and poverty reported by the three major global studies i.e. Millennium Ecosystem Assessment of 2005, Mapping vulnerability and poverty in Africa, the United Nations Livestock long shadow and more recently the Stern Review on economics of climate change give such initiatives new dimensions.

The livestock sector is in the spotlight again as one of the top two or three most significant contributors to serious environmental problems, at every scale from local to global. In the global warming context livestock is more damaging than all the vehicles in the world and also a major source of land and water degradation (FAO 2006). The sector accounts for 9, 37, 65 and 64 percent of carbon dioxide, methane, nitrous oxide and ammonia global emissions, respectively. The largest share of emissions come from extensive systems, where poor livestock keepers, >100 million in East and Southern Africa, extract marginal livelihoods from dwindling natural resources and have a very low capacity to invest in change. Recent developments in agroforestry science provide adaptation/mitigation options that can reduce or reverse adverse effects of this livestock poverty environment enigma. In this presentation we assess one of the agroforestry – livestock innovations introduced by the project in relation to dry season climate adaptation and mitigation strategies.

Materials and methods

A rapid appraisal on integrated agroforestry and livestock production was conducted to characterise agroforestry in two districts of Shinyanga region. Sampling was done to include farmers who adopted fodder trees on farm from the former ICRAF afforestation programme in Tanzania. A check list was used to gather information on agroforestry land use system and tree population. Survey data was analysed for simple descriptive statistics using Statistical Package for Social Science (SPSS) window-based statistical software.

Feeding value of *Acacia nilotica*, *A.polycantha* and *Leucaena leucocephala* was assessed using growing Small East Africa goats stall fed on a basal diet of native pastures hay NLH-T1 and supplemented with NLM –T2, PLM-T3 and LLM-T4 for a period of 84 days. Treatments were arranged in a completely randomised design (CRD) in four groups with five goats in each group. Feed intake and representative samples of feed offered and refused were collected daily for estimation of dry matter intake. The goats were weighed on weekly intervals early in the morning after seven hours of fasting. Initial and final weights of the goats was an average of three days consecutive weighing. Ash, crude protein (CP), ash free neutral detergent fibre (NFF), ash free acid detergent fibre (ADF) and acid detergent lignin (ADL) of the treatment diets was analysed using the standard AOAC (1990) procedure. The forages were analysed for total extractable phenolics (TEP) and total extractable tannins (TET) using Folin-Ciocalteu's reagent (Jolkunen-Tiito, 1985) and total condensed tannin (TCT) is using *n*-butanol/HCl (Porter *et al.*, 1986).

Data on chemical composition were subjected to the General Linear Model (GLM) procedure of SAS/Statview (1999) statistical package based on the statistical model; $Y_{ij} = \mu_i + T_i + e_i$, where Y_{ij} is the general response of the specific parameter under investigation, μ_i the general mean peculiar to each observation, T_i the *i*th effect of the dietary treatment

on the observed parameter and e_i the random error term for each estimate. Analysis of Variance (ANOVA) on live weight gains were conducted by subjecting weekly weight gains changes to the GLM procedure of SAS/Statview (1999) based on statistical model; Live weight gain kg/day, $Y_i = \mu_i + T_i + b(x_i - x)_{ij} + e_i$, where μ_i is general mean T_i the effect of with treatment diet on growth performance parameter. The $b(x_i - x)_{ij}$ term represents a covariance factor for adjustment of live weight changes from initial body weight of the goats and e_i is the random error term. All treatment means were compared by least square difference (LSD).

Results

Table 1 gives the chemical composition of the dietary treatments. The three forages had significantly higher CO content than the naïve pasture hay and that of *A. polyacantha* leaf meal was significantly higher than *A. nilotica* ($P < 0.05$) but the difference between *A. polyacantha* and leucaena leaf meal was not significant. There were significant inter-species difference in TET and TEP content with *A. nilotica* having significantly higher TET than the other two tree forages. *A. polyacantha* had significantly higher TCT than the other two forages. Table 2 show comparative chemical composition values and total tannin concentration for other semi-arid browse species reported by Komwihangilo *et al.* (2005).

Table 1 Chemical composition (g kg⁻¹ DM) of feeds used in growth performance experiment

	MB	NPH	NLM	PLM	LLM
Ash	54.1 ^a	70.8 ^b	63.3 ^{ab}	111 ^c	120.3 ^c
CP	12.2 ^a	45.5 ^b	159 ^c	195 ^d	187 ^d
NDF		702 ^a	189 ^b	448 ^c	264 ^d
ADF		528 ^a	95 ^b	225 ^c	158 ^d
ADL		111.7 ^a	52.2 ^b	121.5 ^c	80.7 ^d
TEP [†]	n.a	n.a	281 ^a	104 ^b	6.7 ^c
TET [‡]	n.a	n.a	256 ^a	93 ^b	5.1 ^c
TCT [§]	n.a	n.a	52.8 ^a	98.3 ^b	2.3 ^c

^{a,b,c,d} Means with different superscripts along the same rows differ significantly ($P < 0.05$)

[†]TEP, total extractable phenolics; [‡]TET, total extractable tannins; [§]TCT, total condensed tannins

n.a TEP, TET and TCT not assayed, MB, maize bran; NPH, native pasture hay; NLM, *A. nilotica* leaf meal; PLM, *A. polyacantha* leaf meal; LLM, *Leucaena leucocephala* leaf meal.

Table 2 Laboratory analysis of the chemical composition of feeds used in the study

Feed material	(g/kg)	Composition as g/kgDM					Total tannins (mg/g)
		DM	Ash	CP	ADF	NDF	
<i>Delonix elata</i>	890.0	99.0	225.0	265.0	456.0	39.0	44.02
<i>Grewia similis</i>	890.0	145.0	184.0	241.0	468.0	34.0	5.59
<i>Tamarindus indica</i>	892.0	94.0	130.0	351.0	463.0	34.0	63.62
Sunflower cake	922.0	62.0	248.0	288.0	396.0	225.0	n.a.
Maize bran	888.0	51.0	117.0	72.0	209.0	45.0	n.a.
<i>Cenchrus ciliaris</i> hay	933.0	57.0	18.0	509.0	786.0	n.a.	n.a.

DM = Dry matter, CP = Crude protein, ADF = Acid detergent fibre, NDF = Neutral detergent fibre, EE= Ether extract, n.a. = Not analysed.

Source: Komwihangilo *et al.* (2005)

Supplementation of the animals with sun-dried browse leaves in T_2 , T_3 and T_4 resulted to higher ($P < 0.05$) total DMI than the control animals on T_1 (Table 2). Animals supplemented with browse (T_2 , T_3 and T_4) had higher total DMI per metabolic weight (DMI/W^{0.75}) than those on T_1 . PLM (T_3) and LLM (T_4) supplements were consumed in slightly higher quantities than PLM (T_2). Animals on T_4 consumed slightly more NPH (basal diet) than those on T_1 , T_2 or T_3 .

Supplementation of the goats with browse foliages resulted to ($P < 0.05$) higher weight gains in T_2 , T_3 and T_4 than the control group T_1 fed on NPH without browse supplementation (Table 3). Animals supplemented with LLM (T_4) had higher ($P < 0.05$) average daily weight gains (ADG) of 157.1 g d⁻¹ than those on T_2 and T_3 , which showed ($P < 0.05$) lowest ADG. Animals in the control group (T_1) lost weight (-71.4 g d⁻¹).

Table 3 Effect of browse leaves supplementation on DMI and growth performance in goats

Parameter	Control (T_1)	NLM (T_2)	PLM (T_3)	LLM (T_4)
Animals	5	5	5	5
Basal DMI (g)	284.7 ^a	276.5 ^a	276.5 ^a	299.8 ^b
Browse supplement DMI (g)	0 ^a	115.3 ^b	125.9 ^c	124.1 ^c
Maize bran DMI (g)	75.2 ^a	75.3 ^a	75.3 ^a	75.3 ^a
Total DMI (g)	359.9	467.1	477.7	499.2
Average initial body weight (kg)	14.4 ^a	14.4 ^a	14.7 ^a	14.8 ^a
Average final body weight (kg)	13.9 ^a	15.2 ^b	15.0 ^b	15.9 ^c
Average weekly liveweight change (kg)	-0.50 ^a	0.80 ^b	0.30 ^c	1.10 ^d
Average daily weight gain (ADG, g d ⁻¹)	-71.4 ^a	114.3 ^b	42.9 ^c	157.1 ^d

^{a,b,c,d} Means with different superscripts along same rows differ significantly ($P < 0.05$).

The significant treatment effects on live weight gains (Table 3) is consistent with other findings in the literature and this performance improvement from tree forage is attributed to the higher N content and more recently to tannin effects on enteric fermentation (Leng 1993). Studies elsewhere associate the increased feed efficiency to reduced methane emission another important aspect in the discussions on climate change and greenhouse gas emissions. Purchala *et al* (2005) reported that condensed tannins decrease methane emission. These feed evaluation results when combined with those of socio-economic studies on the main natural resource management project reported by Monela *et al* 2004 support the concept that agroforestry options have potential to mitigate climate change as well as increase adaptive capacity. In the same project area Nyadzi (2004) reported carbon sequestration potential of browse tree species ranging from 13.3 to 30.3 Mg/ha for *Leucaena pallida* and *Acacia crassicarpa*, respectively.

Conclusion

This study shows that tree forages have enormous potential to increase growth performance of livestock based on low quality forages in agro-pastoral systems. There are large differences in tannin concentration of the different browse species an area which call for more research on the characteristics of the different forage tree species in dry lands. This is a poorly studied area but of much importance especially with the current association of tannins with enteric fermentation efficiency and contribution to climate change mitigation.

Implications

Livestock feed security is a major limitation to livestock production in semi-arid lands. Findings from this study and related research show the potential of tree forages to increase animal production in these areas and consequently contribute to food security and poverty reduction. Furthermore the challenges on desertification, loss of biodiversity, climate change vulnerability and poverty in agropastoral communities call for more research on agroforestry-livestock interaction in the dry lands. The observation on variations in tannin concentration raises a key research question on tannins and their effect on ruminant nutrition. This is an area of high research priority as it will also support selection of best bet fodder tree species for scaling up.

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References

- Barrow, E., and W. Mlengi. 2003. "Trees as Key to Pastoralist Risk Management in Semi-Arid Landscapes in Shinyanga, Tanzania and Turkana, Kenya." Presented at the CIFOR-FLR conference, Bonn, Germany, May 2003. Online at www.cifor.cgiar.org/publications/corporate/cd-roms/bonn-proc/pdfs/papers/T3_FINAL_Barrow.pdf
- FAO 2006. Livestock Long shadow: environmental issues and options. Food and Agriculture Organisation of the United Nations, Rome pp. 390.
- Leng, R.A. 1993. Australian Journal of Agricultural Research 44 (1993) 363-80.
- Nyadzi GI. 2004. Nutrients and water dynamics in rotational woodlots: a case study in Western Tanzania. - Wageningen University and Research Centre, Wageningen, The Netherlands, 192 p.
- Monela, G., S. Chamshama, R. Mwaipopo, and D. Gamassa. 2004. A Study on the Social, Economic and Environmental Impacts of Forest Landscape Restoration in Shinyanga Region, Tanzania. Draft. Dar-es-Salaam: The United Republic of Tanzania Ministry of Natural Resources and Tourism, Forestry and Beekeeping Division, and IUCN The World Conservation Union, Eastern Africa Regional Office.
- Purchala R., Min B.R., Goeysh A.L. and Sahlu T. 2005. Journal of Animal Science 2005. 83:182-186

Improving the utilization of sugarcane (*Saccharum officinarum* L.) tops in goats: effect of supplementation with *Dichrostachys cinerea* fruits

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Introduction

Sugarcane (*Saccharum officinarum* L.) production in the Low veld of Swaziland has taken away most of the arable land that, previously, was the source of much-needed cereal and legume crop residues for ruminant livestock. Sugarcane tops are by-products of sugarcane production, which are low in protein content and thus require protein supplementation for better utilization (Kevelenge *et al.*, 1983). It is important to investigate the possibility of utilising the sugarcane tops as ruminant feed in conjunction with locally available feed resources with appreciable protein content. This study was, therefore, undertaken to evaluate the nutritive value of sugarcane tops as a basal diet when supplemented with *Dichrostachys cinerea* fruits which are abundant in the Low veld.

Material and methods

Sixteen castrated Small East African goats aged, between 18-22 months, and weighing on average 27.4 kg (standard deviation, 2.5 kg), were assigned to four diets, using a randomised complete block design, after the animals had been blocked according to initial live-mass. Each of the four diets (sugarcane tops alone, sugarcane tops + *D. cinerea* fruits, sugarcane tops + fishmeal and sugarcane tops + urea + molasses) was randomly allocated to the four animals in the four weight-blocks. Supplements provided equal amounts of N. The *D. cinerea* fruits were offered at the rate of 200 g/animal/day (Mlambo *et al.*, 2004). Goats were penned individually in metabolism crates and provided with water. Animals were allowed an adaptation period of 14 d before the commencement of a 7 d collection period. Nutrient digestibility and protein retention were estimated.

Results

Table 1 Intake, digestibility and protein retention in goats fed sugarcane tops with or without nitrogen supplements

Parameter	Cane tops + Supplements				s.e.m
	Cane tops alone	<i>D. cinerea</i> fruits	Molasses + urea	Fishmeal	
Intake (g Organic Matter/day)	589.40 ^b	656.30 ^c	557.80 ^{ab}	516.90 ^a	26.790
Organic matter digestibility	0.60 ^b	0.63 ^b	0.53 ^a	0.65 ^b	0.034
Neutral detergent fibre digestibility	0.66 ^b	0.72 ^b	0.58 ^a	0.70 ^b	0.037
Acid detergent fibre digestibility	0.63 ^a	0.63 ^a	0.61 ^a	0.66 ^a	0.038
Protein retention (g/day)	-2.80 ^a	9.60 ^d	5.00 ^c	0.50 ^b	1.140

^{a, d}In a row, means with the same superscripts are not significantly different.

Total organic matter intake was greatest in goats fed *D. cinerea* fruits suggesting that supplementation with *D. cinerea* fruits stimulated the intake and utilisation of sugarcane tops. At 9.6 g/d, *D. cinerea*-supplemented goats had the highest protein retention, followed by those supplemented with molasses and urea (5.0 g/d). Goats offered sugarcane tops alone had the lowest protein retention (-2.8 g/day).

Conclusions By offering the readily available and affordable *D. cinerea* fruits as a protein supplement at a rate of 200g per animal per day, the sugarcane farmers in the Low veld of Swaziland might be able to maintain their goats in good condition through the dry season.

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References

- Kevelenge, J. E. E., Said, A. N. and Kiflwalind, B. (1983). Nutritive value of four arable farm by-products commonly fed to dairy cattle by small-scale farmers in Kenya. *Tropical Animal Production* 8: 180-186.
- Mlambo, V., Smith, T., Owen, E., Mould, F.L., Sikosana, J.L.N., Mueller-Harvey, I., 2004. Tanniniferous *Dichrostachys cinerea* fruits do not require detoxification for goat nutrition: *in sacco* and *in vivo* evaluations. *Livestock Production Science* 90: 135-144.

Reducing dairy herd methane emissions through improved health, fertility and management

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Introduction

Early work on methane production from livestock looked at gross energy lost (Blaxter and Clapperton, 1965). Later the focus moved to feed utilisation efficiency and more recently to the environmental impact of methane emissions and greenhouse gases (IPCC, 2007). Livestock contribute about 16% of total atmospheric methane, behind fossil fuels and wetlands (Johnson & Johnson, 1995), with about 74% of the contribution from livestock coming from cattle (Tammenga *et al.*, 1992). Because of this, and the importance now attached to climate change, there has been an increased interest in the scope for reducing methane emissions. Cattle are the main source of methane from agriculture in the UK, with total emissions in the UK from this source declining over the last thirty years in line with falling livestock numbers (UKGGI, 2007). The dairy industry in the UK is estimated to contribute about 34% of total methane emissions from agriculture (UKGGI, 2007).

Dairy farming over the last thirty years has been characterised by an increase in intensification, and genetic selection for increased milk production. Modern Holstein Friesian dairy cows are associated with increased milk production per cow, lower body condition score, greater response of milk production to concentrate supplementation at pasture and reduced fertility and survival (Dillon *et al.*, 2006). The main mitigation strategies to reduce the total methane emissions from a dairy herd are diet manipulation and increased production efficiency. The former is considered a short-term solution, while the latter is thought to be solution for reducing the environmental impact of methane emissions. Methane emissions are believed to decrease exponentially with increasing milk yields per cow per year (Garnsworthy, 2004). However, these increases in milk production have been associated with an increase in twinning rate (Wiltbank *et al.* 2000), with its associated health problems (Bell & Roberts, 2007). Also, the reduced survivability caused by poor health, increases the number of heifers needed as replacements and the heifer replacement population from which the replacements are selected, thus increasing the methane produced per litre of milk

The aim of the present study was to investigate the predisposing factors associated with culling and the effects of improved survivability and reduction of young stock on the total methane emissions from a Holstein Friesian dairy herd.

Materials and methods

Data were obtained from the Langhill herd of Holstein Friesian cows, which are on a long-term genetic breeding and feeding systems project in Scotland (Pryce *et al.*, 1999). There were 2914 calvings (from 932 cows) during the study period from January 1990 to August 2005. The young stock are the offspring from the milking herd (bull and heifer calves), from which the replacement heifers are selected. All health problem incidences in this study were diagnosed and treated by the farm veterinarian. The incidences of culling (including death) and any health problems during each lactation were recorded for each cow. Cull cows were classified as voluntary (udder confirmation, surplus, temperament and old age) and involuntary (reproductive problem, foot/leg problem, udder problem including poor yield and high SCC, death and abortion). Health problems included: abortion, digital dermatitis (DD) (infection of the skin surrounding the claw, including foul of the foot and growths), displaced abomasums (DA), claw horn lesion including ulcers, hemorrhaging, white line disease and abscesses of the claw (CHL), ketosis, uterine infection, twinning, retained placenta (RP), mastitis (in at least one quarter), cystic ovary (at either ovary) and abnormal oestrous cycle (AOC) (anoestrus, not seen in heat, a repeat cycle, sub oestrus but not including cows with a cystic ovary).

Factors evaluated for each cow were: parity, genetic line, diet, liveweight post-calving, condition score at calving, calving assistance, number of calves born, calf sex, total birth weight of calves, post-calving cow to calf weight ratio, liveweight and condition score at drying off, length of drying off period, lactation length, calving interval and gestation length. Liveweight and condition score were measured within 48 hours of calving and when cows were dried off. Body condition score were recorded by a single operator before 2002 and by three operators after 2002, using a 0 to 5 scale with 0.25 intervals, where 0 is very thin and 5 is very fat (Lowman *et al.*, 1976). The operators were trained to ensure homogeneity of the data over time. The fertility measures evaluated were: days from calving to first service and calving to conception, days from calving to first heat observed, average number of services per conception and conception success or failure. Due to cows being culled, days from calving to conception, the number of services per conception and calving interval were only evaluated from cows that calved again. The average daily feed intake, average daily milk yield, average milk fat and protein content, body condition score and somatic cell count (SCC) were included in the analysis. Milk yields, milk compositions, feed intakes, body condition scores and SCC were split into four periods: one to 21 days in milk (DIM), one to 100 DIM, 101 to 200 DIM and 201 to 300 DIM. Milk yield was recorded daily and milk composition for fat and protein was recorded weekly along with SCC. Cows were fed *ad libitum* and feed intakes were recorded through Calan Broadbent gates (before 2001) or HOKO automatic feed measurement gates (after 2001). Body condition scores were recorded on a weekly basis.

The data were analysed using Genstat Version 7.2 (2004; Lawes Agricultural Trust, Rothamsted Experimental Research Station, Harpenden, Hertfordshire, UK). Using a chi-squared (χ^2) test, the incidence of each health problem and incidence of culling was analysed to test their association. The χ^2 test used Yates' correction to remove bias in the discrete distribution. The effects of the explanatory variables on culling were investigated using a general linear mixed model as described by Breslow and Clayton (1993). Cow identity was added for all models as a random effect. A binomial error distribution was assumed and a logistic link function was added. Wald tests, which use a χ^2 distribution, were used to examine the level of significance of the differences. The continuous variables were separated into four classes using interquartile ranges of each variable thus preventing outlying data from confounding the results. Each variable was analysed with culling (univariate analysis) to reduce the number of variables. Any variable that had a *P*-value greater than 0.25 became a candidate for a multivariate culling model (Hosmer & Lemeshow, 2000). The resulting variables were then used in a multivariate analysis, with the most significant variables from the univariate analysis being added first. Variables that had confounding effects between each other were tested by running the model with and without each variable; any variable showing a significant effect was retained. Significance was attributed at *P*=0.05 or greater.

Methane emissions for the animals and their manure were taken from the IPCC (1997) Tier II emission factor methodology. Annual methane emissions per head were stratified by livestock class as follows: milking cows (152 kg), 24 month old heifers (51 kg), 18 month heifers (40 kg), 12 month heifers (31 kg), 6 month heifers (18 kg), 12 month bulls (39 kg) and 6 month bull calves (24 kg). Average liveweight for these classes were 619, 550, 452, 330, 178, 482 and 252 kg respectively. Other relevant data from the herd were average daily milk yield (27.4 kg), milk fat composition (4.2%), gestation length (282 days for milking cows and 280 days for pregnant heifers), calf birthweight (46.1 kg for milking cows and 42.3 kg for pregnant heifers), lactation length (325 days) and drying off period (62 days). The follow assumptions were made: digestible energy of 65%; methane conversion factor of 6%; ash content of manure of 8%; methane producing capacity of manure of 0.24 m³/ kg⁻¹VS (UKGGI, 2007). Female animals older than 6 months were also assumed to have grazed on good quality pasture.

Results

Table 1 shows the calving performance from January 1990 to August 2005 for the Langhill herd and its effect on the overall methane contribution of the herd using the IPCC emissions factors.

To maintain the same herd size, savings in methane emissions can be made by reducing the number of young stock. If the culling rate or replacement rate of 25% per year (54 replacement heifers) was reduced by 5% (to 43 replacement heifers), the heifer replacement population could be reduced. If the 11 heifers (potentially equivalent to the 5% reduction in replacements) were then slaughtered at 18 months of age in a beef finishing system, this could potentially reduce heifer replacement emissions by 5%. However, if all the bull calves were slaughtered at 6 months instead of on a barley beef system at 12 months (as with 61% of the finished bull calves over the studied period), the estimated total methane produced would decline from 3150 to 2400 kg, which is a 24% reduction. The methane produced by the young stock is 5327 kg per 100 breeding cows, which would potentially be reduced by 10% to 4776 kg per 100 breeding cows if herd replacements were reduced by 5% and sold at 18 months of age and all bull calves were slaughtered around 6 months of age.

Table 1 Langhill herd calving figures during the study period and estimated methane contribution per annum.

Calving cows	216		Heifer calves	Bull calves
Twinning rate (%)	4.5	No. born	106	106
Total calves born	235	Sold and died at 1 year old or less	5	106
Calves born less deaths	212	Sold and died at more than 12 months	47	
Calf mortality at birth (%)	10.0	Replacements	54	
Bull calf mortality 0-12 months (%)	6	Methane from young stock < 1 year old*	3256	1200
Heifer calf mortality 0-12 months (%)	2	Methane from young stock > 1 year old*	5099	1950
Heifer calf mortality 12-24 months (%)	1	Methane from milking herd		32832
Culling rate/replacement rate (%)	25	Total for herd (herd plus young stock)		44337
Calving rate (%)	94			
Heifer:bull calf ratio	1:1			
Heifers sold < 12 months (%)	5	*Methane emission estimates for young stock exclude deaths.		
Bull calves sold at 6 months (%)	39			
Bull calves sold at 12 months (%)	61			

Reducing numbers of young stock is one way of reducing methane emissions. The number of cows required to produce the required amount of milk is less for a higher yielding herd and this is an important factor when milk quotas are in operation. Instead of 216 cows averaging 6853 kilograms for 300 DIM, the same amount of milk could be achieved with a 5% increase in the herd's average milk production, which would require 5% fewer milking cows or a reduced replacement rate of 20% to maintain the same size milking herd. Ill health was associated with culling (voluntary and involuntary) ($\chi^2 = 105.27$, *P*<0.001) and the main health problems associated with culling were AOC ($\chi^2 = 29.34$, *P*<0.001), DD ($\chi^2 = 24.68$, *P*<0.001), mastitis ($\chi^2 = 47.44$, *P*<0.001), uterine infection ($\chi^2 = 18.02$, *P*<0.001), RP (χ^2

=12.00, $P < 0.001$), twinning ($\chi^2 = 15.03$, $P < 0.001$), abortion ($\chi^2 = 14.76$, $P < 0.001$) and ketosis ($\chi^2 = 7.32$, $P < 0.01$). The culling rate for the herd was about 25% per year (728 cows), with 60% occurring before the fourth lactation. Of the cows culled, 64% were classified as involuntary, of which 58% were culled before the fourth lactation. Factors associated with cows that were culled are shown in Table 2.

Table 2 Means (se) from the multivariate analyses showing the main factors associated with cows that were culled

Factor	Wald statistic	df	P					
Uterine infection	3.79	1	0.05	No infection	Infection			
				0.25 (0.01)	0.35 (0.02)			
RP	3.99	1	<0.05	No RP	RP			
				0.25 (0.01)	0.38 (0.04)			
Total milk yield for 300 DIM (kg)	11.45	3	<0.05	(<5685)	(5685 to 7202)	(7203 to 8579)	(>8579)	
				0.47 (0.02)	0.23 (0.02)	0.18 (0.02)	0.16 (0.01)	
Total milk yield for 201 to 300 DIM (kg)	8.75	3	<0.05	(<1400)	(1400 to 1849)	(1850 to 2294)	(>2294)	
				0.31 (0.02)	0.18 (0.02)	0.13 (0.01)	0.15 (0.01)	
Calving condition score	10.66	3	<0.05	(<2.50)	(2.50 to 2.75)	(2.76 to 3.00)	(>3.00)	
				0.21 (0.01)	0.26 (0.02)	0.26 (0.02)	0.39 (0.03)	
Avg. milk yield (kg)	29.81	3	<0.001	(<22.71)	(22.71 to 27.27)	(27.28 to 31.64)	(>31.64)	
				0.29 (0.02)	0.20 (0.02)	0.25 (0.02)	0.30 (0.02)	
Avg. SCC for 1 to 100 DIM ('000)	8.15	3	<0.05	(<26)	(26 to 44)	(45 to 107)	(>107)	
				0.18 (0.02)	0.21 (0.02)	0.25 (0.02)	0.37 (0.02)	
Calving to conception (days)	10.87	3	<0.05	(<73)	(73 to 96)	(97 to 129)	(>129)	
				0.28 (0.02)	0.24 (0.02)	0.24 (0.02)	0.39 (0.02)	
Calving to first service (days)	10.80	3	<0.05	(<63)	(63 to 74)	(75 to 87)	(>87)	
				0.16 (0.02)	0.12 (0.01)	0.14 (0.01)	0.20 (0.02)	
Lactation no.	17.22	4	<0.001	1	2	3	4	≥ 5
				0.21 (0.01)	0.19 (0.02)	0.25 (0.02)	0.27 (0.02)	0.48 (0.02)

Table 2 shows that culling was associated with cows that had either a low or high average daily milk yield ($P < 0.001$), were older ($P < 0.001$), suffered from a uterine infection ($P = 0.05$) and/or RP ($P < 0.05$). Also, cows that were culled were associated with a low total milk yield for 300 DIM and from 201 to 300 DIM ($P < 0.05$), a high calving condition score, average SCC for one to 100 DIM, calving to conception and calving to first service ($P < 0.05$ respectively). Some of the factors shown in table 2 are associated with health problems such as mastitis, twinning (Bell & Roberts, 2007) and fertility.

Conclusions

Methane emissions from dairy herds can be reduced by reductions in young stock and milking herd numbers. Milk production can be increased by improved herd health and minimising involuntary culling. If Holstein Friesian dairy cow milk yields are to continue to increase through selection, this could help reduce dairy herd numbers as long as it is accompanied with an improvement in the dairy cow's environment and health.

Implications

Not only would improvements in the health and the environment of dairy cattle be beneficial for cow welfare but they would also significantly contribute to improved efficiencies in production and reduced methane emissions.

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References

- Bell, M.J., and Roberts, D.J., 2007. Effect of twinning on the feed intake, performance and health of dairy cows. *Livestock Science*; 107:274-281.
- Blaxter, K.L., Clapperton, J.L., 1965. Prediction of the amount of methane produced by ruminants. *British Journal of Nutrition*, 19:511-522.
- Breslow NE, and Clayton DG, 1993. Approximate inference in generalized linear mixed Models, *Journal of The American Statistical Association*, 88:9-25.
- Dillon, P., Berry, D.P., Evans, R.D., Buckley, F., Horan, B., 2006. Consequences of genetic selection for increased milk production in European seasonal pasture based systems of milk production. *Livestock Science*, 99:141-158.
- Garnsworthy, P.C., 2004. The environmental impact of fertility in dairy cows: a modelling approach to predict methane and ammonia emissions. *Animal Feed Science and Technology*, 112:211-223.
- Hosmer, D.W. and Lemeshow, S, 2000. *Applied Logistic Regression*. John Wiley & Sons, Toronto, Canada.
- IPCC, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual. Cambridge, UK

IPCC, 2007. *Climate Change 2007. The IPCC Scientific Assessment*. Cambridge University Press, Cambridge, UK.

Johnson, K.A., Johnson, D.E., 1995. Methane emissions from cattle. *Journal of Animal Science*, 73:2483-2492.

Lowman, B.G., Scott, N. and Somerville, S., 1976. Condition scoring of cattle. East of Scotland College of Agriculture, Edinburgh, Bulletin no. 6.

Pryce, J.E., Nielson, B.L., Veerkamp, R.F. and Simm, G., 1999. Genotype and feeding system effects and interactions for health and fertility traits in dairy cattle. *Livestock Production Science*, 57:193-201.

Tamminga, S., 1992. Nutrition management of dairy cows as a contribution to pollution control. *Journal of Dairy Science*, 75:345-357.

UK Greenhouse Gas Inventory (UKGGI, 2007). 1990 to 2005 annual report for submission under the framework convention on climate change. Defra, London, UK.

Wiltbank, M.C., Fricke, P.M., Sangsritavong, S., Sartori, R. and Ginther, O.J., 2000. Mechanisms that prevent and produce double ovulations in dairy cattle. *Journal of Dairy Science*, 83:2998-3007.

Simulated global warming potential and ammonia emission figures for a range of suckler herd breeding strategies and beef cattle finishing systems

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Introduction

Diffuse gaseous pollution is today recognised as one of the major environmental issues of importance on a global scale. It arises from a diverse range of natural, industrial and agricultural activities across the world. Knowledge of the potential that gaseous pollutants have to impact detrimentally on the global environment has resulted in concerted political effort at national, regional and global scales. The United Nations Framework Convention on Climate Change (The “Kyoto Protocol”) is one such effort, where signatory nations have agreed to reduce the emissions of Greenhouse Gases (GHG) by an average of 5.2% below 1990 levels by 2012 at the latest (Moss, 2001). Similarly, at Gothenburg in 1999, the United Nations Economic Commission for Europe (UNECE) Convention on Long Range Transboundary Air Pollution (CLRTAP) has obliged signatory nations to reduce their ammonia (NH₃) emissions to the atmosphere by the year 2010 (the “Gothenburgh Protocol”). Along with the European Union (EC directive on Integrated Pollution Prevention and Control {IPPC}) and most industrialised western nations, the UK Government has accepted these international treaty obligations. Consequently, they have implemented national policies that aim to achieve them (e.g. the UK is obliged to reduce its total NH₃ emissions to below 297 kt per annum by 2010). Today, UK Government policy seeks to diminish the Global Warming Potential (GWP) and NH₃ emissions from agricultural activities even further, through reductions in Greenhouse Gas (GHG) and NH₃ emissions associated with livestock production in particular.

For suckler beef production systems these GHGs are principally methane (CH₄) and nitrous oxide (N₂O) associated with rumen fermentation of feeds consumed and management of manure produced by animals and spread on land. NH₃ release from suckler beef production systems are principally associated with cattle grazing, emissions during winter housing, storage and management of animal manure’s and spreading of both animal manure’s and artificial fertilisers on land. Recent changes to common agricultural policy (CAP) production linked subsidy payments across the European Union (EU) are encouraging farmers to re-evaluate their production systems with a view to improving overall system efficiency in an effort to maintain economic sustainability in future years. Consequently, there is now a unique opportunity for both environmental and economic issues to be addressed concurrently as beef production systems change across the EU. Identifying those suckler herd management strategies and beef cattle finishing systems which minimise gaseous emissions may help policy makers to formulate revised CAP support mechanisms. In addition, it may inform beef farmers seeking to adopt more economic and environmentally sustainable suckler beef production systems in future.

The project reported here comprises a simulation exercise designed to calculate the GWP and NH₃ emissions associated with a typical suckler beef herd of 100 cows along with the necessary replacement heifers and associated finishing beef cattle systems where all the cattle are finished on the same farm. It is further assumed that the farm is typical of upland UK, grassland based beef farms with modest inputs of fertiliser.

Materials and methods

The suckler beef production systems simulated were based on five potential suckler herd management strategies (HS) as follows:- dairy x beef suckler cows (Dx), pure bred beef cows (PB), a 3-way rotational beef breed crossing strategy (RO), a “composite” beef herd breeding strategy (CO) and a future beef herd management strategy based on the availability and use of sexed semen (SS). For the PB, RO, CO and SS strategies replacement heifers were assumed to be home bred whilst for the Dx strategy replacement heifers were assumed to be purchased as calves and reared within the system. In addition to these 5 herd management strategies, simulations were also conducted according to either a 12, 18, 24 or 30 month weaned calf finishing system (FS) giving a total of 20 system combinations for comparison. Duplicate simulations were carried out for each of these 20 combinations by assuming two typical, yet contrasting breed types (based on UK & continental breeds) within each of the 20 possibilities. Both CH₄ and N₂O outputs were simulated on the basis of the Tier 2 methods adopted by the Intergovernmental Panel on Climate Change (IPCC, 1996, 2000). Similarly, NH₃ outputs were simulated on the basis of the emissions factors detailed by Misselbrook *et al*, (2000) and (Misselbrook, 2003).

Both CH₄ and N₂O simulated figures were converted from GHG outputs into GWP figures for each of the duplicate system combinations according to the conversion factors assumed by IPCC 1996 and expressed as tonnes of CO₂ equivalents per year. Total NH₃ outputs were calculated for all of the major sources listed above and expressed as kg of NH₃ per year. Cattle data feed input and carcass weight output parameters typically associated with each of the 20 system combinations and necessary to calculate the simulated GWP and NH₃ emissions were derived using the BREEDS bioeconomic model which simulates beef production systems defined by the user (Roughsedge *et al*, 2003). In this simulation exercise, figures were generated for an assumed suckler herd of 100 cows, plus all associated heifer replacements along with all weaned calves taken through to slaughter on the various FS listed above. All simulated

GWP and NH₃ emission figures simulated were then statistically analysed by ANOVA using Genstat 5 according to a 5 x 4 (HS x FS) factorial experimental design.

Results

Total GWP figures for each 100-cow system, for each of the 20 HSxFS combinations are given in Table 1. Both HS ($P<0.05$) and particularly FS ($P<0.001$) significantly influenced the GWP of the simulated 100 cow suckler herd system. GWP of the HS ranged from a low of 361 for the PB HS to a high of 438 t/year for the Dx HS largely as a result of more animals being kept on the farm since replacements heifers were purchased rather than homebred. The FS in particular, progressively increasing GWP from 316, 365, 397 to 462, t/year for the 12, 18, 24 and 30 months FS respectively with the largest effect being seen within the Dx and SS HS. The relative GWP contributions from the suckler herd, heifer replacements and finishing cattle sections of the overall simulated 100-cow herds are shown in Figure 1.

Table 1 Simulated GWP output figures for different HS x FS suckler beef production systems (t CO₂ eq / 100-cow system) – [Values not sharing common superscripts differ significantly].

Herd system (HS)	Finishing system (FS)				Mean	Sig of effects		
	12	18	24	30		HS	FS	HSxFS
Dx	360	410	450	534	438 ^a			
PB	301	343	371	429	361 ^b			
RO	316	361	390	450	380 ^c			
CO	306	352	381	447	372 ^d			
SS	295	358	392	449	373 ^d			
Mean	316 ^a	365 ^b	397 ^c	462 ^d		*	***	*
Sed's:	HS 1.7;		FS 1.5;		HSxFS 3.3.			

Total NH₃ emission figures for each 100-cow system, for each of the 20 HSxFS combinations are given in Table 2. Both HS ($P<0.05$) and particularly FS ($P<0.001$) significantly influenced the NH₃ emissions of the simulated 100 cow suckler herd system. NH₃ emission of the HS ranged from a low of 1900 for the SS HS to a high of 2160 kg/year for the Dx HS. The 30 month FS in particular, increasing NH₃ emissions to 2388 kg/year from 1773, 1875, 1881 for the 12, 18 and 24 months FS respectively. The relative NH₃ emission contributions from the suckler herd, heifer replacements and finishing cattle sections of the overall simulated 100-cow herds are shown in Figure 2.

Table 2 Simulated NH₃ output figures for different HS x FS suckler beef production systems (kg / year / 100-cow system) – [Values not sharing common superscripts differ significantly].

Herd system (HS)	Finishing system (FS)				Mean	Sig of effects		
	12	18	24	30		HS	FS	HSxFS
Dx	1929	2026	2038	2647	2160 ^a			
PB	1784	1873	1879	2381	1979 ^b			
RO	1757	1854	1860	2332	1951 ^{bc}			
CO	1713	1807	1810	2294	1906 ^c			
SS	1680	1815	1819	2288	1900 ^c			
Mean	1773 ^a	1875 ^b	1881 ^b	2388 ^c		*	***	*
Sed's:	HS 28.9;		FS 25.9;		HSxFS 57.9.			

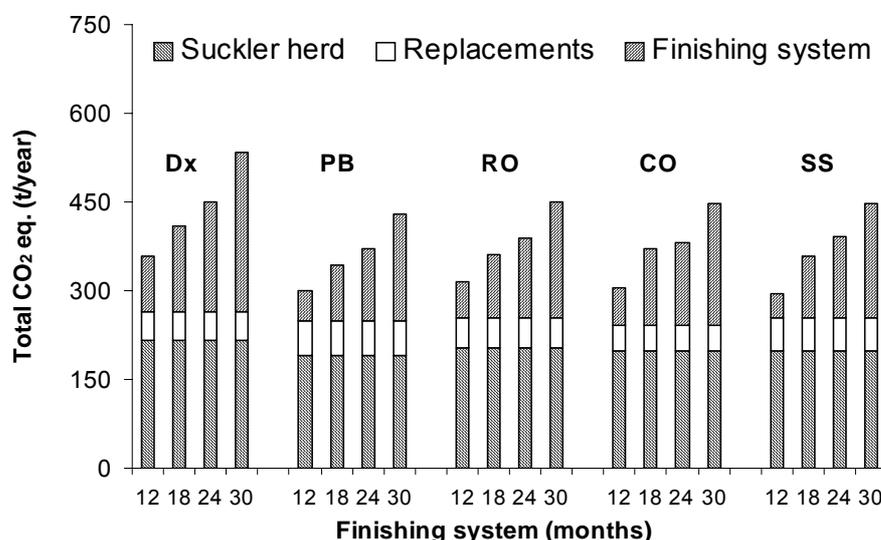


Figure 1 Relative GWP contributions from the suckler breeding herd, heifer replacements and finishing cattle

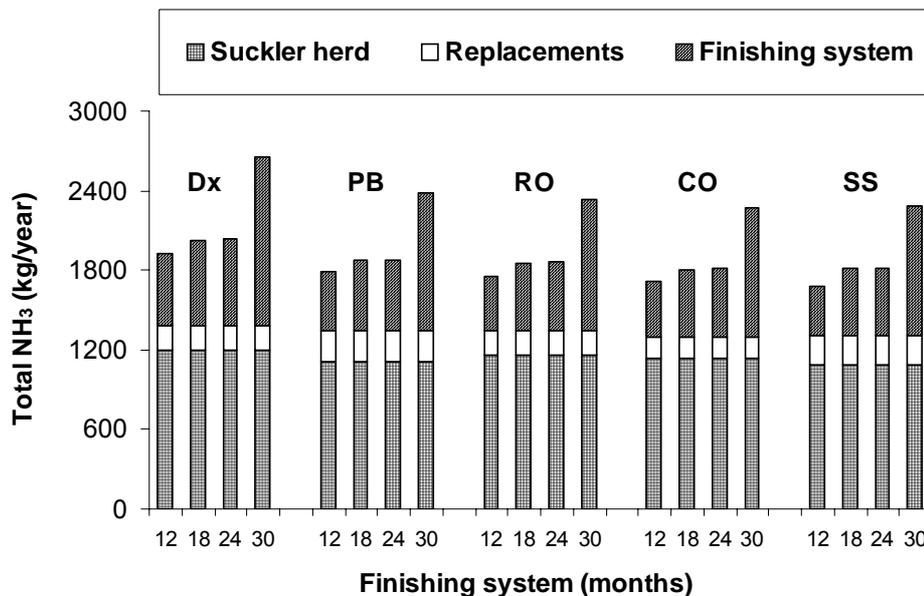


Figure 2 Relative NH₃ contributions from the suckler breeding herd, heifer replacements and finishing cattle

When expressed as GWP per tonne of carcass weight sold (t CO₂ Eq/t carcass weight) from each of the various systems, the FS significantly ($P < 0.001$) increased GWP output at each incremental stage. Values were 12.56, 14.08, 15.15 and 16.07 for the 12, 18, 24 and 30 months' systems respectively. This same general pattern of increasing GWP per unit carcass weight sold as FS increased from 12 to 30 months was evident in all HS simulated.

Conclusions

These simulations suggest that opportunities exist to reduce the GWP and NH₃ emissions through optimum choice of suckler herd management strategy and particularly beef cattle finishing systems on suckler beef farms. Optimum utilisation of hybrid vigour and suckler cow fertility are likely to be one of the contributors to this effect with high calf growth rates and low heifer replacement rates being characteristic of efficient suckler beef production systems. In addition, these simulations also suggest that relatively intensive, short duration finishing systems that make efficient use of input feedstuffs and slaughter animals at younger ages could substantially reduce the GWP and NH₃ emissions of UK suckler beef production systems. Each reduction in finishing time by six months resulted in a significant reduction in gaseous emissions indicating that even modest improvements in the efficiency of beef cattle finishing systems could substantially mitigate GWP. On farms therefore, it would not be necessary to change from a 30 month to a 12 month finishing systems to reduce GWP. In practice, this means that almost all beef farmers are likely to be able to achieve some reductions in GWP and NH₃ emissions through seeking achievable efficiency savings but without making substantial capital investment in major changes to their production systems.

Implications

Governments and farmers should strive to improve the overall efficiency of suckler beef production systems across the world by reducing the time it takes to produce each kg of carcass beef consumed by the human population. By doing so, Government objectives to reduce the GWP and NH₃ emissions associated with suckler beef production will be achieved. Simultaneously, both feed conversion and fixed cost efficiency will be improved on farms, thereby enhancing the economic sustainability of beef production. A win-win scenario for both the global environment and agricultural businesses alike.

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References

- IPCC. 1996. Climate change 95. Impacts, adaptations and mitigation of climate change: Scientific – Technical analyses. Cambridge University Press, Cambridge, UK.
- IPCC. 2000. Good practice in inventory preparation for agricultural sources of CH₄ and N₂O. (<http://www.ipcc.ch/>).
- Roughsedge, T; Amer, P. R., and Simm, G. 2003. A bio-economic model for the evaluation of breeds and mating systems in beef production enterprises. *Animal Science*, 77: 403-416.
- Misselbrook, T.H., Van der Weedenm, T.J., Pain, B.F., Jarvis, S.C., Chambers, B.J., Smith, K.A., Phillips, V.R. and Demmers, T.G.M. 2000. Ammonia emission factors for UK agriculture. *Atmospheric Environment*, 34: 871-880.
- Misselbrook, T.H. 2003. Updating the inventory of ammonia emissions from UK agriculture for the years 2000 and 2001. Report to Defra (Project No: AM0113). IGER, North Wyke, Okehampton, Devon EX20 2SB.
- Moss, A. R. 2001. Environmental control of methane production by ruminants. In: *Greenhouse Gases and Animal Agriculture*. Proceedings of the 1st International Conference on Greenhouse Gases and Animal Agriculture, (Ed. J. Takahashi), Dept of Animal Science, Obihiro University of Agriculture and Veterinary Medicine, Obihiro, Hokkaido, 080-8555, Japan. 35-43.

Methane mitigation in ruminants: from rumen microbes to the animal

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Decreasing the production of methane (CH₄) from ruminant livestock is desirable both as a strategy to reduce global greenhouse gas emissions and as a means of improving feed conversion efficiency. Decreases in CH₄ production have been obtained using different approaches that induce changes in metabolic pathways, that alter the rumen microbial consortium and/or that influence the animal digestive physiology. This paper presents a selection of proved as well as some potential mitigation strategies.

Mechanisms of methanogenesis in the rumen

In the anaerobic conditions prevailing in the rumen, the oxidation reactions required to obtain energy in the form of ATP release hydrogen. The amount of hydrogen produced is highly dependant on the diet and type of rumen microbes as the microbial fermentation of feeds produces different end products that are not equivalent in term of hydrogen output. For instance, the formation of propionic acid consumes hydrogen whereas the formation of acetic and butyric acids releases hydrogen. Methanogenesis is the mechanism favoured by the rumen to avoid hydrogen accumulation. Free hydrogen inhibits dehydrogenases and affects the fermentation process. The utilisation of hydrogen and CO₂ to produce CH₄ is a specificity of methanogenic archaea. The methanogens interact with other rumen microorganisms enhancing the energy efficiency and extent of feed digestion. Positive interactions have been described for cellulolytic (*Ruminococcus albus* and *R. flavefaciens*) and non-cellulolytic bacteria (*Selenomonas ruminantium*), protozoa, and fungi (reviewed by McAllister *et al.*, 1996).

The metabolic pathways involved in hydrogen production and utilisation and the activity of methanogens are two important factors that should be considered when developing strategies to control methane emissions by ruminants. Reduction of hydrogen production should be achieved without impairing feed fermentation. Reducing methanogens activity and/or numbers should ideally be done with a concomitant stimulation of pathways that consume hydrogen to avoid the negative effect of the partial pressure increase of this gas. Many mitigating strategies proposed have indeed multiple modes of action.

Mitigation through biotechnologies

Immunisation and biological control

Several biotechnological strategies are currently being explored. A vaccine against three selected methanogens decreased methane production by nearly 8% in Australian sheep (Wright *et al.*, 2004). However, vaccination using a different set of methanogen species or in other geographical regions did not elicit a positive response (Wright *et al.*, 2004, Clark *et al.*, 2007). The highly diverse methanogenic community present in animals reared under different conditions (Wright *et al.*, 2007) might account for immunization failures. A more fundamental approach based on the genomic information of methanogens will hopefully identify common targets across species that could be used for the development of second generation vaccines (Attwood and McSweeney, 2008). More recently, passive immunisation was also assayed using antibodies prepared from hen's eggs. Antibodies decreased methane production *in vitro* but the effect was short-lived (Cook *et al.*, 2008).

Some bacteriocins are known to reduce methane production *in vitro* (Callaway *et al.*, 1997, Lee *et al.*, 2002). Nisin is thought to act indirectly, affecting hydrogen producing microbes in a similar way to that of the ionophore antibiotic monensin (Callaway *et al.*, 1997). However, there is no published *in vivo* trial of the effects of this bacteriocin on methane. Nisin is widely used in the food industry as a conservative and fears of microbial cross-adaptation might prevent its approval as a feed additive. A bacteriocin obtained from a rumen bacterium, bovicin HC5, decreased methane production *in vitro* up to 50% without inducing methanogens' adaptation (Lee *et al.*, 2002). Klieve and Hegarty (1999) also suggested the use of archaeal viruses to decrease the population of methanogens but, to our knowledge no bacteriophages from rumen methanogens have been isolated.

Probiotics

The use of probiotics or the stimulation of rumen microbial populations capable to decrease methane emissions potentially remains an interesting approach. Diverting hydrogen from methanogenesis towards acetogenesis has been assayed by several authors. The final product of the reaction, acetate, has the additional advantage of being a source of energy for the animal. However, in the rumen environment, acetogens are less efficient than methanogens in the competition for reducing equivalents and attempts to boost their activity had been so far unsuccessful. The recent isolation of new, high-hydrogen utilising species from diverse gut environments could offer a better alternative than previously tested acetogens (Klieve and Joblin, 2007). Methanotrophy, i.e. the oxidation of methane, was reported to be less than 0.5% *in vitro* (Kajikawa *et al.*, 2003). However, it has not been quantified *in vivo* where conditions at the rumen epithelium may favour aerobic oxidation of methane. Capnophily, i.e. the ability to use CO₂, is also present in the rumen. Capnophilic bacteria also use hydrogen to produce organic acids as final products but the influence that they have on hydrogen balance is not known.

Elimination of protozoa

Hydrogen is one of the major end products of the rumen protozoa metabolism and a physical association between protozoal cells and methanogens exist in the rumen ecosystem. Methanogens associated extra- and intra-cellularly to ciliate protozoa have been estimated to contribute between 9 to 37% of the rumen methanogenesis (Finlay *et al.*, 1994, Newbold *et al.*, 1995). The removal of protozoa from the rumen (defaunation) has been shown to reduce CH₄ production by up to 50% depending on the diet (reviewed by Hegarty, 1999). The effect of rumen protozoa on methane production and on methanogens has been recently investigated by molecular biology. The decrease in methane production of 26% per kg DM intake in protozoa-free lambs was related to a decrease in the proportion of methanogens in the total bacterial population of the whole ruminal content (McAllister and Newbold, 2008). In another study, whereas CH₄ production decreased by 20% in protozoa-free sheep (Morgavi *et al.*, 2008), the quantity of methanogens estimated by qPCR, as well as their diversity estimated by PCR-DGGE was not different between faunated and defaunated animals (Mosoni *et al.*, unpublished) suggesting that the decreased methanogenesis might be due to a reduction in the amount of hydrogen substrate.

Mitigation through additives

Ionophores and organic acids

Among feed additives, ionophore antibiotics such as monensin, typically used to improve efficiency of animal production, are known to decrease methane production (Beauchemin *et al.*, 2008). This is due to a shift of fermentation towards propionogenesis, but these additives are now forbidden in the European Union. Other chemical additives, of which neither the efficiency nor the innocuity has been proven, are not described here. Organic acids (malate, fumarate) have been assayed as diet additives. *In vivo* results are inconsistent. An exceptional decrease in methane production by 75% has been shown by (Wallace *et al.*, 2006) with 10% encapsulated fumaric acid in the diet of sheep, but the hydrogen used to produce propionate from fumarate is not enough to explain such a drop in methane. Further research is needed with such a product. It has been suggested by Martin (1998) that the high malate content in fresh forages at early growth stage, especially lucerne, could lead to significant changes in rumen fermentation. McCaughey *et al.* (1999) observed a decrease in methane production by 10% when replacing grasses by a mixture of lucerne and grasses (70:30). Assuming an increase in dietary malate of 3%, the decrease in methane could be explained by this organic acid. However, other factors may be involved such as the high intake and a high rate of passage out of the rumen for lucerne, and presence of saponins.

Plant extracts

In recent years, there is growing interest in the use of plant secondary compounds (tannins, saponins, essential oils) as a CH₄ mitigation strategy because of their natural origin in opposition to chemicals additives. Most trials with plant extracts have been done *in vitro* and the response of these molecules on methanogenesis is highly variable. For tannin-containing plants, the antimethanogenic activity has been attributed mainly to condensed tannins. Two modes of action of tannins on methanogenesis have been proposed by Tavendale *et al.* (2005): a direct effect on ruminal methanogens and an indirect effect on hydrogen production due to lower feed degradation. The mode of action of saponins seems to be clearly related to their anti-protozoal effect (Newbold *et al.*, 1997). However, the effect of saponins on protozoa may be transient (Koenig *et al.*, 2007). It has been recently shown that garlic oil and some of its components decreased *in vitro* methane production (Busquet *et al.*, 2005, Macheboeuf *et al.*, 2006). A direct inhibition of methanogens has been observed by qPCR (McAllister and Newbold, 2008). Additional research *in vivo* is required to determine the optimal dose of the active compounds, to consider the potential adaptation of the microbes, the presence of residues in animal products as well as the potential anti-nutritional side-effects of such molecules (Calsamiglia *et al.*, 2007).

Mitigation through feeding

The nutritional management opportunities discuss here for reducing CH₄ emissions from ruminants are readily available. They include the increase in concentrates and lipid supply. The field application of these strategies will be developed in another paper (O'Mara *et al.*, this symposium). In the following lines we will consider only the modes of action of concentrates and of lipids.

Increased proportion of concentrates in the diet

Replacing plant fibre in the diet with starch induces a decrease in ruminal pH and modifications in microbial populations. A shift of VFA production from acetate towards propionate occurs, which results in less hydrogen production. The poor tolerance to low pH by protozoa and cellulolytic bacteria decreases further hydrogen production. A positive correlation between cellulolytic and methanogens in the rumen of different animal species (cattle, sheep, llamas, deer) has been shown (Morvan *et al.*, 1996), except in the buffalo. This exception was explained by the fact that *F. succinogenes*, a non-hydrogen-producing cellulolytic species, was the major cellulolytic bacteria of this animal. The relationship between concentrate proportion in the diet and methane production is curvilinear (Sauvant and Giger-Reverdin, 2007) with a marked decrease in methane observed when dietary starch is higher than 40%. This has been assessed in young bulls by Martin *et al.* (2007a). Compared to diets containing 30% starch, a diet containing 45% starch decreased methane production by 56% without altering animal growth.

Adding lipids in the diet

Dietary fat seems a promising nutritional alternative to depress ruminal methanogenesis without decreasing ruminal pH as opposed to concentrates. Medium-chain fatty acids (FAs) are known to affect methanogen numbers (Machmüller *et al.*, 2003) but not long-chain FAs such as linolenic acid (Mosoni *et al.*, unpublished). Polyunsaturated FAs also contribute to methane decrease through a toxic effect on cellulolytic bacteria (Nagaraja *et al.*, 1997) and protozoa (Doreau and Ferlay, 1995). This effect, observed with all long-chain FAs, is probably through an action on the cell membrane particularly of Gram-positive bacteria. Linolenic acid is toxic to cellulolytic bacteria: *F. succinogenes*, *R. albus* and *R. flavefaciens* grown *in vitro* (Maia *et al.*, 2007). This has not been confirmed *in vivo* on dairy cows by Mosoni *et al.* (unpublished). These microbial changes favour a shift of ruminal fermentation towards propionate, and thus to an increase in hydrogen utilisation. These multiple actions may impair digestion if the number and activity of primary microbial fermentors is too affected or if the negative effect on methanogens leads to an accumulation of hydrogen in the rumen. Biohydrogenation of polyunsaturated FAs results in an uptake of hydrogen. However, its influence on methanogenesis is low since the complete hydrogenation of one mol of linolenic acid spares 0.75 mol of methane. As adaptation of the rumen microflora to FA supplementation over the long term may be possible, the sustainability of methane suppressing by FA supply should be thoroughly tested (Grainger *et al.*, 2008).

The practical use of lipids to reduce methanogenesis has been reviewed by Beauchemin *et al.* (2008). A special attention should be paid to linolenic acid. It has been shown *in vivo* that FAs from linseeds may decrease methane production in growing lambs (Machmüller *et al.*, 2000) or in dairy cows (Martin *et al.*, 2007b, 2008) without altering animal performances. Supplemental linolenic acid also contributes to improve the quality of fatty acids of ruminant products and this may compensate for the additional cost of lipid supply.

What kind of cow for a lower methane production?

The decrease in emissions through low methane-producing animals is an ongoing debate. It has been established by several research groups that within-animal variability is high and that the ranking of animals in CH₄ production differs with changes in diet and/or physiological stages (Pinares-Patiño *et al.*, 2007) or between successive measurements for a same diet and a same feed intake (e.g. Munger and Kreuzer, 2008). These latter authors evaluated the repeatability (i.e. between animals/total variation) as 47 and 73% depending on diets. The repeatability may be due either to between-animal differences in microbial ecosystems or to intrinsic animal characteristics such as retention time of particles in the rumen. Until now, there is no evidence for the effect of these factors, although methane and VFA productions are correlated. It can be assumed that for a same intake cows with a low retention time of particles in the rumen produce less methane than cows with a high retention time as suggested by Pinares-Patiño *et al.* (2001); however, there is not enough data to analyse the heritability of methane production and thus to consider a possible selection of animals for this trait. Hegarty *et al.* (2007) have shown that the selection on feed efficiency and residual feed intake reduces methane production. Such approach is promising but requires additional research.

Conclusions

Methane mitigation in ruminants is possible through various strategies. Today, the feeding management approach is the most developed. Other strategies (biotechnologies, additives) are promising but the diversity and plasticity of functions of the rumen bacterial and methanogenic communities may be a limiting factor for their successful application. In any case, before practical solutions are proposed for field application more research *in vivo* and time are needed. The sustainability of methane suppressing strategies is an important issue.

Implications

Strategies are proposed to reduce methanogenesis in ruminants. Their complete evaluation should include consequences on animal performances, safety for the ruminant and the consumer, and economical viability. Environmental impacts of such strategies should also take into consideration a global vision of production systems that considers all greenhouse gases emissions from the animal up to the farm scale as well as grassland use.

References

- Attwood G and McSweeney C 2008. Australian Journal of Experimental Agriculture 48, 28-37.
- Beauchemin KA, Kreuzer M, O'Mara F and McAllister TA 2008. Australian Journal of Experimental Agriculture 48, 21-27.
- Busquet M, Calsamiglia S, Ferret A, Carro MD and Kamel C 2005. Journal of Dairy Science 88, 4393-4404.
- Callaway TR, Carneiro De Melo AM and Russell JB 1997. Current Microbiology 35, 90-96.
- Calsamiglia S, Busquet M, Cardazo PW, Castillejos L and Ferret A 2007. Journal of Dairy Science 90, 2580-2595.
- Clark H, Wright AD, Joblin K, Molano G, Cavanagh A and Peters J 2007. New Zealand Pastoral Greenhouse Gas Research Consortium, pp. 100-101.
- Cook SR, Maiti PK, Chaves AV, Benchaar C, Beauchemin KA and McAllister TA 2008. Australian Journal of Experimental Agriculture 48, 260-264.
- Doreau M and Ferlay A 1995. Livestock Production Science 43, 97-110.
- Finlay BJ, Esteban G, Clarke KJ, Williams AG, Embley TM and Hirt RP 1994. FEMS Microbiology Letters 117, 157-162.
- Grainger C, Clarke T, Beauchemin KA, McGinn SM and Eckard RJ 2008. Australian Journal of Experimental Agriculture 48, 73-76.
- Hegarty RS 1999. Australian Journal of Agricultural Research 50, 1321-1327.

Hegarty RS, Goopy JP, Herd RM and McCorkell B 2007. *Journal of Animal Science* 85, 1479-1486.

Kajikawa H, Valdes C, Hillman K, Wallace RJ and C JN 2003. *Letters in Applied Microbiology* 36, 354-357.

Klieve A and Joblin K 2007. *New Zealand Pastoral Greenhouse Gas Research Consortium Report*, pp. 34-35.

Klieve AV and Hegarty RS 1999. *Australian Journal of Agricultural Research* 50, 1315-1319.

Koenig KM, Ivan M, Teferedegne BT, Morgavi DP, Rode LM, Ibrahim IM and Newbold CJ 2007. *British Journal of Nutrition* 98, 504-516.

Lee SS, Hsu J-T, Mantovani HC and Russell JB 2002. *FEMS Microbiology Letters* 217, 51-55.

Macheboeuf D, Lassalas B, Ranilla MJ, Carro MD and Morgavi DP 2006. *Reproduction Nutrition Development* 46, S103.

Machmüller A, Ossowski DA and Kreuzer M 2000. *Animal Feed Science and Technology* 85,41-60.

Machmüller A, Soliva CR and Kreuzer M 2003. *British Journal of Nutrition* 90, 529-540.

Maia MRG, Chaudhary LC, Figueres L and Wallace RJ 2007. *Antonie Van Leeuwenhoek* 91, 303-314.

Martin C, Dubroeuq H, Micol D, Agabriel J and Doreau M 2007a. In *Proceedings of the British Society of Animal Science*, p 46.

Martin C, Ferlay A, Chilliard Y and Doreau M 2007b. In *Energy and Protein Metabolism and Nutrition*, EAAP publication 124, p 609, Wageningen Academic Publishers, the Netherlands.

Martin C, Rouel J, Jouany JP, Doreau M and Chilliard Y 2008. *Journal of Animal Science*, submitted.

Martin SA 1998. *Journal of Animal Science* 76, 3123-3132.

McAllister TA and Newbold CJ 2008. *Australian Journal of Experimental Agriculture* 48, 7-13.

McAllister TA, Okine EK, Mathison GW and Cheng KJ 1996. *Canadian Journal of Animal Science* 76, 231-243.

McCaughy WP, Wittenberg K and Corrigan D 1999. *Canadian Journal of Animal Science* 79, 221-226.

Morgavi DP, Jouany JP and Martin C 2008. *Australian Journal of Experimental Agriculture* 48, 69-72.

Morvan B, Bonnemoy F, Fonty G and Gouet P 1996. *Current Microbiology* 32, 129-133.

Munger A and Kreuzer M 2008. *Australian Journal of Experimental Agriculture* 48, 77-82.

Nagaraja TG, Newbold CJ, Van Nevel CJ and Demeyer DI 1997. In *Rumen microbial ecosystem* (eds. PN Hobson and CS Stewart), pp. 523-632, Blackie Academic & Professional, London.

Newbold CJ, El Hassan SM, Wang J, Ortega ME and Wallace RJ 1997. *British Journal of Nutrition* 78, 237-249.

Newbold CJ, Lassalas B and Jouany JP 1995. *Letters in Applied Microbiology* 21, 230-234.

Pinares-Patiño C, Ulyatt MJ, Holmes CW Barry TN and Lasseby KR 2001. In *Energy and Protein Metabolism and Nutrition*, EAAP publication 103, pp 117-120, Wageningen Academic Publishers, the Netherlands.

Pinares-Patiño CS, Waghorn GC, Machmuller A, Vlaming B, Molano G, Cavanagh A and Clark H 2007. *Canadian Journal of Animal Science* 87, 601-613.

Sauvant D and Giger-Reverdin S 2007. In *Energy and Protein Metabolism and Nutrition*, EAAP publication 124, p 561, Wageningen Academic Publishers, the Netherlands.

Tavendale MH, Meagher LP, Pacheco D, Walker N, Attwood GT and Sivakumaran S 2005. *Animal Feed Science and Technology* 123-124, 403-419.

Wallace RJ, Wood TA, Rowe A, Price J, Yanez DR, Williams SP and Newbold CJ 2006. *International Congress Series*, 1293, 148-151.

Wright ADG, Auckland CH and Lynn DH 2007. *Applied and Environmental Microbiology* 73, 4206-4210.

Wright ADG, Kennedy P, O'Neill CJ, Toovey AF, Popovski S, Rea SM, Pimm CL and Klein L 2004. *Vaccine* 22, 3976-3985.

Nutritional routes to attenuate heat stress in pigs

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Introduction

Over the last decade, pig production in tropical and subtropical countries has increased rapidly due to increased population, the consumer's rising income and, in some countries, availability of local feed ingredients (Delgado *et al.*, 1999). Despite many challenges faced by pig industries in developing countries including price of imported raw materials, economical crisis, environmental problems, it is still predicted that pig production in these areas will continue to sustain future world growth of pig production. In these regions, production and performance remain generally lower than those obtained in temperate countries in Western Europe and North America. Although many factors can be involved, climatic factors are the first most limiting factors of production efficiency in these warm regions. While heat stress is only an occasional challenge during summer heat waves in temperate climate, it is a constant problem in many tropical and subtropical areas. In addition, in these regions, the effects of high ambient temperature can be accentuated by a high relative humidity (Morrison *et al.*, 1968). Under heat stress, pigs reduce their appetite in order to reduce their heat production due to the thermic effect of feed (TEF). This reduction of feed intake is dependent on animal related factors such as BW, breed and sexual type and environmental factors such as housing, feeding and the climatic conditions. The reduction of feed consumption results in a decrease of growth of pigs and reproductive performance of sows which affects the profitability of the swine producers. Moreover, the heat stress related problems are emphasized in modern strains of pigs with a high level of growth or reproductive potential (Nienaber *et al.*, 1997). Due to the recognition that heat stress is a problem for pig production efficiency in geographical high temperatures regions, the objectives of many research trials in recent years have been to develop solutions to alleviate the negative effects of heat stress. Several management techniques have been tested but only a few ones were found effective and economical in minimizing the impact of heat stress in pig production. These solutions include management strategy to reduce the building ambient temperature (fan, evaporative cooling system) and/or to increase animal heat losses (floor cooling, drip cooling, snout cooling) (McGlone *et al.*, 1988; Silva *et al.*, 2006). Moreover, some authors (Gourdine *et al.*, 2006) suggested that a genetic selection can be used to improve pig's resistance to heat stress. According to the fact that management strategies are usually expensive, not economically feasible in most cases particularly in many tropical small scale producers, nutritional strategies are alternative techniques that can be recommended to minimize the negative effect of heat stress. Therefore, this review is focusing on the modification of nutritional strategies to alleviate the detrimental effects of heat stress on pig performance. Nutritional solutions can mainly be described according to their ability to reduce dietary heat increment or to increase dietary nutrient density.

Reduction of dietary heat increment

According to the net energy system for pigs, heat increment due to metabolic utilization of digestible crude protein (CP) is significantly higher than for starch or ether extract (40 vs. 18 and 10% of the ME content; Noblet *et al.* (1994)). The higher heat increment of digestible CP is partly related to the deamination of excess of amino acids (AA) for the urea synthesis. In addition, the increase of CP supply is associated with a higher protein turn over which enhances heat production. According to Le Bellego *et al.* (2001), a reduction of dietary CP content from 18.9 to 12.3 % in 35-kg pigs resulted in a reduction of 7% of total heat production attributed to a decrease of the thermic effect of feed (TEF) component of energy expenditure. It can then be hypothesized that low CP diets should attenuate the reduction of feed intake associated with heat stress. Practically, CP is partially replaced by starch and/or fat and industrial amino acids in order to meet the protein requirement for optimal performance. A decrease of dietary CP content without a synthetic AA supplementation results in a strong reduction in growth performance due to AA imbalance. Considering only the experiments available in the literature in which essential AA supplies were kept constant, adequately balanced and above the requirement for growth performance, the use of low heat increment diets would not limit the negative consequence of heat stress on performance in growing pigs. In most studies, the animals were individually housed and submitted to a constant high temperature with a low relative humidity level (50-60%). However, a benefit of using low CP diets has been reported in group housed late finishing pigs submitted to an environmental temperature cycling between 27 and 35°C (Spencer *et al.*, 2005). In this study, the negative effect of high temperature on growth performance was significantly attenuated in pigs fed with a low CP diet (i.e., 11.3%). In fact, these findings suggest that the use of low increment diets under high ambient conditions can potentially improve performance when pigs are housed in rather severe conditions close to those found in commercial farms. In comparison with growing pigs, the voluntary feed intake related to maintenance requirement is much higher in lactating sows than in growing pigs in connection with the high requirement for milk production. As a consequence, the potential gain in using low increment diets under hot conditions should be increased in lactating sows. In comparison to growing pigs, few studies are available on the effect of low-CP diets on performance of lactating sows exposed to heat stress. In response to a reduced protein level from 16.8 to 14.3%, Quiniou and Noblet (1999) reported no improvement of performance in lactating sows housed at 29°C. Johnston *et al.* (1999) observed an increase in litter BW gain (+60 g/d) in hot season for mixed parity sows fed a low CP diet (13.7 vs. 16.5%). In this study, the increase of daily weight gain of litter was attributed to an increase of sow body reserves mobilization due to a probable imbalance of some essential AA (threonine, tryptophan, and valine) in LP diet. Renaudeau *et al.* (2001) showed a numerical increase of about 8 MJ in daily NE

intake and a decrease of 30 % of BW loss in multiparous sows kept at 29°C using a diet with a combined reduced CP level (17.6 to 14.2 %) and increased fat content (+4%). From the results available in the literature, the utilization of low CP diets at high ambient temperature can alleviate the effects of heat stress only in more heat susceptible animals (finishing pigs and lactating sows). It can also be suggested that the benefit of using low increment diets should be increased in commercial conditions, in particular those found in tropical humid areas.

Increase of dietary nutrient density

The increase of the dietary nutrient density in the diet could also be a good alternative for alleviating the depressed feed consumption and performance in pigs maintained in hot conditions. The increase of dietary energy and/or protein contents can compensate the reduced feed intake in pigs reared under hot conditions. Some trials were carried out for evaluating the performance of growing pigs reared under high temperature conditions and fed with high-energy diets (Table 3). According to their high energy density, fat products were added to increase energetic content of the diet. Moreover, energy from fat is more efficiently used for production than starch purposes which reduce dietary heat increment and the heat burden of the pig during heat stress. First studies on this topic were published by researchers from the universities of Georgia and Kentucky (Coffey *et al.*, 1982; Schenck *et al.*, 1992a; Schenck *et al.*, 1992b; Schoenherr *et al.*, 1989a; Stahly *et al.*, 1981; Stahly and Cromwell, 1979). Stahly *et al.* (1996) and Schenk *et al.* (1992a; 1992b) increased by 5% the dietary fat content and did not report any improvement on growth performance in weaning and growing pigs housed at an ambient temperature higher than 29°C. In these studies, growing pigs tended to adjust their voluntary feed intake to energy density of the diet to maintain a constant level of ME intake. In contrast, some works showed that feeding high fat diets to heat stressed finishing pigs positively affected growth performance (Stahly *et al.*, 1981). This increase of growth rate was often connected to an increase of daily ME intake, especially in late finishing pigs. It appeared that, for these animals, the adjustment of intake in response to changes in nutrient density was not complete. In other words, the increase of body weight and the related increase of gastrointestinal capacity might play a large role in the ability of the pig to adjust its feed intake to energy density. Finishing pigs fed with high fat diets were fatter than pigs fed with control diet. This effect was mainly related to an excess of energy relative to protein intake. Despite many studies have been done for evaluating the effect of energy-concentrated diet in growing pig, very few studies evaluated the effect of a combined diet with high energy correctly balanced for the protein to energy ratio in hot conditions. More recently, Myer and Bucklin (2001) evaluated the effect of nutrient density in growing finishing pigs reared during summer in North Florida using a fat added diet supplemented with synthetic lysine in order to maintain a constant lysine to ME ratio. They demonstrated that pigs fed high nutrient density (14.9 MJ ME and 0.82 lysine/kg) consumed less feed but grew faster than pigs fed the control diet (13.8 MJ ME and 0.71 lysine/kg). These authors did not report any effect of dietary treatment on carcass adiposity. Using a low CP diet in late finishing pigs reared under heat stress, Spencer *et al.* (2005) did not find further improvement in growth performance when fat was added in the diet. The response to high dietary fat addition-energy diets has also been studied in heat stressed lactating sows but under variable conditions. When high-fat diets were used without an increase of CP or essential AA to maintain a constant CP/ME ratio, the BW loss during lactation and the milk yield were not affected by the dietary treatment (McGlone *et al.*, 1988). In contrast, when the diet was correctly balanced for CP or Lys to ME ratio, the increase of nutrient density in heat stressed sows improved litter BW gain via an increase of milk-fat content but did not limit the body reserves mobilization (Dove and Haydon, 1994; Quiniou *et al.*, 2000; Schoenherr *et al.*, 1989b). However, the magnitude of these effects seems to be dependent on the rate of dietary fat incorporation.

Some studies were carried out for evaluating the effects of AA complementation in pigs or lactating sows raised under high temperature. Witte *et al.* (2000) did not report any improvement of growth or carcass performance in finishing pigs reared at 32°C fed with a diet supplemented with synthetic lysine, threonine, and tryptophan or a control diet with the same amount of CP and ME. In lactating sows, increasing lysine content from 0.75 to 0.95% did not increase milk production or reduce body reserve mobilization in warm season (Cheng *et al.*, 2006). Assuming an increase of arginine requirement in heat stressed lactating sows due to specific mammary gland requirement, Liaspiur and Trottier (2001) did not report any effect on sows' performance for an arginine to lysine ratio ranging from 1.0 to 1.8. Further studies are required to identify ideal profiles of amino acids for supporting performance in heat stressed pigs. For example, the heat stressed lactating sows often lose their body protein to support amino acids needed for milk protein synthesis. According to the fact that the profile of amino acids released from the tissue mobilization is quite different from that found in milk (Kim *et al.*, 2001), one can hypothesize that dietary amino acids pattern could change according to the housing conditions of the sow.

Use of water

Water intake during heat stress is a limiting factor for survival and performance since water has a fundamental role in heat exchange system for temperature regulation and maintenance of hydric balance. High ambient temperatures increase water requirements in pigs. The increased consumption coupled with increased urinary water losses is an effective mechanism by which pigs loose body heat. For example, expressed as L/kg feed intake, the average water consumption of lactating sows is twice higher at 29°C than at 20°C (4 vs. 8 L/kg; Renaudeau *et al.*, 2001). A reduction of water availability can accentuate the effect of high temperature on performance. In lactating sows, Leibbrandt *et al.* (2001) reported that a reduced water intake as a result of a restricted water flow through nipple drinker decreased the voluntary feed intake and increased the BW loss. Similar results were found in growing pigs (Nienaber and LeRoy Hahn, 1984). In addition, in many high temperatures regions, drinking water provided to pigs is often warm. According to Jeon *et al.* (2006), supplying water at 15°C instead of 22°C improved performance of both lactating sows and their

litters during summer period. In consequence, chilled water can provide sufficient cooling to allow the lactating sow to increase their feed intake and milk production during heat stress. In addition, improved feed intake in lactating sows during summer has been reported using a system combining self-feeding and an option for the sow to wet her feed compared to a dry feed hand-fed system (Pettigrew *et al.*, 1985).

Other nutritional techniques

Provision of supplemental feed or milk substitute in nursing piglets

The growth performance of nursing piglets is directly dependent on the ability of the sow to produce milk. As mentioned above, milk yield is reduced in lactating heat stressed sows. When offered during the last week of lactation, the amount of creep feed consumed before weaning by nursing piglets was higher when sows were kept in hot conditions (Renaudeau and Noblet, 2001). This higher intake was interpreted as an adaptation to compensate the insufficient milk production of the heat stressed sow. According to these authors, there was a strong relationship between creep feed consumption and daily growth rate of piglets: each gram increase of creep feed intake resulted in a 2-g increase of litter BW gain. In fact, protein to energy ratio was higher in creep feed than in milk. As a result, the high marginal feed efficiency was due to an increase in protein deposition in connection with a higher protein to energy ratio in the feed (milk + creep feed). Moreover, Azain *et al.* (1996) showed that providing litter with milk substitute during the warm season is more effective to improve litter BW gain than during the cool season (+38 vs. +10%). These results suggest that the practice of provisioning of supplemental feed or milk substitutes can attenuate the reduced growth rate of nursing piglets during heat stress. However, these practices need to be economically evaluated in regard of the relative high cost of these types of substitutes.

Micronutrients complements

The decrease of nutrient intake at high temperatures has also some repercussions on the intake of micronutrients such as vitamins which play an important role in performance and immune function of the pig. The positive effect of vitamins complementation on poultry performance is well known (Lin *et al.*, 2006), but little is published in pigs. Zhao and Guo (2005) showed that selenium and vitamin E complementation improved the resistance of pigs against heat stress. According to the lower density in functional sweat glands in pigs (Renaudeau *et al.*, 2006), the excess of heat is dissipated via an increase of respiratory rate. This thermal panting results in a respiratory alkalosis with possible negative consequence on acid/base metabolism. Heat stress increases the urinary excretion of various minerals leading to a reduction of their retention in pigs (Holmes and Grace, 2007). Thus, it can be suggested that more research should be focused on the determination of vitamins and minerals requirements in pigs reared under heat stress.

Feeding strategies

In growing pigs and in lactating sows, the nycthemeral pattern of feed intake is mainly diurnal with two peaks occurring in the morning and late afternoon. The occurrence and the size of these peaks are driven by light and temperature changes. For example, the time between peaks increases in such way the feed intake tends to happen under the lowest temperatures in early morning and evening periods (Renaudeau *et al.*, 2005). According to knowledge of diurnal pattern of the feeding behaviour of pigs or lactating sows raised under hot conditions, it can be suggested that use of feeding programs would improve the performance under heat stress. These strategies may include a change in the feeding time with feed distributions corresponding to the cooler phases of the day or a dual feeding system with a high-protein and an energy-rich diet provided during the cooler and the warmer periods of the days, respectively. In contrast to poultry, these feeding techniques have not yet been investigated and deserve future research.

Conclusion and implications

The higher performance potential of present pigs tends to generate a higher susceptibility to heat stress. According to the increase of pig production in tropical and subtropical regions, nutritional strategies can limit the lower nutrients intake of pigs under heat stress and improve their performance. The use of low increment diets or high-density diets can effectively attenuate the effect of heat stress in particular in finishing pigs or in lactating sows but only when diets are correctly balanced for AA to energy ratio. Some changes in the feeding management can also be efficient to enhance productivity of pigs in hot conditions. However, optimal pig production under heat stress requires an appropriate combination of nutritional and management solutions.

References

- Azain, M. J., T. Tomkins, J. S. Sowinski, R. A. Arentson, and D. E. Jewell. 1996. Effect of supplemental pig milk replacer on litter performance: seasonal variation in response. *J. Anim. Sci.* 74:2195-2202.
- Cheng, C. S., H. T. Yen, J. C. Hsu, S. W. Roan, and J. F. Wu. 2006. Effects of dietary lysine supplementation on the performance of lactating sows and litter piglets during different seasons. *Asian-Aust. J. Anim. Sci.* 19:568-572.
- Coffey, M. T., R. W. Seerley, D. W. Funderburke, and H. C. McCampbell. 1982. Effect of heat increment and level of dietary energy and environmental temperature on the performance of growing-finishing swine. *J. Anim. Sci.* 54:95-105.
- Delgado, C., M. Rosegrant, H. Steinfeld, E. Siméon, and C. Courbois. *Livestock to 2020: The Next Food Revolution. Vision initiative food, agriculture, and the environment discussion Paper 28.* IFPRI, FAO, and ILRI. Paper 28, 1-88. 1999. Washington D.C., International Food Policy Research Institute.
- Dove, C. R. and K. D. Haydon. 1994. The effect of various diet nutrient densities and electrolyte balances on sow and litter performance during two seasons of the year. *J. Anim. Sci.* 72:1101-1106.

- Ferguson, N. S. and R. M. Gous. 1997. The influence of heat production on voluntary food intake in growing pigs given protein-deficient diets. *Anim. Sci.* 64:365-378.
- Ferreira, R. A., R. F. M. Oliveira, J. L. Donzele, C. V. Araujo, F. C. O. Silva, R. G. M. V. Vaz, and W. O. Rezende. 2006. Effect of feeding crude protein, amino acid-supplemented diets on performance of castrated swine from 15 to 30 kg on high environmental temperature. *Revista Brasileira de Zootecnia* 35:1056-1062.
- Ferreira, R. A., R. F. M. Oliveira, J. L. Donzele, E. P. Saraiva, F. C. Silva, U. A. D. Orlando, and R. G. M. V. Vaz. 2007. Reduction of crude protein levels and amino acid supplementation for 30 to 60 kg barrows maintained in a high environmental temperature. *Revista Brasileira de Zootecnia* 36:818-824.
- Gourdine, J. L., N. Mandonnet, M. Naves, J. P. Bidanel, and D. Renaudeau. 2006. Genetic parameters of rectal temperature in sows in a tropical humid climate and its association with performance during lactation: preliminary results. 8th World Congress on Genetics Applied to Livestock Production, Communication 16-09. 2006. Belo Horizonte, MG, Brasil.
- Holmes, C. W. and N. D. Grace. 2007. A note on the metabolism of Ca, P, Mg, Na and K by pigs growing at a high ambient temperature. *Anim. Prod.* 21:341-343.
- Jeon, J. H., S. C. Yeon, Y. H. Choi, W. Min, S. Kim, P. J. Kim, and H. H. Chang. 2006. Effects of chilled drinking water on the performance of lactating sows and their litters during high ambient temperatures under farm conditions. *Livestock Science* 105.
- Johnston, L. J., M. Ellis, G. W. Libal, V. B. Mayrose, W. C. Weldon, and NRC. 1999. Effect of room temperature and dietary amino acid concentration on performance of lactating sows. *J. Anim. Sci.* 77:1638-1644.
- Katsumata, M., Y. Kaji, and M. Saitoh. 1996. Growth and carcass fatness responses of finishing pigs to dietary fat supplementation at a high ambient temperature. *Anim. Sci.* 62:591-598.
- Kerr, B. J., J. T. Yen, J. A. Nienaber, and R. A. Easter. 2003. Influences of dietary protein level, amino acid supplementation and environmental temperature on performance, body composition, organ weights and total heat production of growing pigs. *J. Anim. Sci.* 81:1998-2007.
- Kim, S. W., D. H. Baker, and R. A. Easter. 2001. Dynamic ideal protein and limiting amino acids for lactating sows: The impact of amino acid mobilization. *J. Anim. Sci.* 79:2356-2366.
- Kuan, K. K., T. K. Mak, and D. J. Farrell. 1986. Effect of dietary energy concentration, protein:energy and lysine:energy ratios on growth of pigs in the humid tropics. *Aust. J. Expt. Agric.* 26:285-289.
- Laspiur, J. P. and C. Trottier. 2001. Effect of dietary arginine supplementation and environmental temperature on sow lactation performance. *Livest. Prod. Sci.* 70:159-165.
- Le Bellego, L., J. Noblet, and J. van Milgen. 2002. Effect of high temperature and low protein diets on performance of growing-finishing pigs. *J. Anim. Sci.* 80:691-701.
- Le Bellego, L., J. van Milgen, S. Dubois, and J. Noblet. 2001. Energy utilization of low protein diets in growing pigs. *J. Anim. Sci.* 79:1259-1271.
- Leibbrandt, V. D., L. J. Johnston, G. C. Shurson, J. D. Crenshaw, G. W. Libal, and R. D. Arthur. 2001. Effect of nipple drinker water flow rate and season on performance of lactating swine. *J. Anim. Sci.* 79:2770-2775.
- Lin, H., H. C. Jiao, J. Buyse, and E. Decuyper. 2006. Strategies for preventing heat stress in poultry. *World's Poultry Science Journal* 62:85.
- Lopez, J., R. D. Goodband, G. L. Allee, G. W. Jesse, J. L. Nelssen, M. D. Tokach, D. Spiers, and B. A. Becker. 1994. The effects of diets formulated on an ideal protein basis on growth performance, carcass characteristics, and thermal balance of finishing gilts housed in a hot, diurnal environment. *J. Anim. Sci.* 72: Notes: J
- McGlone, J. J., W. F. Stansbury, and L. F. Tribble. 1988. Management of lactating sows during heat stress: effects of water drip, snout coolers, floor type and a high energy-density diet. *J. Anim. Sci.* 66:885-891.
- Miller, P. S., A. J. Lewis, C. K. Wolverton, and C. A. Borland. 1996. Performance of growing-finishing pigs consuming diets formulated on an ideal protein (first four limiting amino acids) basis., 27-30. 1996. university of Nebraska Cooperative Extension. Nebraska Swine Report.
- Morrison, S. R., Bond, T.E., and Heitman, H. 1968. Effect of humidity on swine at high temperature. *Transactions Am. Soc. Agric. Eng.* 11:526-528.
- Myer, R. O., R. A. Bucklin, and F. B. Fialho. 1998. Effects of increased dietary lysine (protein) level on performance and carcass characteristics of growing-finishing pigs reared in a hot, humid environment. *Transactions Am. Soc. Agric. Eng.* 41:447-452.
- Myer, R. O. and R. A. Bucklin. 2001. Effect of season (summer vs. fall) and diet nutrient density on performance and carcass characteristics of growing-finishing swine. *Transactions Am. Soc. Agric. Eng.* 45:807-811.
- Nienaber, J. A. and G. LeRoy Hahn. 1984. Effects of Water Flow Restriction and Environmental Factors on Performance of Nursery-Age Pigs. *J. Anim. Sci.* 59:1423-1429.
- Nienaber J. A., Hahn G. L., Eigenberg R.A., Korthals R.L., Yen J.T. and Harris D.L. 1997. Genetic and heat stress interaction effects on finishing swine. In (eds RW Bottcher and SJ Hoff), pp. 1017-1023. American Society of Agricultural Engineers, Bloomington, Minnesota.
- Noblet, J., J. Y. Dourmad, and M. Etienne. 1990. Energy Utilization In Pregnant and Lactating Sows: Modelling of Energy requirements. *J. Anim. Sci.* 68:562-572.
- Noblet, J., H. Fortune, X. S. Shi, and S. Dubois. 1994. Prediction of net energy value of feeds for growing pigs. *J. Anim. Sci.* 72:344-354.

- Orlando, U. A. D., R. F. M. Oliveira, J. L. Donzele, A. M. Ferreira, and R. G. M. V. Vaz. 2007. Crude protein levels and amino acid supplementation in diets of gilts maintained in a high environmental temperature from 60 to 100 kg. *Revista Brasileira de Zootecnia* 36:1069-1075.
- Pettigrew, J. E., R. L. Moser, S. G. Cornelius, and A. F. Sower. Feed intake of lactating sows as affected by feeder design. Minnesota Swine Research Reports. AG-BU-2300. 1985. St Paul. Minnesota Swine Research Reports.
- Quiniou, N., D. Gaudré, S. Rapp, and D. Guillou. 2000. Influence de la température ambiante et de la concentration en nutriments de l'aliment sur les performances de lactation de la truie primipare. *Journée des Recherches Porcines en France* 32:275-282.
- Quiniou, N. and J. Noblet. 1999. Influence of high ambient temperatures on performance of multiparous lactating sows. *J. Anim. Sci.* 77:2124-2134.
- Renaudeau, D., J. L. Gourdine, N. Quiniou, and J. Noblet. 2005. Feeding behaviour of lactating sows in hot conditions. *Pig News Inform.* 26:17N-22N.
- Renaudeau, D., M. Leclercq-Smekens, and M. Herin. 2006. Difference in skin characteristics in European (Large White) and Caribbean (Creole) growing pigs with reference to thermoregulation. *Animal Research* 55:209-217.
- Renaudeau, D. and J. Noblet. 2001. Effects of exposure to high ambient temperature and dietary protein level on sow milk production and performance of piglets. *J. Anim. Sci.* 79:1540-1548.
- Renaudeau, D., N. Quiniou, and J. Noblet. 2001. Effects of exposure to high ambient temperature and dietary protein level on performance of multiparous lactating sows. *J. Anim. Sci.* 79:1240-1249.
- Schenck, B. C., T. S. Stahly, and G. L. Cromwell. 1992a. Interactive effects of thermal environment and dietary amino acid and fat levels on rate and efficiency of growth of pigs housed in a conventional nursery. *J. Anim. Sci.* 70:3803-3811.
- Schenck, B. C., T. S. Stahly, and G. L. Cromwell. 1992b. Interactive effects of thermal environment and dietary lysine and fat levels on rate, efficiency, and composition of growth of weanling pigs. *J. Anim. Sci.* 70:3791-3802.
- Schoenherr, W. D., T. S. Stahly, and G. L. Cromwell. 1989a. The effects of dietary fat or fiber addition on energy and nitrogen digestibility in lactating, primiparous sows housed in a warm or hot environment. *J. Anim. Sci.* 67:473-481.
- Schoenherr, W. D., T. S. Stahly, and G. L. Cromwell. 1989b. The effects of dietary fat or fiber addition on yield and composition of milk from sows housed in a warm or hot environment. *J. Anim. Sci.* 67:482-495.
- Silva, B. A. N., A. I. G. Oliveira, J. L. Donzele, H. C. Fernandez, M. L. T. Abreu, J. Noblet, and C. G. V. Nunes. 2006. Effect of floor cooling on performance of lactating sows during summer. *Livest. Prod. Sci.*
- Spencer, J. D., A. M. Gaines, E. P. Berg, and G. L. Allee. 2005. Diet modifications to improve finishing pig growth performance and pork quality attributes during periods of heat stress. *J. Anim. Sci.* 83:243-254.
- Stahly, T. S. and G. L. Cromwell. 1979. Effect of environmental temperature and dietary fat supplementation on the performance and carcass characteristics of growing and finishing swine. *J. Anim. Sci.* 49:1478-1488.
- Stahly, T. S., G. L. Cromwell, and M. P. Aviotti. 1979. The effect of environmental temperature and dietary lysine source and level on the performance and carcass characteristics of growing swine. *J. Anim. Sci.* 49:1242-1251.
- Stahly, T. S., G. L. Cromwell, and J. R. Overfield. 1981. Interactive effects of season of year and dietary fat supplementation, lysine source and lysine level on the performance of swine. *J. Anim. Sci.* 53:1269-1277.
- Witte, D. P., M. Ellis, I. F. K. MacKeith, and E. R. Wilson. 2000. Effect of dietary lysine level and environmental temperature during the finishing phase on the intramuscular fat content of pork. *J. Anim. Sci.* 78:1272-1276.
- Zhao, H. J. and D. Z. Guo. 2005. Effects of selenium and vitamin E on the free radical metabolism of pigs suffering from heat stress. *Chinese Journal of Veterinary Science* 25:78-80

Feeding strategies to alleviate negative impacts of drought on ruminant production

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Drought is certainly one of the most important natural threats for water availability and quality, affecting production of rangelands and, therefore, livestock performance and health in the already difficult context of arid areas. In the low-rainfall areas of much of Africa and Asia, small ruminants represent the principal economic output, contributing a large share of the income of farmers. Animal numbers have increased over the last two decades, driven by a rising demand for animal products and, in some countries, subsidized feed prices (e.g. barley, maize). Side effects of this and changing climatic patterns are increasing desertification, resulting in a decline in rangeland resources, which are often insufficient to meet current demand, coupled with a fall in total feed resources due to overgrazing, ploughing of marginal land and soil erosion. Consequently, livestock in dry environments are facing serious nutrient shortages. These animals often depend on low quality crop residues (e.g. straws, stubbles) and expensive feed supplements. The situation is aggravated by the increasing use of some key feed supplements like maize, barley and soya bean in the rapidly expanding biofuel industry. The drastic increase of the prices of these feeds, to levels beyond the reach of resource-poor livestock keepers, during the last two years is threatening global poultry and ruminant production. Technical solutions to some of these problems are available, for example the advantageous use of fodder trees, shrubs and cactus has been demonstrated. Conservation through ensiling and the use of feed blocks and pellets gives greater efficiency of use of a wide range of agro-industrial by-products. But their adoption has been slow, often because of lack of knowledge of the farmers' problems and expectations. Adaptive research of technologies and management practices, involving relevant practitioners, are needed, to provide the policy and institutional support for wider adoption of improved production and resource management practices. Some research-development projects based on the farmer participatory approach have resulted in improved crop and livestock technologies being successfully transferred. The lesson learned is that technologies and policies that might help ensure sustainable livelihoods and enhance the productive capacity of dry lands everywhere should be refined and promoted. Moreover, adjusting current feeding strategies or developing new ones which fit with the recent challenges imposed by prolonged droughts and global climate warming should be considered at the local, national and international levels. All partners, i.e. farmers, technicians, scientists, and policymakers, should collaborate to achieve the latter objectives.

Keywords: *Livestock, feeding strategies, alternative feed resources, dry environment, technology adoption.*

Linseed oil and a combination of sunflower oil and malic acid decrease rumen methane emissions *in vitro*

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Introduction

Methanogenesis is the main pathway present in the rumen for removing the hydrogen generated during ATP production by anaerobic microbes. Methane emissions from ruminants have two negative consequences: (i) they represent a loss in energy estimated at 7 – 12 % of the diet digestible energy; (ii) they contribute 3 – 5 % of the total greenhouse effect (Moss *et al.*, 2000). For these reasons, the development of mitigation techniques to decrease enteric methane emissions is an active area of research. These techniques aim either to reduce hydrogen production, to increase hydrogen utilisation by pathways other than methanogenesis or to reduce the number of methanogens. Among additives, organic acids (OA) such as malic acid and fumaric acid are known to enhance the uptake of hydrogen to produce propionate (Newbold and Rode, 2006). Other additives/supplements that have been shown to reduce methane production through a different mode of action are fatty acids (FA) (Beauchemin *et al.*, 2008). Whereas the efficacy of polyunsaturated FA to reduce methane production has been assessed *in vivo* (e.g. Martin *et al.*, 2007 for linseed oil rich in linolenic acid and McGinn *et al.*, 2004 for sunflower oil rich in linoleic acid), the *in vivo* efficacy of OA has not been clearly demonstrated with no effect reported by McGinn *et al.* (2004) and a strong decrease in methane production reported by Wallace *et al.* (2006). These latter authors suggested that a stronger decrease in methane with lipid-encapsulated fumarate than with free fumarate may be explained by the association of OA and FA. However, to our knowledge, a possible synergistic effect of OA and FA has not been studied under controlled conditions.

The aim of this work was to test the interaction between two additives with different mode of action on rumen hydrogen metabolism and methanogenesis. To this purpose, two sources of unsaturated fatty acids differing in their unsaturation degree, linseed oil and sunflower oil, were used alone or in combination with malic acid.

Materials and methods

***In vitro* batch system** Two sheep fitted with rumen cannulae and fed 970 g dry matter per day of a mixed diet composed of grass hay (35 %) + barley grain (52 %) + soyabean meal (13 %), were used as rumen juice donors. Serum bottles of 120 mL volume were filled under a stream of CO₂ gas with 15 mL rumen juice, 25 mL of Coleman buffer solution (Simplex type), and finely ground feed (175 mg of grass hay + 175 mg of maize grain + 50 mg of soyabean meal). Four series of 13 incubation bottles each were carried out. Each series included 3 control incubators without any additive and 10 experimental incubators with 55 mg of pure DL-malic acid added (2 incubators), 80 mg of linseed oil (2 incubators), 80 mg of sunflower oil (2 incubators), a mixture of 55 mg of malic acid + 80 mg of linseed oil (2 incubators), and a mixture of 55 mg of malic acid + 80 mg of sunflower oil (2 incubators). Bottles were stoppered with a crimped butyl septum and incubated at 39°C for 20 h. Production of the end products of fermentation was quantified in each incubator at the end of the incubation.

Gases were collected in a glass syringe with a needle inserted through the butyl septum and were immediately analysed. The digesta content of each incubator was centrifuged at 5,000 g for 15 min and supernatants were used for analyses of volatile fatty acids (VFAs).

The amount of “Glucose Equivalents” fermented were calculated through the formula $[C6f \text{ (moles)} = \text{acetate (moles)}/2 + \text{propionate (moles)}/2 + \text{butyrate (moles)}]$ as indicated by Demeyer (1991). Ammonia content and pH values in incubators were measured as a control of the correctness of the fermentation.

Analyses

VFAs were analysed by gas chromatography as described previously (Morgavi *et al.*, 2003). Gases were analysed by gas-solid chromatography using a stainless steel column (2.3 m in length x 3 mm in e.d.) packed with 60/80 Carboxen 1000 (Supelco), carrier gas Argon, and a thermal conductivity detector. Temperatures were set at 130°C, 100°C and 120°C for the injector, the column and the detector, respectively. Ammonia nitrogen (NH₃-N) was assayed by the method of Berthelot, modified and adapted for a Technicon autoanalyser (Van Eenaeme *et al.*, 1969).

Statistics

Data were statistically analysed by one-way analysis of variance using the GLM procedure of SAS (SAS/STAT, version 8, SAS Inst., Cary, NC) with a model including treatment and series effects. Means were compared using the Duncan test. The significance level was set at $P < 0.05$.

Results

Concentrations of NH₃-N were always higher than 100 mgL⁻¹, which confirms that the nitrogen requirements of microbes were met. Also, pH in incubators always remained above 6.0, which corresponds to a normal value for rumen content. Acetate and butyrate productions were not influenced by any of the tested additives ($P > 0.05$). Compared to

control, propionate production was higher with linseed oil and the two oil combinations with malic acid ($P < 0.05$) but not with sunflower oil alone.

Methane production was not affected by malic acid or sunflower oil when added separately ($P > 0.05$). In contrast, methane production decreased by 14 % in incubators supplemented with linseed oil or with the mixture of sunflower oil and malic acid ($P < 0.05$). Addition of malic acid to linseed oil did not change the decrease observed with linseed oil alone.

Large variations in free hydrogen concentrations have been observed between replicate incubators. Thus, no significant differences could be evidenced on free hydrogen concentrations among treatments. However, larger accumulation of hydrogen in the headspace of incubators receiving malic acid and sunflower oil indicates that fermentations were disturbed with this type of mixed additives.

Table 1 Effect of malic acid, sunflower oil (SO), linseed oil (LO) and their combination on rumen metabolite production

Incubators	Control	MA	SO	LO	MA + SO	MA + LO	SEM	P value
CH ₄ production (mmol/incubator)	0.73 ^a	0.74 ^a	0.70 ^{ab}	0.63 ^b	0.62 ^b	0.62 ^b	0.028	0.011
H ₂ production (μmol/incubator)	0.15	0.97	1.75	3.67	19.40	6.33	7.07	0.38
Acetate production (mM)	41.4	41.1	35.1	41.7	39.7	38.2	3.29	0.67
Propionate production (mM)	13.9 ^b	18.5 ^a	14.0 ^b	17.7 ^a	20.3 ^a	20.4 ^a	0.96	0.001
Butyrate production (mM)	9.6	10.3	9.6	9.9	11.2	10.9	0.64	0.30
Glucose equivalents (mM)	37.5	40.1	34.1	39.6	41.2	40.2	2.48	0.35

Mean values within a row with unlike superscript letters are significantly different ($P < 0.05$)

Discussion

The abatement effect of organic diacids on ruminal methane production has been shown forty years ago (Demeyer and Henderickx, 1967). However, this positive response is not consistently observed, recent reports are contrasting showing either a decrease, which was higher with malic acid than with malate (Newbold *et al.*, 2005) or no change in methane production (Martin, 2004, Tejido *et al.*, 2005). Between-experiment differences may be due to the concentration of the diacid in incubators, but more likely to pH or microbial characteristics, e.g., the nature of the microbial community present in the inoculum, which may act on the competition between methanogens and propionate-producing bacteria (Asanuma *et al.*, 1999). Malic acid stimulated ($P < 0.05$) the production of propionate, in this experiment as in all other experiments, and this effect is likely due to a direct use of malic acid by rumen microbes through the “randomizing pathway” (Russell and Wallace, 1997). In spite of these results, the effect of organic acids is usually more pronounced *in vivo* and in continuous *in vitro* systems than in *in vitro* batch systems (Wallace *et al.*, 2006, Ungerfeld *et al.*, 2007). It was suggested that continuous supplementation increases the population of microbes utilising organic acids and hence they become more efficient at competing for H₂ with methanogens.

Polyunsaturated FA in the diet increase the concentration of essential FA in milk and meat and hence contribute to enhance the nutritional quality of ruminant-derived foods (Demeyer and Doreau, 1999). Their interest to mitigate methane emission could thus add to their nutritional interest. In the present experiment, linseed oil reduced methanogenesis, whereas sunflower oil did not. In a trial by Machmüller *et al.* (1998) sunflower oil was found to reduce *in vitro* methanogenesis to the same extent than linseed oil. In this experiment, the effect of linseed oil may have been stronger because linseed oil decreases protozoal numbers, contrary to sunflower oil (Doreau and Ferlay, 1995), and the absence of protozoa reduces methanogenesis (Hegarty, 1999; Morgavi *et al.*, 2008). Fatty acids also have a negative effect on cellulolytic bacteria, which may result in a shift of fermentation towards propionate production. This toxic effect has recently been proven with both linolenic and linoleic acids (Maia *et al.*, 2007). These changes in the microbial ecosystem may have occurred in fermentors despite the short-term incubation times of the experiments. In addition, some fatty acids have a toxic effect on methanogens. It has been clearly shown for medium-chain FA (Machmüller *et al.*, 2003) and to a lesser degree for oleic acid (Henderson, 1973). This direct toxic effect of polyunsaturated FA on methanogens cannot be excluded, although, to our knowledge, it has never been tested.

Hydrogen did not accumulate in linseed-treated incubators despite the decrease in methanogenesis. Such result could be explained either by a lower production of hydrogen corresponding to less active fermentations or by activation of an alternative pathway for hydrogen use in the rumen. The fact that the total amount of fermented organic matter evaluated here through the amount of “Glucose Equivalents” was not significantly altered by linseed oil indicates that fermentations were not affected and that hydrogen produced was used through an alternative pathway. Our results suggest that propionate synthesis was the major hydrogen acceptor in incubators producing less methane in presence of linseed oil.

A synergistic effect of malic acid with fatty acids has been shown only for sunflower oil whereas the decrease in methane production with linseed oil was not enhanced by the addition of malic acid addition. The mechanism

explaining the positive interaction between malic acid and sunflower oil is not known. Nevertheless, the higher H₂ concentration in sunflower-supplemented incubators may suggest a disturbance in ruminal fermentation.

Conclusions

This study showed that linseed oil is an inhibitor of rumen methanogenesis (- 14%) that do not affect negatively fermentations. The increase in propionate production observed with this additive will benefit the host ruminant with regard to energy use.

Sunflower oil, which had no significant effect on any of the biochemical parameters measured when added alone, was active in reducing methanogenesis and increasing propionogenesis when mixed with malate. No explanation is available for such interactive effects between these two products, so that further research is needed to analyse possible changes in microbial ecosystem.

Implications

The utilization of polyunsaturated fatty acids, especially from linseed, to decrease rumen methanogenesis may be a practical abatement technology in ruminant production. The use of products from linseed is interesting owing to a simultaneous enhancement of the nutritional value of milk and ruminant meat, provided that linseed supply does not decrease overall fermentation and thus does not impair animal performance.

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References

- Asanuma N, Iwamoto M and Hino T 1999. Effect of the addition of fumarate on methane production by ruminal microorganisms *in vitro*. *Journal of Dairy Science* 82, 780-787
- Beauchemin KA, Kreuzer M, O'Mara F and McAllister TA 2008. Nutritional management for enteric methane abatement : a review. *Australian Journal of Experimental Agriculture* 48, 21-27
- Demeyer DI 1991. Quantitative aspects of microbial metabolism in the rumen and hindgut. In *Rumen microbial metabolism and ruminant digestion* (ed JP Jouany), pp. 217-237. INRA Editions, Paris
- Demeyer D and Doreau M 1999. Targets and procedures for altering ruminant meat and milk lipids. *Proceedings of the Nutrition Society* 58, 593-607
- Demeyer DI and Henderickx HK 1967. Competitive inhibition of *in vitro* methane production by mixed rumen bacteria. *Archives Internationales de Physiologie et de Biochimie* 75, 157-159
- Doreau M and Ferlay A 1995. Effect of dietary lipids on nitrogen metabolism in the rumen: a review. *Livestock Production Science* 43, 97-110
- Hegarty RS 1999. Reducing rumen methane emissions through elimination of rumen protozoa. *Australian Journal of Agricultural Research* 50, 1321-1327
- Henderson C 1973. The effects of fatty acids on pure cultures of rumen bacteria. *Journal of Agricultural Science, Cambridge* 81, 107-112
- Machmüller A, Ossowski DA, Wanner M and Kreuzer M 1998. Potential of various fatty feeds to reduce methane release from rumen fermentation *in vitro* (Rusitec). *Animal Feed Science and Technology* 71, 117-130
- Machmüller A, Soliva CR and Kreuzer M 2003. Methane-suppressing effect of myristic acid in sheep as effected by dietary calcium and forage proportion. *British Journal of Nutrition* 90, 529-540
- Maia MRG, Chaudhary LC, Figueres L and Wallace RJ 2007. Metabolism of polyunsaturated fatty acids and their toxicity to the microflora of the rumen. *Antonie van Leeuwenhoek* 91, 303-314
- Martin SA 2004. Effects of DL-malate on *in vitro* forage fiber digestion by mixed ruminal microorganisms. *Current Microbiology* 48, 27-31
- Martin C, Ferlay A, Chilliard Y and Doreau M 2007. Rumen methanogenesis of dairy cows in response to increasing levels of dietary extruded linseeds. In *Energy and Protein Metabolism and Nutrition* (Ed I Ortigues-Marty), pp 609-610. Wageningen Academic Publishers, Wageningen, The Netherlands
- McGinn SM, Beauchemin KA, Coates T and Colombatto D 2004. Methane emissions from beef cattle : effects of monensin, sunflower oil, enzymes, yeast, and fumaric acid. *Journal of Animal Science* 82, 3346-3356
- Morgavi DP, Boudra H, Jouany JP and Graviou D 2003. Prevention of patulin toxicity on rumen microbial fermentation by SH-containing agents. *Journal of Agricultural Food and Chemistry* 51, 6906-6910
- Morgavi DP, Jouany JP and Martin C 2008. Changes in methane emission and rumen fermentation parameters induced by refaunation in sheep. *Australian Journal of Experimental Agriculture* 48, 69-72.
- Moss AR, Jouany JP and Newbold J 2000. Methane production by ruminants: its contribution to global warming. *Annales de Zootechnie* 49, 231-253
- Newbold CJ, Lopez S, Nelson L, Ouda JO, Wallace RJ and Moss AR 2005. Propionate precursors and other metabolic intermediates as possible alternative electron acceptors to methanogenesis in ruminal fermentation *in vitro*. *British Journal of Nutrition* 94, 27-35
- Newbold CJ. and Rode LM 2006. Dietary additives to control methanogenesis in the rumen. In *Greenhouse gases and animal agriculture: an update* (eds CR Soliva, J Takahashi and M Kreuzer), pp 138-147. International Congress Series, vol. 1293, Elsevier, Amsterdam, The Netherlands

Russell JB and Wallace RJ 1997. Energy-yielding and energy-consuming reactions. In The rumen microbial ecosystem, 2nd Ed (Eds PN Hobson and CS Stewart), pp 246-282, Blackie Academic and Professional, London

Tejido ML, Ranilla MJ, Garcia-Martinez R and Carro MD 2005. *In vitro* microbial growth and rumen fermentation of different substrates as affected by the addition of disodium malate. *Animal Science* 81, 31-38

Ungerfeld EM, Kohn RA, Wallace RJ and Newbold CJ 2007. A meta-analysis of fumarate effects on methane production in ruminal batch cultures. *Journal of Animal Science* 85, 2556-2563

Van Eenaeme C, Bienfait JM, Lambot JM and Pondant A 1969. Détermination automatique de l'ammoniaque dans le liquide du rumen par la méthode de Berthelot adaptée à l'autoanalyser. *Annales de Médecine Vétérinaire* 7, 419-425

Wallace RJ, Wood TA, Rowe A, Price J, Yanez DR, Williams SP and Newbold CJ 2006. Encapsulated fumaric acid as a means of decreasing ruminal methane emissions. In *Greenhouse gases and animal agriculture: an update* (eds CR Soliva, J Takahashi and M Kreuzer), pp. 148-151. International Congress Series, vol. 1293, Elsevier, Amsterdam, The Netherlands

Livestock nutrition in future: taking into account climate change, restricted fossil fuel and arable land used also for biofuel leading to high grain prices

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From recent travels in developing countries it became clear to me that such recent developments as doubling of grain prices have global consequences for animal nutrition and we need in future livestock research to address these problems. I will not here discuss in any detail the causes which relate to restricted fossil fuel, used of arable land for biofuel production, climate change etc. but the consequences will almost certainly be that less high quality feed will be available for livestock which is already reflected in the huge increases, in grain prices. This has great challenges both in plant breeding, animal breeding and animal nutrition both for ruminants and monogastrics.

Ruminants

It is well recognised that particularly in so-called developed countries grain has become used a great deal both for dairy cows and beef cattle feed lots etc. For dairy cows sometimes up to 60% of the diet consists of grain. In fact to some extent feeding practices such as total mixed diets for dairy cows have been developed to make the use of rapidly fermenting feed such as grain tolerable as the mixing with the roughage ensures a less rapid uptake of the concentrate.

Breeding for better capacity to utilise roughage

There are many breeds of cattle and in particular buffaloes which have a much larger capacity to utilise poorer quality roughage than the cattle which have been selected in recent years in developed countries. For beef cattle it has been economic to feed grain to achieve high growth rate as grain has been cheap. A big problem in retrospect is that killing out percentage of beef cattle became an important selection parameter. This of course has meant that effectively some breeds of beef cattle have been selected against rumen volume and therefore against their capacity to consume large amounts of slowly fermenting feed. There is clearly a great challenge in future cattle breeding to select for cattle with greater capacity for roughage digestion and less reliance on grain feeding. The same will also apply to feeding dairy cattle unless the milk price can be greatly increased.

Improving value of by products for ruminants

Several years ago my group examined the nutritive value of straw from different varieties of barley, oats and wheat. It was quite clear that there were often large differences in nutritive value of straw which was not correlated with yield and quality of grain nor with stiffness of straw. There was some relationship with proportion of leaves as leaves were more digestible than stems except in the case of rice straw. Though the information was made available to plant breeders and farmers nobody took any note of it simply because grain was cheap and often superfluous. There is a need for improving quality of roughages such as straw and other by-products if this can be accomplished with little or no influence on the quantity and quality of the main product.

Feeding and breeding of monogastric animals

Feeding of pigs

For the past 50 years or so feeding of pigs in developed countries, USA and Europe has virtually been based on grain and limited amounts of cereal brans and of course protein supplements from soya, sunflower, rape seed etc. Their selection was also based on high killing-out percentage and therefore since there was no need for a voluminous large intestine they were virtually selected against capacity to use a large proportion of high quality roughages as feed. This is not so in Asia such as Vietnam and China where the local pigs have voluminous large intestines and are able to feed entirely on grain free feed. The grain is used for human consumption. So in fact most pigs in the world are not fed on grain. What is the future for grain feeding to pigs? Can the price of pig meat be more than doubled? Yet there is a high demand. There is a need to re-examine the breeding and feeding of pigs in Western Countries. It may be that the so-called improved pigs are not so improved after all. There is certainly a need for consideration for future development.

Feeding of poultry

As for feeding of pigs there is maybe even more problem for intensive feeding of particularly chicken, turkey and layer hens. By for the greatest proportion of chickens, turkeys and eggs are produced in this manner in developed countries and indeed also in some developing countries where it has been based on cheap imported grain from the USA. Presently there are welfare problems being discussed on aspects of intensive poultry keeping. In Asia however the keeping of poultry as scavengers is most important. The growth rate and egg laying capacity in these systems is much lower but on the other hand much cheaper and sometimes meat from scavenging chickens fetches a much higher price. What is the future for intensive poultry production based on grain? Can the price of poultry meat be doubled or more? Maybe in developed countries where the cost of food is still a relatively small proportion of income but not likely in developing countries such as Indonesia. What will be the consequences for human nutrition?

Conclusion

There are many challenging new issues in the field of livestock production and these issues are coming earlier than we had expected. The increase in grain prices due to use of arable land for production of biofuel has great global consequences which must be attended to rapidly by people concerned with livestock production.

A win-win scenario with flaxseed supplementation to reduce methane output and increase weight gains of grazing cattle

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Introduction

It is well established that ingestion of medium and long-chain fatty acids can substantially reduce methane emission by ruminants (Blaxter and Czerkawski 1966; Van Nevel and Demeyer 1996; Beauchemin and McGinn 2006; Machmüller 2006). It is also well documented that feeding flaxseed (linseed), an oilseed with high levels of the long-chain omega-3 fatty acid alpha-linolenic acid, can result in red meat that has higher levels of healthful omega-3 fatty acids (Scollan et al. 2001; Maddock et al. 2006; Kronberg et al. 2006). However, few if any cattle producers in the USA will voluntarily feed these fats to reduce methane output from their animals unless they are paid to do so, but they could have greater incentive to do so if feeding these fats resulted in improved production or (and) higher prices for their livestock. Fortunately, omega-3 enriched beef could sell for a higher price than normal beef; consequently, producers of flaxseed-fed cattle could obtain higher prices for these animals. With high grain prices in the USA that are related to greater flow of corn and other grains to ethanol production rather than to cattle feed, cattle may be grown and fattened with more forage and less grain in the USA in the future. Therefore, the objective of the trial herein described was to determine if growing and fattening yearling steers would have faster growth rates during the final months of their lives if they were supplemented with flaxseed while grazing high quality forages.

Materials and methods

Eighteen yearling Angus steers weighing 399 kg (\pm 21) at the beginning of August 2007 were randomly divided into three groups. All steers grazed high quality growing forage as a group through August, September, October, and the first week of November when they were slaughtered. All procedures used in the study were approved by the institution's animal care and use committee. Average live weight the day before slaughter was 499 kg (\pm 26). The forage was predominantly perennial grasses that were typical pasture species on the northern Great Plains of North America or Proso millet. One group of six steers received a supplement of ground flaxseed (0.20% of body weight) and another group of six steers received a supplement of corn and soybean meal (0.28% of body weight) that had levels of crude protein and digestible energy that were similar to those in the flaxseed supplement. The other six steers were not supplemented. A small amount of dry molasses was added to both supplements to improve their palatability. Steers were individually supplemented daily between 0800 and 1000 hours. All steers had continuous access to high quality water and trace mineral salt. Steers were held off feed and water overnight for about 14 hours before they were weighed. Average daily body weight gains (ADG) were compared for the three treatment groups using the MIXED procedure of the SAS statistical package (1996) with animal as the random effect. Treatment means were compared with the LSMEANS statement of the MIXED procedure.

Results

Mean ADG of steers supplemented with flaxseed and the corn-soybean meal mixture were 1.04 and 1.09 kg per day (SE = 0.09) and were not significantly different ($P = 0.45$). The ADG of non-supplemented steers was 0.83 kg per day and was significantly less than the ADG of the supplemented steers ($P < 0.01$). The steers supplemented with flaxseed daily had 25% greater ADG than the non-supplemented steers. Maddock et al. (2006) demonstrated that pre-weaned calves had 7% greater ADG when creep-fed a mixture containing 25% flaxseed. Thus, it appears that there is good potential to improve the ADG of young cattle by supplementing their diets with flaxseed.

Conclusions

The results from this study indicate that the growth rates of yearling cattle grazing high quality forages can be increased by supplementing their diets with ground flaxseed at 0.20% of body weight. Intake of ground flaxseed at this rate should reduce methane production from grazing cattle, and thus increase the opportunity for a win-win situation for both cattle producers and those interested in reducing greenhouse gas production.

Implications

This study demonstrates that there is a good opportunity to improve growth rates of young grazing cattle and reduce methane emissions from these animals by supplementing their diets with flaxseed. This will allow for a win-win situation for both cattle producers and all people interested in reducing greenhouse gas production.

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References

- Beauchemin, K. A. and S. M. McGinn. 2006. *Journal of Animal Science* 84: 1489-1496.
- Blaxter, K. L. and J. Czerkawski. 1966. *Journal of the Science of Food and Agriculture* 17: 417-421.
- Kronberg, S. L., G. Barceló-Coblijn, J. Shin, K. Lee, and E. J. Murphy. 2006. *Lipids* 41: 1059-1068.
- Machmüller, A. 2006. *Agriculture, Ecosystems and Environment* 112: 107-114.

- Maddock, T. D., M. L. Bauer, K. B. Koch, V. L. Anderson, R. J. Maddock, G. Barceló-Coblijn, and E. J. Murphy. 2006. *Journal of Animal Science* 84: 1544-1551.
- Maddock, T. D., B. Kreft, R. J. Maddock, V. L. Anderson, and G. P. Lardy. *Journal of Animal and Veterinary Advances* 5: 156-160.
- Scollan, N. D., N. -J. Choi, E. Kurt, A. V. Fisher, M. Enser, and J. D. Wood. 2001. *British Journal of Nutrition* 85: 115-124.
- SAS. 1996. *SAS Systems for Mixed Models*. SAS Institute Inc. Cary, NC, USA.
- Van Nevel, C. J. and D. I. Demeyer. 1996. *Environmental Monitoring and Assessment* 42: 73-97.

The nutrient degradability of *Acacia nilotica* pods offered to indigenous goats after mixing with wood ash or polyethylene glycol

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Introduction

In semi-arid areas, during the dry season low quality roughages, including grass, crop residues and wild fruits, are usually the only feeds available for livestock. Most of the rangelands in the semi-arid areas of Zimbabwe are endowed with *Acacia* trees which produce abundant fruits rich in proteins. Ripe and dry fruits from *Acacia* and other tree species are potential feed resources for livestock, including goats. The wild fruits can be harvested and stored for future use. Goats provide smallholder farmers with meat and milk. Goats are also sold at farm gates to generate cash for the household. Most goat flocks range in size from 5 to 100 animals, although some flocks exceed 200 goats. About 98 per cent of the goat population is raised in the smallholder sector, especially in the drier areas of the country. Smallholder owned goats depend largely on the rangelands for their feed. Goats are not supplemented in the dry season. This results in low productivity due to loss of kids born during the dry season, and slow growth and delayed maturity in young goats. Productivity of goats can be improved through improved feeding strategies by using locally available feed resources. Goat keeping in Zimbabwe is now moving from subsistence to commercial production and these calls for improved feeding strategies. Commercial feeds are very expensive making continuous evaluation of local available feed resources essential for the industry. Tree fruits, fed as supplements, increase the growth rate in young goats, but the presence of high levels of phenolics limits their utilisation (Mlambo, 2002). Maximum utilisation of these fruits can be achieved by reducing the secondary compounds. A study was undertaken to investigate the effect of tannin inactivation using wood ash and polyethylene glycol (PEG) on *Acacia nilotica* fruits *in sacco*. However, PEG is not readily available and is expensive. Farmers need cheaper alternatives that are less demanding in terms of labour. Wood is used in most rural homesteads for cooking, resulting in a continuous supply of easily collectable ash.

Materials and methods

The study was carried out at Matopos Research Station (20°23'S and 28°28'E), in south-west Zimbabwe, at an altitude of 1340m. Mean day-time temperatures vary from 21°C in June to 29°C in October. Mean annual rainfall is 600mm, normally falling between November and May. The natural vegetation is dominated by thorny *Acacia* species and ground cover comprises perennial grasses with occasional annuals (Ward *et al.* 1979).

Animal management: Three mature castrated indigenous Matabele goats fitted with ruminal fistulae were used in this study. The animals had an average weight of 30 kg. They were offered hay, which had about 3 per cent crude protein, *ad libitum* supplemented with 200g/day/animal of *A. nilotica* fruits for 60 days before the *in sacco* measurements commenced. All pods were eaten. They had access to water through out the experimental period and were housed in individual pens under a roof.

***A. nilotica* fruits and treatments:** The *A. nilotica* fruits were harvested at the Research Station between the months of July and August in 2007. They were crushed first through a hammer mill and then ground through a 2 mm screen. Wood ash was collected from burnt *A. nilotica* wood and the Peg (4 600: Aldrich Chemical Co Inc, USA) was purchased. The sample materials were prepared by: Mixing 500g of *A. nilotica* fruit with an equal weight of wood ash (MWA). Mixing 500 g of *A. nilotica* fruit with 90 g of PEG (MP) 500 g of *A. nilotica* fruit unmixed (UM, control). The incubation was carried out in a 3*3 Latin Square Design trial. The effect of treatments on degradable protein was evaluated using a complete randomized design. Each period was of three days and a 24 hour changeover period was allowed. Three grammes of the samples were weighed into each nylon bag (6*12cm, pore size 40µm). Twelve bags were then placed in the rumen of each fistulated goat. All the bags were placed in the rumen at the same time and were withdrawn sequential, in pairs, at 3, 6, 12, 24, , 48 and 72 hours. The bags were washed under running tap water and then dried at 55°C for 48 hours. The residues were then weighed. Data for dry matter losses were fitted into the exponential equation $p = a + b(1 - e^{-ct})$ to obtain the degradation constants (Orskov and Macdonald, 1979). The effect of the treatments was obtained by subjecting the data to one-way analysis of variance using the general linear model (GLM) procedure.

Results

Results from the chemical analysis of *A. nilotica* pods are shown in Table 1. Wood ash (ph 12.1, containing only a trace of N) reduced the fibre contents (Neutral detergent fibre [NDF] and Acid detergent fibre [ADF]) of the fruits. Untreated fruits contained significantly less organic matter (OM). Table 2 shows degradabilities of dry matter (DM), NDF, ADF) and N. Dry matter degradability increased the soluble (a) fraction in MWA. There was no significant difference between UM and MP. There was a decrease in the degradable (b) fraction in MWA and UM. The degradable fraction in MP was higher (P < 0.05). The effects of wood ash were greatest (P < 0.05). Nitrogen degradability was greater

in the soluble fraction than in the degradable fraction. There was a significant difference ($P < 0.05$) in effective degradability (ED) between MWA and the other treatments (UM and MP).

Table 1 Chemical composition of treated and untreated *Acacia nilotica* pods. Chemical composition (g/kg DM)

Component	Acacia Nilotica fruits/pods			S.E
	Mixed with Wood Ash (MWA)	Unmixed (UM)	Mixed with PEG (MP)	
Dry Matter (DM) (g kg ⁻¹)	967 ^c	887 ^a	946 ^b	39.8
Nitrogen (N) g kg ⁻¹ OM	9.9680 ^a	19.4240 ^c	18.1600 ^b	0.018
(Neutral Detergent Fibre (NDF)(g kg ⁻¹ DM)	223.20 ^b	236.60 ^c	219.70 ^a	0.94
Acid Detergent Fibre (ADF) (g kg ⁻¹ DM)	175.9 ^a	190.3 ^b	193.6 ^b	2.98
Organic matter (OM)(g kg ⁻¹ DM)	958.0 ^b	481.7 ^a	965.5 ^b	3.18

Means in a row with different superscripts differ significantly ($P < 0.05$)

Table 2 *In sacco* disappearance of dry matter, Nitrogen Detergent Fibre, Acid Detergent Fibre and Nitrogen of *Acacia nilotica* pods incubated in the rumen of the indigenous Matebele goats.

Component	Parameter [‡]	Acacia Nilotica pods/fruits		
		Mixed with Wood Ash (MWA)	Unmixed (UM)	Mixed with PEG (MP)
Dry matter	a	62.44 ^a	42.18 ^b	26.02 ^b
	b	31.86	40.69	52.75
	c (% h ⁻¹)	0.02	0.03	0.09
	PD (a + b)	94.31	82.87	78.77
	ED	73.09 ^a	62.75 ^b	65.88 ^b
Nitrogen Detergent Fibre	a	45.89 ^a	31.19 ^b	29.65 ^b
	b	37.16	37.95	53.15
	c (% h ⁻¹)	0.01 ^{ab}	0.05 ^a	0.02 ^b
	PD (a + b)	83.05	69.15	82.79
	ED	58.26	54.38	52.37
Acid Detergent Fibre	a	51.69	42.14	44.49
	b	26.34 ^b	48.07 ^a	37.58 ^b
	c (% h ⁻¹)	0.04	0.02	0.04
	PD (a + b)	78.03 ^b	90.20 ^a	82.07 ^{ab}
	ED	65.91	59.97	66.29
Crude Protein	a	80.59 ^a	73.41 ^{ab}	64.35 ^b
	b	14.65	20.93	29.95
	c (% h ⁻¹)	0.05	0.03	0.06
	PD (a + b)	95.24	94.34	94.31
	ED	89.89 ^a	83.88 ^b	84.79 ^b

In a row, means with different superscripts differ significantly ($P < 0.05$)

[‡]Units: For Dry matter a, b, PD and ED are measured as % of DM, for Nitrogen a, b, PD and ED are measured as % of N incubated.

Conclusions

Wood ash increases rumen degradation of protein and this could improve protein utilisation by goats. There is a strong possibility of using ash as an alkali to increase intake of tree fruits and also inactivate tannins.

Wood ash is freely available at most homesteads in the rural communities and can be put into good use. From our experience, wood ash in solution with *A. nilotica* fruits are not an alternative because the fruits need time to dry before they are crushed and after soaking are sticky and difficult to handle. The benefits of using wood ash and PEG on the protein value of *A. nilotica* fruits need to be tested in growth and intake studies in the near future. Wood ash can also be a useful source of minerals for livestock (Imbeah, 1990).

Implications

This study examines a cheap source of alkali, wood ash, for improving optimum utilisation of *A. nilotica* fruits as a protein source for small livestock in arid and semi-arid areas in the tropics. The results indicate an increased degradability of N from tree fruits in the soluble fraction after treatment with wood ash. Wood ash, which is usually thrown away, can be used for the benefit of livestock, both as a mineral supplement and as a detannification “agent” for fruits having a high content of phenolics. Some farmers used ash as means of controlling weevil attack in cereals. The multi purpose

use of ash needs to be promoted and exploited for agricultural purposes. Future studies need to examine the role of wood ash treatment in growth and intake studies.

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References

- Imbeah, M.1999. Small Ruminant Research. ,32;191-194.
Mlambo, V.2002. Phd thesis. University of Reading
Orskov ,E.R. and McDonald, I. 1979. Journal of Agricultural Science Cambridge 92:499-503.
Ward, H.K., Richardson, F.D., Denny, R.P. and Dye, P.J.1979. Rhodesia Agricultural Journal 76:5-18.

Effect of wattle tannins on the hatchability of gastrointestinal nematodes eggs in faeces of the Small East African goats

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Introduction

Small ruminants, particularly goats, make a significant contribution to food security and income of many resource-poor families in most developing countries (Mtenga *et al.*, 1990; Devendra, 1994). Infections caused by parasitic nematodes of the gastrointestinal tract are among major constraints to small ruminant productivity (Gill and Le Jambre, 1996) particularly in the tropical and subtropical regions because the warm climate is conducive for the survival and spread of the parasites (Waller, 1997). Although control of worm infections is traditionally done using chemicals grouped as anthelmintics (Waller and Faedo 1996), emergency and spread of worm populations which are resistant to the available synthetic anthelmintics (van Wyk *et al.*, 1997; Jackson and Coop, 2000) are challenges which require alternative control approaches. The alternative approaches need to be less reliant on the use of chemicals and should be sustainable for the resource-poor majorities in the developing regions of the world. Exploitation of natural products such as the use of plants with anthelmintic activity has been advocated as one of such alternatives (Hammond *et al.*, 1997). Field studies in the temperate regions indicated positive results when nematode parasitized sheep were fed on forages rich in tannins (Niezen *et al.* 1995). Incorporation of a commercial tannin preparation, quebracho tannin (QT) in diets (Butter *et al.*, 2000) or administration of the extract as a drench (Max *et al.*, 2005a) was found to significantly reduce both faecal egg counts (FEC) and worm burdens of the temperate sheep during experimental haemonchosis. Similar studies using different commercial tannin preparation, wattle tannin (WT), in a tropical host, Black Head Persian (BHP) sheep gave significant reductions in FEC and worm burdens of 75 and 84 per cent respectively. However, WT drenches did not give significant reductions in neither FEC nor worm burdens in Small East African (SEA) goats (Max *et al.*, 2005b). Despite discouraging results observed in goats, other studies have shown that tannins can affect other parameters of nematode parasitism in goats, such as increased host resilience (Paolini *et al.*, 2005), reduced worm fecundity (Paolini *et al.*, 2003) as well as reduced diarrhoea index (Niezen *et al.*, 1994; Max *et al.*, 2007).

The aim of this study was to investigate the effect of wattle tannin (WT), a commercial extract from a tropical tree, *Acacia mearnsii*, on hatchability of egg passed out in faeces of goats following spiking of faeces with WT or its administration as an oral drench. Two batches of the extract from the same supplier but distinguished on the basis of their shelf life were studied to find out whether storage can affect tannins biological activities.

Materials and methods

An egg hatch assay (EHA) was carried out to investigate the effect of two types (an old & a new batch) of wattle tannin (WT), on hatchability of nematode eggs passed out in faeces by goats. The two batches differed in the sense that the old batch (OWT) was produced in the year 2000 and the package was stored intact in our laboratory at room temperature until used in this study. The new batch (NWT) was produced in the year 2006 and was used in this study early 2007. According to the manufacturer, the WT powder contains approximately 700 g/kg DM condensed tannins and it is usually used in the leather industries for tanning purposes.

In one experiment fresh faeces from worm infected goats were collected per rectal and pooled to make a large composite sample. The latter was ground and thoroughly mixed while little amount of water was being added at a time until the mixture become crumbly in consistence. Exactly 10 g faecal sub-samples were then measured and placed in disposable plastic cups. The sub-samples were then spiked, in duplicate, with: 0, 0.0625, 0.125, 0.25, 0.5, 1.0 and 2.0 g of either OWT or NWT and mixed thoroughly before being cultured at room temperature using the standard Baerman technique (Hansen & Perry 1994). A wide inclusion range was chosen to clearly measure the dose-effect but 1.0g WT in 10 g faeces was approximately 9% w/w; this was equivalent to a dose administered orally in a previous study (Max *et al.*, 2005b). A total of five separate rounds of cultures were carried out. Larvae were harvested and suspended in a known volume of distilled water and kept at 4°C until counted under a microscope. Larvae counting involved an average number of larvae in three 50µL aliquots of each duplicate.

In another experiment, worm infected goats were blocked on the basis of their faecal egg count numbers into low, moderate and high egg per gram (EPG) blocks. Equal number of animals from each block were then assigned randomly into three groups (n = 13). Drench solutions were prepared by dissolving 1 part of WT in approximately 2 parts of lukewarm water to make a known volume of final solution. New tannin (OWT) and old tannin (NWT) groups received drenches of old and new tannin respectively at a dose of 1.6 g WT/kg body weight for three consecutive days. This dose was chosen because higher dosage has been shown to cause side effects mainly low feed intake and sometimes diarrhoea. The untreated (CONT) group received a placebo (i.e., plain water). Faeces were collected per rectal from all goats on days 0, 3, 6 and 9 post-drenching and used in the egg hatch assay. Briefly, each day approximately 15 g of freshly obtained faeces from each animal were pooled in a 500 mL beaker to make OWT, NWT and CONT composite samples. The three composite samples were processed as explained above to obtain the crumbly consistence mixture. Exactly 10

g faecal sub-samples in triplicates were weighed from each of the three composite samples and cultured. The larvae were harvested and counted as explained above.

Larvae counts were converted to percentage hatchability (%H) using the relationship:

$$\%H = (LCwt/LCctrl) \times 100$$

Where: LCwt = larvae count in culture media with given concentration of WT

LCctrl = larvae count in the control culture medium (i.e. no WT)

The %H data was subjected to regression analysis to find out how an increase in WT concentration in the culture media affected egg hatching. Comparison between the two batches of tannin was done using paired t-test.

Results and discussion

Figure 1 shows results from the faecal spiking experiment i.e., the effect of varying concentrations of wattle tannin in culture media on the ability of worm eggs to hatch into infective stage larvae (L_3). In general, addition of tannins in worm-infected goat faeces significantly reduced the ability of eggs to hatch *in vitro* in a dose-dependent manner. This observation was supported by significant regression coefficients (OWT: $R^2 = 0.81$; $P < 0.01$; NWT: $R^2 = 0.87$; $P < 0.01$) between concentration of WT in media and percentage hatchability of eggs. The effect of condensed tannins on egg hatching and larval development *in vitro* has also been demonstrated by Molan *et al.*, (2002, 2003) against *Trichostrongylus colubriformis*. According to the t-test analysis of the current data there was no significant difference ($P > 0.05$) between OWT and NWT in their ability to reduce hatching of worm eggs in cultures. This was an indication that storage and possible seasonal variation in tannins structure did not influence its activity against nematode eggs. The egg hatchability profile (fig 1) showed an unusual pattern whereby %H of both batches dropped with increasing tannin concentration to around 55% then increased to 75% before a steady decline to nearly 0% at the highest tannin concentration used. Reasons for this unusual pattern are not yet clear.

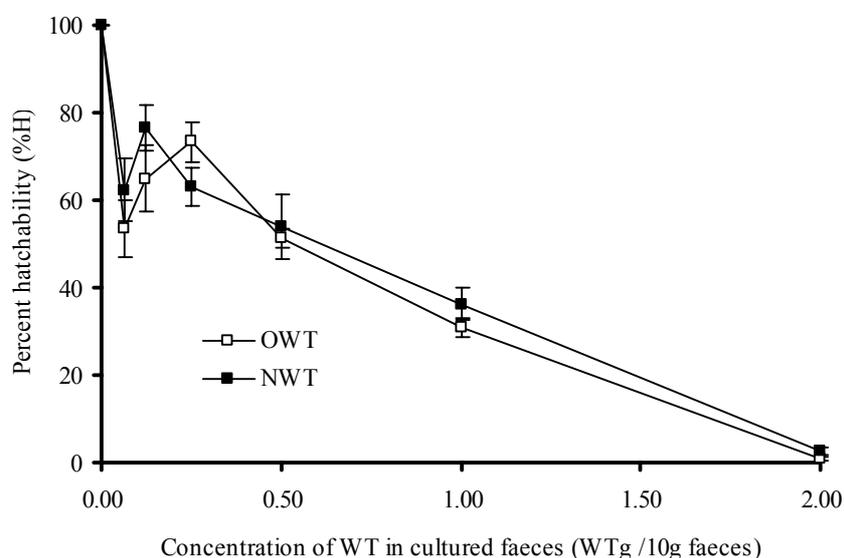


Figure 1 Percent hatchability (%H) of worm eggs in faeces following spiking of goat faeces with varying levels of wattle tannin. (OWT & NWT = old and new wattle tannin batches respectively. The error bars = standard deviation x 0.2)

Administration of WT in form of oral drench also reduced hatchability of eggs passed out in faeces (see Figure 2). Following the administration, the percent hatchability (%H) dropped steadily to day 6 post-drenching and then started to increase afterwards. The ability of WT to reduce worm egg hatchability even after passing through the animal's digestive tract is interesting and is probably an indication of tannins resistance to the digestive tract enzymes.

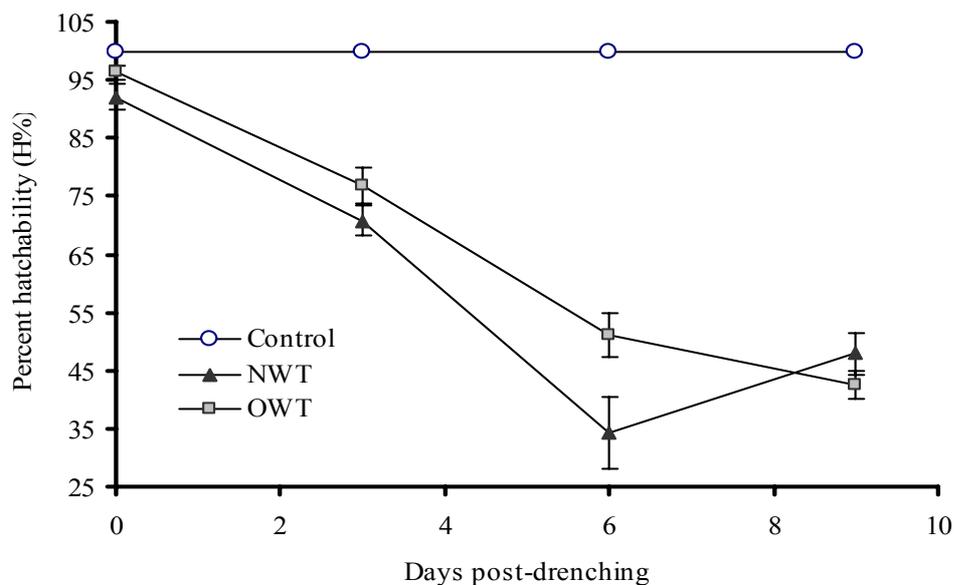


Figure 2 Percent hatchability (%H) of worm eggs in faeces of goats following administration of wattle tannin in form of oral drench. (OWT & NWT = old and new wattle tannin batches respectively. The error bars = standard deviation x 0.2)

This observation conforms to reports in the literature on the fate of tannins in the rumen which suggests that dietary tannins are rather nutritionally inert (Makkar *et al.*, 1995). Although both batches of WT showed significant reductions in comparison with the control group, the new batch appeared to be slightly more effective than the old one. Results from both experiments have indicated that WT is capable of interfering with the ability of worm eggs in goat faeces to hatch. This finding confirms our previous speculation that even though WT had no significant effect in goats in terms of reduction in FEC and worm burdens (Max *et al.*, 2005b) it could affect other aspects of parasitism. Reduced egg hatchability is an important factor which contributes towards reducing contaminations of pastures with larvae and consequently slows down the dynamics of animal infection (Niezen *et al.*, 1995; Paolini *et al.*, 2005). Other observations following administration of the WT drench included reduced appetite and increased faecal water and mucus content.

Conclusion

The current study has demonstrated the ability of wattle tannins in reducing hatchability of eggs passed out in faeces of goats. Storage (or shelf life) of the wattle tannin extract did not appear to affect its activity against the nematode eggs. Furthermore, the activity of wattle tannin on egg hatching was not significantly affected by its passage through the host animal's digestive system. However, further work is needed to mitigate the side effects associated with administration of WT drench to the host animal.

Implications

Several studies have investigated the effect of various types of tannins and tannin-rich plants on parasitic nematodes in small ruminants by measuring anthelmintic activity in terms of faecal egg count and worm burden reductions. The current findings suggest that tannins can have negative effect on some important parasitological aspects including worm egg hatchability. The latter is an important epidemiological factor which determines the dynamics of worm populations in the pasture and hence animal infection. Inclusion of tannin-rich plants in the small ruminants feed could be a good practice as far as alternative worm control approaches is concerned.

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References

- Butter, N.L., Dawson J.M., Wakelin, D. & Buttery, P.J. 2000. *Journal of Agricultural Science, Cambridge* 134: 89 – 99.
- Devendra, C. 1994. *Outlook on Agriculture* 23: 97 – 103.
- Gill, H.S. & Le Jambre, L.F. 1996. *International Journal for Parasitology* 26: 797 – 798.
- Hammond, J.A.; Fielding, D. & Bishop, S.C. 1997. *Veterinary Research Communications* 21: 213 – 228.
- Hansen J. & Perry B. 1994. ILCA, Addis Ababa.
- Jackson, F. & Coop, R.L. 2000. *Parasitology* 120: 95 – 107.
- Makkar, H.P.S. & Becker, K. 1995. *Journal of the Science of Food and Agriculture* 69: 495 – 500.
- Max, R. A., Wakelin, D., Craigon, J., Kassuku A. A., Kimambo, A. E. and Mtenga, L.A. & Buttery P.J. 2005a. *South African Journal of Animal Science* 35: 213 - 220.

- Max, R.A., Kassuku, A. A., Kimambo, A. E., Mtenga, L. A. & Buttery, P. J. 2005b. Proceedings of the International Conference on “Integrating Livestock-Crop Systems to Meet the Challenges of Globalization”. November 14-18, 2005, Khon Kaen, Thailand.
- Max, R. A., Kimambo, A. E., Kassuku, A. A., Mtenga, L. A. & Buttery, P. J. 2007. South African Journal of Animal Science 37: 97 – 106.
- Molan, A.L., Waghorn, W.C. & McNabb, W.C. 2002. Veterinary Record 150: 65 – 69.
- Molan, A.L., Meagher, L.P., Spencer, P.A. & Sivakumaran, S. 2003. International Journal for Parasitology 52: 209–218.
- Mtenga, L.A., Kifaro, G.C., Madsen A. & Nkya, R. 1990. Proceedings of the Tanzania Society of Animal Production 17: 66 – 78.
- Niezen, J.H., Waghorn, T.S., Raufaut, K., Robertson, H.A. and McFarlane, R.G. 1994. Proceedings of the New Zealand Society of Animal Production 54: 15 – 18.
- Niezen, J.H.; Waghorn, T.S.; Charleston, W.A.G. & Waghorn, G.C. 1995. The Journal of Agricultural Science, Cambridge 125: 281 – 289.
- Paolini V., Bergeaud J.P., Durantou-Grisez C.; Prevot F., Dorchies Ph. & Hoste H. 2003. Veterinary Parasitology 113: 253 - 261.
- Paolini V., De La Farge F. Prevot F., Dorchies Ph. & Hoste H. 2005. Veterinary Parasitology 127: 277 - 283.
- van Wyk, J.A., Malan, F.S. & Bath, G.F. 1997. Workshop held at the 16th International Conference of the WAAVP, pp. 51 – 63. Sun City, South Africa.
- Waller, P.J. & Faedo, M. 1996. International Journal for Parasitology 26: 915 – 925.
- Waller, P.J. 1997. International Journal for Parasitology 27: 1193 – 1201.

The Gender-Livestock-Climate Change connection: local experiences and lessons learned from Morocco

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Introduction

Livestock production is an integral component of Moroccan agriculture. Based on the last agricultural census (RGA 1996), livestock raising is practiced by 1 100 123 farm-households which represents three fourths of the approximately one million and half (1 496 349) farm-households of Morocco (MADRPM, 1998). Livestock provides employment to 20 percent of the active population, contributes 36 percent of agricultural add –value, and satisfies up to 87 percent of the national demand for dairy products, 98 percent for red meat and 100 percent for poultry meat (MADRPM, 2005). In pastoral and agro pastoral systems of the country, livestock is central to livelihoods of rural communities. It constitutes the most important, if it is not the main source of income.

Most importantly, the essential of livestock production is carried out in arid and semi arid regions of the country. This means the high degree of exposure of livestock to climatic variability and erratic nature. In Morocco, variations of animal stock are well correlated to climatic conditions (Alary and El Mourid, 2007). In addition, as the climate associated risks become stronger, the vulnerability of the livestock becomes greater. Over the last 30 years, Morocco has experienced nationwide severe successive droughts with significant effects on livestock. To alleviate these negative effects, the government has developed several measures and programs geared to livestock protection. The droughts during the eighties and their accompanying government measures, combined with herders' adaptation efforts such as gradual destocking, purchase of feedstuffs, and increased care for animal health, have led to changing animal husbandry practices. The most important expression of these changes has been the increased tendency towards more intensive livestock management than before. Such changes are crucial in terms of strengthening farmers and herders' resilience and preparedness against climatic hazards. As argued by Delgado *et al* (2001), the livestock revolution could well become a key means of alleviating poverty in the next 20 years.

In Morocco, livestock intensification implies more involvement of women in production. Over the years, the traditional contributions of women in livestock have been reinforced by additional responsibilities as the sector activities become more intensified. Short term sheep fattening and dairy cattle are examples of this trend. The situation is exacerbated by climate change effects on the sector and increased labor requirements of intensive animal husbandry. The increase in the labor demand is generally satisfied by female and children unpaid labor within small scale farms which constitute the most common type of farms in Morocco (Table 2). However, women's role in livestock production continues to be neglected and ignored, and unvalued. Research addressing gender issues in pastoral and agro pastoral systems is scarce.

The predominant literature is based on agricultural communities and very few studies have examined gender and livestock issues among pastoral and agropastoral communities. Examples of such studies include the investigation of survival, change and decision- making in rural households from Eastern Morocco (Lubbock, 1996). As reported, the case studies show how, even in conservative Muslim societies where men are in the forefront in community life, women's role in production and in decision-making is a crucial (more so in the poorer communities and households), although less visible than in other societies (Lubbock, 1996). The second example is the study on gender and remobilization of settled pastoral nomads in Eastern Morocco (Steinmann, 2006). One conclusion of the study was the need for further analysis of how gender-based labor allocation and livestock management in the pastoral household intersects with rangeland conservation at local and regional scales (Steinmann, 2006).

The purpose of this paper is threefold: to establish the link between livestock, climate change and the increase in women's work, to examine the gender division of labor in livestock production systems, and to demonstrate the relevance of a gender perspective in assessing livestock and climate change evolutionary trends.

Materials and methods

This paper is essentially based on the analysis of secondary data, particularly livestock statistics (population, trends), climate data, and available quantitative data on women's contributions in the livestock sector. The literature is also explored to demonstrate the increasing role of women in livestock as this sector becomes more intensive. With respect to primary data sources, preliminary results from on-going studies are included. The adopted methodology is based on gender analysis techniques, namely the access and control and activity profiles.

Results

According to latest available figures, in 2004, Morocco's ruminant population counted more than 25 millions with 17 millions of sheep, 5.4 millions of goats and 2.7 millions of cattle.

Table 1 Ruminant populations (in millions) in Morocco - selected years

Type	1976	1978	1980	1982	1984	1986	1988	1992	1996	2000	2002	2004
Cattle	3.62	3.60	3.38	2.54	2.36	2.85	3.14	3.00	2.41	2.67	2.67	2.73
Sheep	14.27	14.30	16.51	10.16	11.50	14.54	16.73	13.15	14.54	17.30	16.33	17.03
Goats	5.75	5.97	6.15	4.10	4.22	5.28	5.03	4.67	4.59	4.93	5.10	5.36

FAOSTAT, selected years

Non food functions of livestock

In addition to its main role as a source of foodstuffs in Morocco, livestock plays several additional key functions. Livestock supplies raising farms with manure, means of transport, hides and skins. In mountain areas, donkeys, mules, and cattle are used for land tillage. Economically, livestock is considered a form of savings and risk mitigation strategy and most importantly a source of cash whenever needed. Socially and culturally, different species are assigned particular functions in the lives of the peoples and their communities. Donkeys are often assigned the task of transporting water and fuel, mules the task of transporting people and heavy goods over long distances, sheep for celebrating the feast of sacrifice, and horses are generally kept for their prestigious function in the traditional fantasia.

Main livestock production systems

In the case of cattle, three systems fashion cattle production in Morocco. The first system is the intensive dairy cattle based on improved breeds for milk production, commonly found in irrigated areas where forages are produced regularly combined with the use of feed concentrates. Produced milk is essentially marketed through formally organized chains. The remaining two systems are mixed cattle and local breed based system. With respect to sheep, predominant systems include pastoral systems, agro-pastoral semi intensive systems, intensive systems and oasis systems. Goats are primarily kept in entirely extensive rangelands and forests. A dairy goat system of improved breeds through import and or cross-breeding, is gaining space in certain parts of the country.

The gender division of labor in livestock production systems

It is important to look at the socioeconomic characteristics of farm environment where livestock is produced.

As noted, the essential of Morocco's livestock is kept on small scale farms. This means two things the limited amount of land and other capital endowments and the substantial contribution of family labor in both crop and livestock production. In fact, the second most important characteristic of Moroccan farms after their small size is their dependence on unpaid family labor.

Table 2 Cattle and sheep populations by farm size in Morocco

Farm size (ha)	Total number of farms	% of livestock farms	Cattle Number of cattle farms	Farm average (heads)	% of cattle population	Sheep Number of sheep farms	Farm average (heads)	% of total sheep population
Landless	64 716	97	32 994	2.74	3.79	43 169	30.68	7.92
0 - < 1	315 323	68	135 846	2.09	11.89	140 435	9.81	8.24
1 - < 3	446 710	70	217 247	2.47	22.53	205 623	12.80	15.74
3 - < 5	237 669	74	127 794	2.95	15.84	124 448	16.72	12.44
5 - < 10	247 766	77	142 488	3.49	20.84	144 834	22.70	19.66
10 - < 20	125 169	79	75 445	4.31	13.66	81 739	35.43	17.31
20 - < 50	47 985	81	30 291	5.97	7.59	33 823	60.81	12.30
50 - < 100	7 829	80	5 104	10.54	2.26	5 511	113.22	3.73
100 +	3 182	70	1 751	21.81	1.60	1 981	225.79	2.67
Total	1 469 349	75	768 960	3.10	100	781 563	21.40	100

Source: MADRPM, 1998.

In Morocco, more than 80% of the farms use permanent family labor while only 5% of farms tend to have some permanent salaried labor (Table 3). Most importantly, given the growing trend of out-migration of male household members and their continued search for off-farm employment opportunities, women and children constitute the bulk of the permanent family labor supply available for diverse on-farm activities.

Table 3 The status of farm labor by farm size

Farm size	Total number of farms	% of farms with perm. family labor	% of farms with perm. salaried labor
Landless	64 716	77.73	5.09
0 - < 1	315 323	77.72	3.12
1 - < 3	446 710	79.06	3.39
3 - < 5	237 669	82.48	4.24
5 - < 10	247 766	84.82	5.93
10 - < 20	125 169	86.57	9.95
20 - < 50	47 985	87.12	20.31
50 - < 100	7 829	83.81	39.76
100 +	3 182	69.08	60.07
Total	1 469 349	81.11	5.36

Source: MADRPM, 1998.

Impact of climate change on livestock production systems

According to the report on 50 years of human development and perspectives to 2025, rainfall patterns have revealed a general decreasing trend in all regions of Morocco (Maroc, 2006). In addition to becoming more and more limited in quantity, rains are characterized by high spatial disparities and considerable fluctuations between droughts, severe at times, and high rainy years. Over the period 1955-2004, Morocco has experienced seven periods of extreme droughts of which five are after 1975. The number of rainy days is limited to 50 in important parts of the country (Maroc, 2006). Located in arid and semi arid zone, Morocco is characterized by high annual average temperatures with more than 20°C in the south. Records from several national observation stations over the last 50 years show that winter maximum temperatures as well as minimum and maximum summer temperatures have increased. Minimum winter temperatures, however, have slightly decreased. In general, the national average temperature in Morocco has increased by about 1°C (Maroc, 2006).

Under these climatic conditions, livestock management practices are increasingly changing in Morocco with a steady trend towards more intensification in the cattle sector and diversification of feed sources in the case of sheep. One of the main causes behind observed changes, especially feeding practices, is the frequent and successive droughts during the last thirty years. The losses of the livestock in the drought of the 80 have been instrumental to farmers and herders. Between 1980 and 1982, the losses in livestock have been substantial. The loss in the case of cattle amounted to about 840 thousands heads. The losses in sheep and goat flocks counted six millions and two millions respectively (Table 1). Then, most of the livestock was dependant on grazing, fallow and on-farm cereals and cereal by products. During this period both cereals production and range vegetation were negatively affected. Farmers and herders were under the shock of the drought and the government was not prepared to take necessary measures in this type of situation. But lessons were learned and what happened in the livestock sector was not repeated ever in spite of occurred droughts since then.

The role of women revisited

Women's role in livestock husbandry is rather significant. In general, they participate and often times are responsible for most livestock rearing activities. Women are active in on-farm livestock activities of feeding, watering, fodder collecting, stable cleaning, milking and butter-making, caring of small and sick animals, poultry rising and wool work (tents, rugs, etc), traditional health care, etc. Men are generally responsible for marketing, shearing, animal feed purchase, veterinary health actions, and herding when it is done far away from the house. It is important to note that while men's tasks are highly seasonal, most women's activities need to be performed on a daily basis.

One of the consequences of observed trends and changes in livestock management in Morocco because of climatic conditions, among other factors, is the increase in women's involvement in the livestock sector. When livestock intensification is looked at in the light of farm size, herd size, and the status of labor supply (Table 3), it becomes clear that women play an important role in allowing the development and consolidation of the new practices. In the past, small ruminants used to be continually moved to available water and grazing areas. Today, growing numbers of farmers and herders are developing small-scale fattening activities to satisfy the high demand of the feast of sacrifice for lambs and increased demand of urban growing populations. Short term lamb fattening at home is often achieved with family female labor.

In the case of cattle, the introduction of improved breeds for dairy production has been translated into more work for women at all levels. To mention only few areas with increased women's work, there is the cut and carry of green forages, namely alfalfa, milking, feeding and watering, and cleaning stables. The traditional local breed cattle systems called for less work from women as the cows and calves spend most of the day outside the house and milk destined to household consumption. Today, improved cows are cared for at home and milk is marketed. This means greater care, more milk to extract, timely work and cleaning of milk delivery utensils. It is important to pinpoint that a large share of milk production is still done in small family farms which represent the majority of farms in Morocco as previously indicated (Table 2).

The results of several focus groups confirm the notion of women's involvement in the family lamb fattening enterprises of up to 50 lambs either originating from the farm ewes or purchased for the market. The focus groups are parts of an ongoing study on the role of women in small ruminant production in two agro pastoral communities in the oriental region of Morocco. According to women's declarations in the two communities, most families undertake lamb fattening for Aid Lekbir. The herd size, the length of the fattening process, the feed composition, the origin of the lambs may vary but the common feature among these families is that none of them hires a salaried person for the activity. With the exception of marketing and veterinary treatments, the work is performed by the family female labor force.

In women's own words, lamb fattening for Aid Lekbir requires close watch with provisioning feed and water. If water is not available nearby, which is often the case in the region, it needs to be brought from the nearest well. It is evident that fetching water for livestock especially during summer takes time and effort especially if the well is far from the house or if it is deep. Some women considered this task as the most tiresome and time consuming activity in the lamb fattening enterprise. Also, according to women, one needs to pay attention to diseases and to keeping the pen clean. While men are responsible for veterinary treatments, women recognize practicing some commonly experimented health

care. The most important gratification obtained by women is to choose the lamb to be slaughtered by the family. When the lambs are sold, they may receive some gifts and may not.

It is clear that the role of women in livestock is increasing as the livestock production systems change with higher degree of diversification, greater farm-based husbandry, market integration, use of purchased feed and on-farm produced forages. Box 1 provides a summary women's role in livestock production in Morocco.

Box 1 The role of women in livestock production in Morocco. Reproduced from the FAO Near East Report 1995

With the exception of marketing, women are involved in all aspects of livestock production, and their roles appear to vary according to zone. Women in marginal rainfed areas have a greater responsibility for livestock production than their counterparts in favorable rainfed areas or irrigated areas. In marginal rainfed areas, women and girls are responsible for feeding, watering and cleaning sheep pens, while in irrigated zones, women and men share the responsibility in feeding. About 10% of women in this zone are involved in marketing livestock. Domestic animal husbandry is the most important economic activity for women in rural Morocco. Women are in charge of feeding, maintenance, milking and butter-making. Approximately 77%, 76%, 43% and 81% of all women surveyed were active in dairy, sheep, goat and bird husbandry, respectively, and 70%, 39%, 74% and 76% of the work needed in dairy, sheep, goat and bird husbandry is provided by women, respectively. Moreover, according to an RRA study conducted in 1994, the majority of primary and secondary animal products are used for commercial, rather than for domestic purposes. In spite of women's heavy involvement in livestock production, it is usually the men who own livestock, with the exception of 10% of women in irrigated zones.

In the latest gender report which accompanied the 2008 financial bill, it is stated that women are essentially responsible for livestock. In fact, they contribute 70 and 40 percent of the work required in dairy cattle and sheep respectively. Goat rearing in mountain areas is essentially women's responsibility (Ministère de l'Economie et des Finances, 2007). Unfortunately women role in livestock is not valued. Nor is it yet translated into opportunities and benefits. Rural women continue to suffer from high illiteracy rates, poverty and limited access if any to resources.

In fact, the greatest paradox in the situation is the unchanged perception of both men and women as well as the official valuation of the work provided. In official statistics, farm women are at best considered as family aid. Because of its unpaid nature, the work itself is perceived as an extension of women's reproductive roles instead of considering it productive work as it should. While women are heavily involved in productive work, development projects and policies continue to curtail women directed actions within the social sphere. Therefore it is not surprising that women continue to be excluded from education and training opportunities, access to information, credit and income. Moreover, it is most likely that the performance of the sector may improve if its generated benefits are extended to profit women and their role rightfully valued.

Conclusions

This paper has shown the existing connection between gender, livestock and climatic conditions. The evolution of the division of labor in pastoral and agro pastoral activities under climate hazards and market forces has been reviewed. Despite the increasing evidence on women's substantial work in the livestock sector, prevailing perceptions, policies continue to undermine this role. Gender analysis must be integrated in addressing livestock and climate change linkages because it can be instrumental in bringing about useful insights towards better performance of the sector and greater social equity. Identifying and promoting better livestock management practices and best sector development policies to reduce its vulnerability to climate change requires understanding of the evolving gender roles in livestock based systems.

Implications

In Morocco, livestock production is essentially achieved in small family farms where women and children are main labor providers. To mitigate the effects of frequent and acute droughts, the evolution of the ruminant sector is headed towards more intensive practices bringing livestock activities home. This affects the traditional division of labor in pastoral and agro pastoral systems. With increased out-migration of adult males, female members are called upon to bear the intensification labor requirements of sheep fattening and dairy cattle for example. Unfortunately this increase in women's workload, very often, is not accompanied with better opportunities for income earning, capacity building, training and social recognition.

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References

- Alary, V. and M. El Mourid. 2007. Constraints to technology adoption by small and medium scale farmers in arid and semi arid areas of the Maghreb. CIRAD, ICARDA, Femise network.
- Delgado, Ch., M. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 2001 Livestock to 2020: The Next Food Revolution. In: Pinstrup-Andersen and Pandya-Lorch, editors. The Unfinished Agenda: Perspectives on Overcoming Hunger, Poverty, and Environmental Degradation. Chapter 14.
- FAO. 1995. Women, Agriculture and Rural Development A Synthesis Report of the Near East Region.

- Lubbock, A.1998. Survival, Change and Decision-Making in Rural Households: Three Village Case Studies from Eastern Morocco. Based on original research by Dr. R. Bourqia (IFAD).
- Maroc. 2006. 50 ans de Développement Humain & Perspectives 2025. Climat, Hydraulique, Environnement et Territoire.
- Ministère de l'Agriculture, du Développement Rural et des Pêches Maritimes. 1998. Recensement Général de l'Agriculture: Résultats préliminaires.
- Ministère de l'Agriculture, du Développement Rural et des Pêches Maritimes (MADRPM). 2005. Rapport National sur l'Etat des Ressources Génétiques Animales
- Ministère de l'Economie et des Finances. 2007. Projet de Loi de Finances pour l'Année Budgétaire 2008. Rapport sur le Budget Genre.
- Steinmann, S. 2006. Gender and remobilization of settled pastoral nomads: Lessons from a rangeland conservation project in Eastern Morocco. Science et changements planétaires / Sécheresse. Volume 17, Numéro 1, 47-50, Janvier-Juin 2006.

Climate scenarios and agriculture/food risks in southern and central regions of Benin (West of Africa)

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Today it has been proved that the planet is marked by warming due to human activities, which are beyond the limits of natural climate variability (IPCC, 2001). Most studies have shown that the world climate is marked by an evolution without analogy when we refer to available data concerning the last two millennia (Berger, 1992)

This study establishes the impacts of climate changes on food security in southern and central Benin and proposes a lot of adaptation strategies.

In 2050, on the basis of emissions SRESB2 and by using HadCM2 of MAGICC SCENGEN, temperatures will increase by between 1.5 and 2°C in the two regions, compared to the reference period 1961-1990. Decreases in rainfall would lie between 11 and 30 %. A shift in the structure of the seasons will add to these modifications. A fall of 5.8 and 10.9 % is predicted respectively in April and May, and of 16 and 5 % respectively in June and July. On the other hand, a rainfall increase of 25 % is predicted for October compared to the period 1961-1990.

In such a serious context, the outputs of the DSSAT V.4 show that agricultural yields will decrease. A comparison of the "future yields" to those contained in the compendium of the MAEP's statistics shows that reductions in the yields would lie overall between 10 and 30 % in the similar scenarios dry and SRESB2/HadCM2 in both areas. In these two scenarios, 40 and more than 55 % of the populations will be exposed to food insecurity in southern Benin by 2050. In central Benin, only the production of beans is predicted to be insufficient.

Keywords: Southern and central regions of Benin; climate change; DSSAT, agriculture and food risks

Livestock and drought in Indian states of Andhra Pradesh and Madhya Pradesh

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Introduction

The demand for and production of livestock and livestock products in LDCs is expected to double in the 20 years from the base year 2000 (Delgado *et al.* 1999). The livestock sector of India plays a crucial role in the welfare of its population by contributing about 6.8% to GDP and employing 8% of the labour force (FAO 2005). India's intensification programme began more than three decades ago in the area of poultry and dairy sub-sectors comprising subsidised inputs, veterinary and extension services. The programmes were successful in terms of growth. The real value of livestock products grew by 6% per annum between 1985 and 1992 (World Bank 1999). The reasons for this remarkable success were mainly twofold.

First, due mainly to government policy and investment as well as private sector investment towards dairy and intensive poultry production, technologies improved and these two enterprises grew extremely rapidly. For example, between 1980/81 and 1998/99 egg production was increased from 10,000 to 29,000 million (Ramaswamy *et al.* 2006).

Second, due to sustained economic growth and rising incomes, demand for all types of livestock products grew and is still growing. The country is far behind the realisation of potential.

The success achieved so far, has heavily disadvantaged the poor (Turner 2004, Akter *et al.* 2007). The interests of the poor have not been well represented in policy processes, public sector livestock research tends to be of limited relevance to the priorities of smallholders and landless livestock keepers and extension services are not pro-poor (Conroy 2004). Extension services are biased towards 'progressive' farmers, large ruminants, intensive systems, higher potential areas and men (Matthewman and Ashley 1996). In addition priority on coping strategy in the short term disaster was not given to the policy and research towards livestock production. Unfavourable climatic conditions like drought could cause more immediate damage to milch animals as they depend more on fodder crops. The species like the goat may survive more in the face of drought.

The objectives of this paper are to:

- Examine the dynamics of livestock keeping in recent years when occurrence of droughts was severe.
- Examine the function of livestock in reducing the vulnerability to shocks and stresses to which the poor are exposed

Materials and methods

This study draws on data collected under the Livelihood Options Project of the Overseas Development Institute, a three-year project beginning 2001 and a panel re-survey of livestock enterprises in early 2005 on the same site. The study was conducted in six villages chosen purposively from three regions of Andhra Pradesh, and the same pattern for Madhya Pradesh. The intention in each State was that these regions should represent divergent historical, political and agro-ecological conditions and therefore distinct patterns of livelihood evolution and diversification, because the focus of the study was livelihood diversification. Within each region, two contrasting villages from a particular district were selected for detailed household level study. The selection of villages was guided by a number of different criteria including proximity to urban areas, roads and markets; social and economic indicators of development etc. (Farrington *et al.* 2006).

The study conducted several rounds of survey over 14 months in 2001-02, includes a village census of all twelve villages comprising 4,647 households in AP and 1,297 households in MP, and details enterprise/activity survey of a sample of 662 households (360 in Andhra Pradesh and 302 in Madhya Pradesh). Sample sizes for the villages varied from 40–80 households, depending on the size of the village, and were selected through stratified random sampling by landholding and caste to capture the land and caste based differences in wealth and power (Deshingkar *et al.* 2006). A further short study on livestock was undertaken for a panel of households from the same samples during early 2005 to cover the year 2003/4, immediately after a prolonged drought, largely with the intention of generating more detailed information on revenues from the sale of livestock products and services by types and to identify the reasons for the decreasing trend of livestock. Six of the study villages were located nearer to the town and the other six were located relatively farther from the town. In general, within a region/district the nearer village enjoys better infrastructure, access to better education, communication and employment etc. and so the nearer villages are named "well-connected", the other category is farther from the town and is termed "poorly-connected" in this paper.

Descriptive methods are used to generate ratios and percentages. Transition matrices were used to describe the short term dynamics of livestock keeping and test the hypotheses.

Results and Discussions

About 52% of the sample households in Andhra Pradesh were holders of livestock in 2001/2 and the proportion reduced 48% in 2003/4. The density was relatively higher in Madhya Pradesh (64% in 2001/2 and 58% in 2003/4).

The size of livestock holding had fallen for most species except for calves, goats and poultry in Andhra Pradesh and calves in Madhya Pradesh over the three year period beginning 2001-02 (Akter *et al.* 2007). The increase in poultry resulted from the introduction of intensive poultry-keeping technology. India's impressive supply growth in the dairy and poultry sub-sectors are considered more related to the response to growing demand (Staal *et al.* 2006). The demand driven growth is translated into technical change, which is not pro-poor. An IFPRI study claimed that in the period of 1980/81 to 1998/99 in AP poultry meat production increased by 4.5 times and egg production by 3.5 times due to technological breakthroughs in breeding, feeding and health, and sizable investments from the private sector (Ramaswamy *et al.* 2006).

The long drought preceding the 2005 survey was the most important reason for the decline in the overall livestock holding in AP (excluding poultry farms). The impact of drought is especially visible in the case of bovines, particularly the milch animals, due to factors such as water and fodder scarcity. The impact of drought can also be gauged from the drought-related reasons for decrease as mentioned by the farmers.

Overall, domestic shocks or stresses and pest/disease problems were identified as the most important cause for a decrease in numbers of livestock. Other natural/environmental factors such as drought and loss of grazing land were also identified as important reasons. The loss of access to grazing/fodder has resulted both from natural factors as well as man made factors such as rules and regulations and overgrazing. Natural/environmental factors altogether were identified as the major cause of decrease in the livestock population. The poorer households identified shock/stress variables as the most important reasons, with priority being given to the poor natural environment. These drought-related results are likely to be a temporary phenomenon; for the long term, the keeping of milch animals is likely to grow quickly in response to demand growth.

One can divide the cattle farms into four categories and goat farms into two categories for each period and then compare the changes using a transition matrix. More than 4.2% of the sample farms in AP entered into cattle farming in this three-year period, whilst 6.5% exited. Farms having a holding of more than 2 cattle declined from 4.8% to 2.5% but two-cattle farms increased slightly. So the net exit from cattle farming was 2.3% in AP and net entry into the cattle farming was 4.3% in MP.

Akter *et al.* (2007) found that in the period 1996/7 to 2001/2 cattle farming density was slightly higher and entry was more than exit. More than 15% farms entered into cattle farming, whilst 8% exited.

Unlike cattle, goat farming increased in the three-year period. Farming density was higher in MP than in AP. Goat farming increased gradually from 1996/7. The goat farming trend was not reversed due to drought. Perhaps affordable investment allowed rapid adjustments to stock numbers, but the farming density was much lower than cattle and buffalo farming.

From this analysis of transition matrices, it can be concluded that stock holding size and farming density of large ruminants decreased in the period 2001/2 to 2002/3, from an earlier increasing trend. This is in part due to prolonged drought in the region. Goat farming has increased and appears less risky in relation to drought but the farming density is still less than of cattle.

Domestic shocks and stresses were reported particularly strongly by poorer households as a reason for sale, which is responsible for the decrease in cattle. This indicates the important role played by livestock in "buffering" or "smoothing" expenditures. About 37% of the households which experienced a decline in stock in Andhra Pradesh and about 23% of the households with a decline in stock in Madhya Pradesh reported this reason as a major cause.

The number of farmers who re-stocked following sales of this kind varied widely between States. It was very low in Andhra Pradesh – only around 10% did so, with a slightly higher ratio among the poorer quintiles. More households in MP – almost half – restocked, and the levels of re-stocking appear to be higher in poorly-connected villages in AP and well-connected villages in MP. The difference between the two States is no doubt in some measure attributable to the drought conditions which hit AP much harder than MP in the period of study. It may also be in part attributable to the wider range of opportunities (in the non-farm economy, seasonal migration etc.) available to poor people in AP than in MP. The fact that small livestock are among the very few assets owned by the poor, and appear to be used extensively as "buffers" against shocks and stresses, suggests that approaches to poverty reduction which combine livelihood protection and promotion would do well to focus on how the (re-)building of assets such as livestock can be assisted. The provision of "matching grants" for livestock purchase may be one means of supporting the rebuilding of assets.

Conclusions and Implications

Overall, livestock production shows a declining trend in the three year period beginning 2001/2 in the drought hit areas of Indian States of Andhra Pradesh and Madhya Pradesh. India's intensification programme in the livestock sector is considered successful in terms of growth but biased towards wealthier households by ignoring wider groups of species.

The poor who use livestock, the most fluid asset they own, to cope with crises have been disadvantaged by this pattern of public expenditure. Nor do public policies provide support for re-stocking, essential though it is to enhance robustness against future shocks and stresses.

Analysis provided by the transition matrices indicate that the drought was in fact a deviation from an otherwise upward trend. Bad drought can cause significant damage to livestock. Small ruminants and poultry appear more tolerant to drought.

Livestock sales often take place to meet major items of expenditure and that meeting domestic shocks and stresses are among the most important of these among poorer households. However, re-stocking rates are low, at least in part because of the drought conditions, and some support might be merited here, in the form of e.g. “matching grants” for the purchase of small stock.

Domestic shocks and stresses were reported particularly strongly by poorer households as a reason for sale indicating greater dependency on livestock to tide over shocks. This in fact indicates the important role played by livestock in “buffering” or “smoothing” expenditures.

Drought is convincingly connected with the decline in livestock farming and population. This implies that drought preparedness programmes taking care of reducing sales forced by drought along with ‘matching grants’ are necessary to mitigate vulnerability. Better livestock and animal health services could reduce the death of livestock as recommended by Varma and Winslow (2004) for the African drought affected countries. Training farmers as community health workers to deliver basic veterinary health care to livestock could be an option; the practice appeared viable in remote areas (Catley *et al.* 2002, Akter and Farrington 2007). Some areas are more affected by drought than others. Geographic Information Systems (GIS) technology could be used to identify the severely affected areas to exercise specific packages to mitigate vulnerability (Ndikumana *et al.* 2002).

References

- Akter S. and Farrington J. (2007). ‘Sustainability of an Innovation for Poverty Alleviation: the Case of Bangladesh Poultry Model, paper read at the Development Studies Association Annual Conference on ‘Connecting Science, Society and Development’, 18-20 September, University of Sussex, UK
- Conroy C. (2004). Livestock Sector Growth and Poverty, with Particular Reference to India, Natural Resources Institute, Chatham, UK.
- Delgado C., Rosegrant M., Steinfeld H., Ehui S., and Courbois C. (1999) “Livestock to 2020 – The Next Food Revolution”. Food, Agriculture and the Environment Discussion Paper 28. IFPRI/FAO/ILRI.
- Deshingkar P, Farrington J, Rao L, Akter S, Sharma P, Freeman A, and Reddy J. (2006). Livestock and Poverty reduction in India, International Livestock Research Institute and Overseas Development Institute, Draft Working Paper.
- FAO (2005). Evaluation of Livestock Production, Policy and Information (Programme 2.1.3), Report of the External Peer Review Panel, FAO, Rome.
- Farrington John, Deshingkar P, Johnson C. and Start D. (2006). Policy Windows and Livelihood Futures: Prospects for Poverty Reduction in Rural India. Oxford University Press. New Delhi.
- Matthewman, R. and Ashley, S. (1996). The Generation, Assembly and Delivery of Information on Livestock Production: A Case Study of India. Natural Resources Institute: Chatham.
- Ndikumana J., Kamidi R., Desta K. S., Marambii R., Abdi A. I. and Shori R. (2002). Assessment of possible USAID/OFDA-led activities for increasing resilience of pastoral communities in the Greater Horn of Africa. Addis Ababa, Ethiopia: International Livestock Research Institute and ASARECA Animal Agriculture Research Network.
- Ramaswamy B., Birthal P.S. and Joshi P.K. (2006). Efficiency and Distribution of Contract Farming: The Case of Indian Poultry Growers, MTID Discussion Paper No. 91, International Food Policy Research Institute (IFPRI), Washington.
- Staal S. J., Pratt A. N. and Jabbar M. (2006). A Comparison of Dairy Policies and Development in South Asia and East Africa: Part 1: A Conceptual Framework for Dairy Development, and Regional Analysis Among 15 South Asian and East African Countries, A report prepared for the FAO Pro-Poor Livestock Policy Initiative, International Livestock research Institute (ILRI), Kenya.
- Turner, R.L. (2004) Livestock Production and the Rural Poor in Andhra Pradesh and Orissa States, India. Pro-Poor Livestock Policy Initiative Working Paper No. 9. Rome: FAO.
- Varma, S. and Winslow, M. (2004). Healing Wounds: How the International Centers of the CGIAR Help Rebuild Agriculture in Countries Affected by Conflicts and Natural Disasters. Consultative Group on International Agricultural Research (CGIAR), Washington, DC. xiv + 80 pp.
- World bank (1999). India Livestock Sector Review: Enhancing Growth and Development. The World Bank, Washington, D.C. and Allied Publishers, New Delhi.

Industry and Government strategies for reducing methane and nitrous oxide emissions from New Zealand agriculture

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The prosperity of New Zealand rests to a large extent on agriculture. Although our greenhouse gas (GHG) emissions are small compared with most developed countries, agricultural emissions make up almost half of total emissions. In addition emissions from New Zealand agriculture have been rising at close to 1% a year since 1990 and by 2010, the mid-point of the first commitment period of the Kyoto Protocol, they are projected to be 7.2Mt per annum higher than the 1990 baseline.

The New Zealand agricultural sector has actively engaged in the search for cost effective mitigation solutions and, in partnership with the Government, has funded research through the Pastoral Greenhouse Gas Research Consortium (PGGRC). The PGGRC has been in existence since 2002 and has developed a comprehensive research strategy for reducing methane and nitrous oxide emissions from pastoral agriculture. The key elements of this strategy, along with the key achievements, and future plans will be outlined.

In a two pronged approach to reducing GHG emissions from agriculture the New Zealand Government in late 2007 signalled (a) an investment of approximately \$100m new funding for research and development and (b) the introduction of an emissions trading scheme for agriculture in 2013. The research and development science strategy will be presented along with an outline of the proposed emissions trading scheme.

Global farm animal production and global warming: Impacting and mitigating climate change

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Introduction

Though much evidence of its negative impacts on environmental integrity, community sustainability, public health, and animal welfare has been amassed, the totality of the animal agriculture sector's global impacts has remained largely underestimated and underappreciated. A recent review of the relevant data calculated the sector's contributions to global greenhouse gas (GHG) emissions and determined them to be so significant that, measured in carbon dioxide equivalent, the animal agriculture sector's emissions surpass those of the transportation sector (Steinfeld *et al.* 2006).

Global Warming and Climate Change

The three main GHGs are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) (Steinfeld *et al.* 2006). While most attention has focused on carbon dioxide, methane and nitrous oxide—both extremely potent GHGs—have greater global warming potentials (GWPs) than CO₂. By assigning CO₂ a value of one GWP, the warming potentials of these other gases can be expressed on a CO₂-equivalent basis (Paustian *et al.* 2006; Steinfeld *et al.* 2006): CH₄ has a GWP of 23 while N₂O has a GWP of 296. Global warming's many impacts are already detectable. As glaciers retreat, the sea level rises, the tundra thaws, hurricanes and other extreme weather events occur more frequently, and penguins, polar bears, and other species struggle to survive (Topping 2007), experts anticipate even greater increases in the intensity and prevalence of these changes as the 21st century brings rises in GHG emissions. The five warmest years since the 1890s were 1998, 2002, 2003, 2004, and 2005 (NASA 2006). Indeed, average global temperatures have risen considerably (IPCC 2007c), and the Intergovernmental Panel on Climate Change (IPCC) predicts increases of 1.8-3.9°C (3.2-7.1°F) by 2100 (IPCC 2007c). The IPCC's latest report, released in November 2007, warns that climate change "could lead to some impacts that are abrupt or irreversible" (IPCC 2007b).

Anthropogenic Influences

Although some natural occurrences contribute to GHG emissions (IPCC 2007c), the overwhelming consensus among the world's most reputable climate scientists contends that human activities are culpable for a majority of this increase in temperature (IPCC 2007a). An IPCC report issued in April 2007 concluded "with high confidence that anthropogenic warming over the last three decades has had a discernible influence on many physical and biological systems" (IPCC 2007a). While transportation and the burning of fossil fuels have typically been regarded as the chief contributors to GHG emissions and climate change, a November 2006 report, *Livestock's Long Shadow: Environmental Issues and Options*, by the Food and Agriculture Organization (FAO) of the United Nations highlighted the farm animal production sector's substantial role. Identifying it as "a major threat to the environment" (FAO 2006), the FAO found that the animal agriculture sector emits 18 percent, or nearly one-fifth, of human-induced GHG emissions, more than cars, SUVs, and other vehicles (Steinfeld *et al.* 2006).

Objectives

The authors' objective is to outline the animal agriculture sector's share of global GHG emissions by synthesizing and expanding upon the data in *Livestock's Long Shadow* with more recent reports by the IPCC, data from the U.S. Environmental Protection Agency (EPA), and studies on GHGs from agriculture and mitigation strategies (Cederberg and Stadig 2003; IFOAM 2004; IPCC 2007a, 2007b, 2007c; McMichael *et al.* 2007; Ogino *et al.* 2007; U.S. EPA 2007a; Verge *et al.* 2007). We also draw attention to links between this sector and the far-reaching impacts of climate change on conflict, hunger, and disease, while underscoring the roles of animal agriculture industries, policymakers, and individual consumers in mitigating this sector's contributions to climate change and global warming.

Discussion

Impacts of Growing Livestock Populations and Intensifying Production

According to FAOSTAT, globally, approximately 56 billion land animals are reared and slaughtered for human consumption annually, and livestock inventories are expected to double by 2050, with most increases occurring in the developing world (Steinfeld *et al.* 2006). As the numbers of farm animals reared for meat, egg, and dairy production rise, so do their GHG emissions. The U.S. Department of Agriculture (USDA 2004) has noted that "GHG emissions from livestock are inherently tied to livestock population sizes because the livestock are either directly or indirectly the source for the emissions." Since the 1940s, for example, escalating farm animal populations—in large, confined operations, in particular—have significantly increased methane emissions from both animals and their manure (Paustian *et al.* 2006). In recent decades, increasing numbers of animals are raised in intensive production systems, in which chickens, pigs, turkeys, and other animals are confined in cages, crates, pens, stalls, and warehouselike grow-out facilities. These production systems are devoid of environmental stimuli, adequate space or means by which to experience most natural behaviors. Furthermore, because these industrialized, "landless" facilities tend to produce more manure than can be used as fertilizer on nearby cropland (FAO 2005b), manure is instead "distributed to a small, local landmass resulting in soil accumulation and runoff of phosphorus, nitrogen, and other pollutants" (Thorne 2007). While

extensive, or pasture-based farming methods remain the norm in Africa and some parts of Asia, the trend in Latin America and Asia is to increasingly favour intensive production systems over more sustainable and welfare-friendly practices (Nierenberg 2006). According to a 2007 report describing GHG emissions from agriculture, “[i]n recent years, industrial livestock production has grown at twice the rate of more traditional mixed farming systems and at more than six times the rate of production based on grazing” (Verge *et al.* 2007). Confining greater numbers of animals indoors and further separating production operations from agricultural land will only exacerbate the environmental problems already posed by this sector, which the FAO has deemed “one of the top two or three most significant contributors to the most serious environmental problems, at every scale from local to global” (Steinfeld *et al.* 2006).

CO2 Emissions from Animal Agriculture

Regarded as the most important GHG, CO₂ has the most significant direct warming impact on global temperature due to the sheer volume of its emissions. Of all the natural and human-induced influences on climate over the past 250 years, the largest is due to increased CO₂ concentrations attributed to burning fossil fuels and deforestation (Bierbaum *et al.* 2007). The animal agriculture sector accounts for approximately 9 percent of total CO₂ emissions (Steinfeld *et al.* 2006), which are primarily the result of fertilizer production for feed crops, on-farm energy expenditures, feed transport, animal product processing and transport, and land use changes (Steinfeld *et al.* 2006). Burning fossil fuels to produce fertilizers for feed crops may emit 41 million tonnes of CO₂ per year (Steinfeld *et al.* 2006), with 1 tonne equalling 1 metric ton, or 1,000 kilograms. Vast amounts of artificial nitrogenous fertilizer are used to grow farm animal feed, primarily comprised of corn and soybeans. Most of this fertilizer is produced in factories dependent on fossil-fuel energy (Steinfeld *et al.* 2006). The Haber-Bosch process, which produces ammonia in order to create nitrogen-based artificial fertilizer, is used to produce 100 million tonnes of fertilizer for feed crops annually (Steinfeld *et al.* 2006). An additional 90 million tonnes of CO₂ per year may be emitted by fossil fuels expended for intensive confinement operations (Steinfeld *et al.* 2006). Energy uses in these industrial facilities differ substantially from those in smaller-scale, extensive or pasture-based farms. While a large portion goes toward heating, cooling, and ventilation systems, more than half of the energy used for intensive confinement operations is expended by feed crop production, specifically to produce seed, herbicides, and pesticides, as well as the fossil fuels used to operate farm machinery in the production of feed crops (Steinfeld *et al.* 2006). According to the FAO’s estimates, CO₂ emissions from farm animal processing total several tens of millions of tonnes per year (Steinfeld *et al.* 2006). The amount of fossil fuels burned varies depending on the species and type of animal product. For example, processing 1 kilogram of beef requires 4.37 megajoules, or 1.21 kilowatt-hours, while processing 1 dozen eggs requires more than 6 megajoules, or 1.66 kilowatt-hours (Steinfeld *et al.* 2006). That same 1 kilogram of beef may result in GHGs equivalent to 36.4 kilograms of CO₂, with almost all the energy consumed attributed to the production and transport of feed (Ogino *et al.* 2007). Approximately 0.8 million tonnes of CO₂ are emitted annually from the transportation of feed and animal products to the places where they will be consumed (Steinfeld *et al.* 2006). Indeed, the international trade of meat alone can result in 500,000 to 850,000 tonnes of CO₂ annually (Steinfeld *et al.* 2006). Farm animals and animal production facilities cover one-third of the planet’s surface, using more than two-thirds of all available agricultural land (Haan *et al.* 1997). The livestock sector’s CO₂ emissions from land use changes result from deforestation, land degradation, soil cultivation, and desertification. A significant catalyst for the conversion of wooded areas to grazing land or cropland for feed production (Steinfeld *et al.* 2006), animal agriculture may emit 2.4 billion tonnes of CO₂ annually as a result of deforestation (Steinfeld *et al.* 2006). This sector has particularly devastated Latin America (Steinfeld *et al.* 2006), the region experiencing the largest net loss of forests and greatest releases of stored carbon into the atmosphere, resulting from disappearing vegetation (Steinfeld *et al.* 2006). One of the chief causes of Latin America’s deforestation, according to the FAO, is cattle ranching (FAO 2005a). Other important ecosystems are also threatened by increasing farm animal populations. Brazil’s Cerrado region, the world’s most biologically diverse savannah, produces half of the country’s soy crops (Klink and Machado 2005; WWF 2007a, 2007b). As noted by the World Wildlife Fund (WWF 2007a), the region’s animal species “are competing with the rapid expansion of Brazil’s agricultural frontier, which focuses primarily on soy and corn. Ranching is another major threat to the region, as it produces almost 40 million cattle a year.” Farm animal production also results in releases of up to 28 million tonnes of CO₂ per year from cultivated soils (Steinfeld *et al.* 2006). Soils, like forests, act as carbon sinks and store more than twice the carbon found in vegetation or in the atmosphere (Steinfeld *et al.* 2006). Human activities, however, have significantly depleted the amount of carbon sequestered in the soil, contributing to GHG emissions. Desertification, or the degradation of land in arid, semi-arid, and dry sub-humid areas, is also exacerbated and facilitated by the animal agriculture sector (FAO 2007). By reducing the productivity and amount of vegetative cover, desertification allows CO₂ to escape into the atmosphere. Desertification of pastures due to animal agriculture is responsible for up to 100 million tonnes of CO₂ emissions annually (Steinfeld *et al.* 2006).

Nitrogen from Fertilizer and Feed Production

Feeding the global population of livestock requires at least 80 percent of the world’s soybean crop and more than half of all corn (Ash M, Nierenberg D, personal communication; Halweil B, Smil V, personal communication), a plant whose growth is especially dependent on nitrogen-based artificial fertilizers. Natural sources of fixed nitrogen, the form easily available as fertilizer for plants, are limited, necessitating artificial fertilizer production. Prior to the development of the Haber-Bosch process, the amount of sustainable life on Earth was restricted by the amount of nitrogen made available to plants by bacteria and lightning. Modern fertilizer manufacturing, heavily reliant on fossil fuels, has taken a once-limited nutrient and made it available in massive quantities for crop farmers in the industrialized world and, increasingly, the developing world. “The changes to the nitrogen cycle are larger in magnitude and more profound than

the changes to the carbon cycle....But the nitrogen cycle is being neglected” (Bohan 2007), according to Elizabeth Holland, a Senior Scientist with the National Center for Atmospheric Research (NCAR). In addition, the Third International Nitrogen Conference’s co-chairs highlighted the role of farm animal production in the Nanjing Declaration on Nitrogen Management, a statement presented to the United Nations Environment Programme, recognizing that “a growing proportion of the world’s population consumes excess protein and calories, which may lead to human health problems. The associated production of these dietary proteins (especially animal products) leads to further disturbance of the nitrogen cycle” (Zhu *et al.* 2004). According to University of Manitoba’s Vaclav Smil, a nitrogen cycle expert, “we have perturbed the global nitrogen cycle more than any other, even carbon” (Pollan 2006). Indeed, the overwhelming majority of all crops grown in the industrialized world are nitrogen-saturated, and overuse of nitrogen in crop production, nitrogen run-off into waterways, and the millions of tons of nitrogen found in farm animal manure threaten environmental integrity and public health.

Methane and Nitrous Oxide

The animal agriculture sector is also responsible for 35 to 40 percent of annual anthropogenic methane emissions (Steinfeld *et al.* 2006) that result from both enteric fermentation in ruminants and farm animal manure. Methane emissions are impacted by a number of factors including the animal’s age, bodyweight, feed quality, digestive efficiency, and exercise (Paustian *et al.* 2006; Steinfeld *et al.* 2006). Ruminants emit methane as part of their digestive process, which involves microbial (enteric) fermentation (Steinfeld *et al.* 2006; U.S. EPA 2006). While individual animals produce relatively small amounts of methane (U.S. EPA 2007b), the more than one billion ruminants, as documented by FAOSTAT, reared annually amount to a significant methane source. Indeed, enteric fermentation generates approximately 86 million tonnes of methane emissions worldwide (Steinfeld *et al.* 2006). Typically, cattle confined in feedlots or in intensive confinement dairy operations are fed an unnatural diet of concentrated, high-protein feed comprised of corn and soybeans. While cattle may gain weight rapidly when fed this diet (Pollan 2002), it can cause a range of illnesses (Smith 1998). This diet may also lead to increased methane emissions. The standard diet fed to beef cattle confined in feedlots contributes to manure with a “high methane producing capacity” (U.S. EPA 1998). In contrast, cattle raised on pasture, eating a more natural, low-energy diet comprised of grasses and other forages, produce manure with about half of the potential to generate methane (U.S. EPA 1998). Farm animals produce billions of tons of manure, with confined farm animals in the United States alone generating approximately 500 million tons of solid and liquid waste annually (U.S. EPA 2003). Storing and disposing of these immense quantities of manure can lead to significant anthropogenic emissions of methane and nitrous oxide (U.S. EPA 2007a). For example, according to the Pew Center on Global Climate Change, farm animal manure management accounts for 25 % of agricultural methane emissions in the United States and 6 % of agricultural nitrous oxide emissions (Paustian *et al.* 2006). Globally, emissions from pig manure alone account for almost half of all GHG emissions from farm animal manure (Steinfeld *et al.* 2006). Farm animal manure is the source of almost 18 million tonnes of annual methane emissions (Steinfeld *et al.* 2006). Between 1990 and 2005 in the United States, methane emissions from dairy cow and pig manure rose by 50 and 37 %, respectively (U.S. EPA 2007a). The U.S. EPA (2007a) traces this increase to the trend towards housing dairy cows and pigs in larger facilities that typically use liquid manure management systems, which were first in use in the 1960s (Miner *et al.* 2000) but are now found in large dairy operations across the United States and in some developing countries, as well as in the majority of industrial pig operations worldwide. While 70 % of anthropogenic emissions of nitrous oxide result from crop and animal agriculture combined (Steinfeld *et al.* 2006), farm animal production accounts for 65 % of global nitrous oxide emissions (Steinfeld *et al.* 2006). Manure and urine from ruminants, once deposited on the soil, emit nitrous oxide, and, in the United States, a 10% rise in nitrous oxide emissions between 1990 and 2005 can be traced, in part, to changes in the poultry industry, including an overall increase in the domestic stock of birds used for meat and egg production (U.S. EPA 2007a).

Conflict, Hunger, and Disease

As is the case with animal agriculture’s impacts on soil, water, and air quality, the sector’s contributions to climate change cannot be viewed in a vacuum. Climate change is having far-reaching consequences, perhaps most startlingly seen in growing conflicts among pastoral communities. Environmental degradation has been cited as one of the catalysts for ongoing conflicts in Darfur and other areas of Sudan (UNEP 2007) where the effects of climate change have led to untenable conditions. As temperatures rise and water supplies dry up, farmers and herders are fighting to gain and control diminishing arable land and water (Baldauf 2006). In a 2007 report issued by the United Nations Environment Programme, the agency tied two of its critical concerns in Sudan—land degradation and desertification—to “an explosive growth in livestock numbers.” In addition to citing climate change as one factor that led to the Darfur conflict (Ban 2007), United Nations Secretary-General Ban Ki-moon has noted that natural disasters, droughts, and other changes brought about by global warming “are likely to become a major driver of war and conflict” (UN 2007). According to the IPCC (2007a), many areas already suffering from drought will become drier, exacerbating the risks of both hunger and disease. By 2020, up to 250 million people may experience water shortages, and, in some countries, food production may be cut in half (IPCC 2007a). By 2050—the same year by which the FAO projects that meat and dairy production will double from present levels, primarily in the developing world (Steinfeld *et al.* 2006)—130 million people in Asia may suffer from climate change-related food shortages (Casey 2007). Global temperature shifts may also hasten the speed at which infectious diseases emerge and re-emerge (Epstein and Mills 2005). According to the World Health Organization, “the chief risk factor for emerging zoonotic diseases is environmental degradation by humans, particularly deforestation, logging, and urbanisation” (Fleck 2004). The clear-cutting of forests for soybean cultivation, logging, and other industries enables viruses to exploit such newly exposed niches (Greger 2007).

Strategies and Next Steps

Mitigating the animal agriculture sector's contributions to climate change necessitates comprehensive and immediate action by policy makers, producers, and consumers. Enhanced regulation is required in order to hold facilities accountable for their GHG emissions. One critical step is accurately pricing environmental services, natural resources that are typically free or underpriced, leading to "overexploitation and pollution" (Steinfeld *et al.* 2006). Thus far, most mitigation and prevention strategies undertaken by the animal agriculture sector have focused on technical solutions. For example, researchers are investigating the reformulation of ruminant diets to reduce enteric fermentation and some methane emissions (Connolly 2007). One such remedy is a plant-based bolus, formulated to reduce excessive fermentation and regulate the metabolic activity of rumen bacteria to reduce methane emissions from both the animals and their manure (Drochner W, Nierenberg, D, personal communication). The USDA and U.S. EPA assist in funding anaerobic digester projects domestically and abroad (U.S. EPA 2007c; Sutherly 2007). These digesters, now in use at some large-scale intensive confinement facilities, capture methane from manure to use as a source of energy (Storck 2007), but are typically not economically viable for small-scale farms (Silverstein 2007). In addition, producers are burning animal waste for fuel. The world's foremost pig producer, Smithfield Foods, and one of the top poultry producers, Tyson Foods, are both using animal byproduct fats to create biofuels (Johnston 2007; PR Newswire 2007). McDonald's and agribusiness giant Cargill, which was supplying the company with soy for use as chicken feed, recently entered into an agreement with Brazil's other chief soy traders. Engineered by international environmental organization Greenpeace, a two-year moratorium is currently in place to prevent purchases of soy from the country's newly deforested areas (Kaufman 2007). As consumers increasingly favour more environmentally friendly products and techniques, reducing consumption of meat, eggs, and milk, as well as choosing more sustainably produced animal products, such as those from organic systems, may prove equally critical strategies. Indeed, organic farming has the potential to reduce GHG emissions and sequester carbon, according to the International Federation of Organic Agriculture Movements (IFOAM 2004), and raising cattle for beef organically on grass, in contrast to fattening confined cattle on concentrated feed, may emit 40-percent less GHGs and consume 85-percent less energy than conventionally produced beef (Cederberg and Stadig 2003; Fanelli 2007; Ogino *et al.* 2007). There remains, however, an immediate need for more research regarding both technical and less technology-dependent strategies to record existing GHG emissions from individual production facilities and to provide lessons to producers and policy makers for reducing the climate damaging impacts of animal agriculture. Given the urgency for global action, calls echoed by scientists and world leaders alike, individual consumers must also participate. The authors of a September 2007 Lancet article put forth several recommendations, including the reduction of meat and milk intake by high-income countries as "the urgent task of curtailing global greenhouse-gas emissions necessitates action on all major fronts," and concluded that, for high-income countries, "greenhouse-gas emissions from meat-eating warrant the same scrutiny as do those from driving and flying" (McMichael *et al.* 2007).

Conclusion

As the numbers of farm animals reared for meat, egg, and dairy production increase, so do their emissions. By 2050, global farm animal production is expected to double from present levels. The environmental impacts of animal agriculture require that governments, international organizations, producers, and consumers focus more attention on the role played by meat, egg, and dairy production. Mitigating and preventing the environmental harms caused by this sector require immediate and substantial changes in regulation, production practices, and consumption patterns.

References

- Baldauf S. 2006. Africans are already facing climate change. *Christian Science Monitor* (Boston, MA) 6 November: 4.
- Ban K. 2007. A climate culprit in Darfur. *The Washington Post* (Washington, DC) 16 June: A15.
- Bierbaum RM, Holdren JP, MacCracken MC, Moss RH, Raven PH, eds. 2007. *Confronting Climate Change: Avoiding the Unmanageable, Managing the Unavoidable*. Report prepared for the United Nations Commission on Sustainable Development. Research Triangle Park, NC and Washington, DC:Sigma Xi and United Nations Foundation. Available: http://www.unfoundation.org/files/pdf/2007/SEG_Report.pdf [accessed 23 October 2007].
- Bohan S. 2007. Nitrogen overdose. *Oakland Tribune* (Oakland, CA) 12 August.
- Casey M. 2007. Report: millions face hunger from climate change. *The Christian Post* (Washington,DC) 10 April. Available: http://www.christianpost.com/article/20070410/26802_Report:_Millions_Face_Hunger_from_Climate_Change.htm [accessed 3 January 2008].
- Cederberg C, Stadig M. 2003. System expansion and allocation in life cycle assessment of milk and beef production. *Int J LCA* 8:350-356.
- Connolly K. 2007. Pill stops cow burps and helps save the planet. *The Guardian* (London, England) 23 March: 23.
- Epstein P, Mills E, eds. 2005. *Climate Change Futures: Health, Ecological, and Economic Dimensions*. Boston, MA:Center for Health and the Global Environment.
- Fanelli D. 2007. Meat is murder on the environment. *New Scientist*, 18 July: 15. Available: http://environment.newscientist.com/article.ns?id=mg19526134.500&feedId=onlinenews_rss20 [accessed 23 October 2007].
- Fleck F. 2004. Experts urge action to stop animal diseases infecting humans. *BMJ* 328:1158. 19
- FAO. 2007. Desertification. Available: <http://www.fao.org/desertification/default.asp?lang=en> [accessed 23 October 2007].
- FAO. 2005a. Cattle ranching is encroaching on forests in Latin America. Available: <http://www.fao.org/newsroom/en/news/2005/102924/index.html> [accessed 23 October 2007].

FAO. 2005b. Responding to the “livestock revolution”—the case for livestock public policies. Available: http://www.fao.org/ag/againfo/resources/documents/polbriefs/01/EN/AGA01_10.pdf [accessed 23 October 2007].

FAO. 2006. Livestock a major threat to the environment: remedies urgently needed. Available: <http://www.fao.org/newsroom/en/news/2006/1000448/index.html> [accessed 23 October 2007].

Greger M. 2007. The human/animal interface: emergence and resurgence of zoonotic infectious diseases. *Crit Rev Microbiol* 33:243-299.

Haan C, Steinfeld H, Blackburn H. 1997. *Livestock and the Environment: Finding a Balance*. Brussels, Belgium:European Commission Directorate-General for Development.

IFOAM (International Federation of Organic Agriculture Movements). 2004. The role of organic agriculture in mitigating climate change. Available: http://www.ifoam.org/press/positions/pdfs/Role_of_OA_migitating_climate_change.pdf [accessed 23 October 2007].

IPCC. 2007a. *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability, Summary for Policymakers, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report*. Brussels, Belgium: Intergovernmental Panel on Climate Change.

IPCC. 2007b. *Climate Change 2007: Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report*. Draft copy, 16 November.

IPCC. 2007c. *Climate Change 2007: The Physical Science Basis, Summary for Policymakers, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Paris, France: Intergovernmental Panel on Climate Change.

Johnston T. 2007. Tyson teams with ConocoPhillips to produce renewable diesel fuel. *MeatingPlace.com* 16 April. Available: <http://meatingplace.com/MembersOnly/webNews/details.aspx?item=17806> [accessed 23 October 2007].

Kaufman M. 2007. New allies on the Amazon: McDonald’s, Greenpeace unite to prevent rainforest clearing. *The Washington Post* (Washington, DC) 24 April: D01.

Klink CA, Machado RB. 2005. Conservation of the Brazilian Cerrado. *Conserv Biol* 19:707-713.

McMichael AJ, Powles JW, Butler CD, Uauy R. 2007. Food, livestock production, energy, climate change, and health. *Lancet* 370:1253–1263; doi:10.1016/S0140-6736(07)61256-2 [Online 13 September 2007].

Miner J, Humenik F, Overcash R. 2000. *Managing Livestock Wastes to Preserve Environmental Quality*. Ames, Iowa: Iowa University Press.

NASA (National Aeronautics and Space Administration). 2006. 2005 warmest year in over a century. Available: http://www.nasa.gov/vision/earth/environment/2005_warmest.html [accessed 23 October 2007].

Nierenberg D. 2006. Rethinking the global meat industry. In: *State of the World 2006: A Worldwatch Institute Report on Progress Toward a Sustainable Society* (Starke L, ed). New York: W.W. Norton & Company, Inc., 24-40.

Ogino A, Orito H, Shimada K, Hirooka H. 2007. Evaluating environmental impacts of the Japanese beef cow-calf system by the life cycle assessment method. *Animal Sci J* 78:424-432.

Paustian K, Antle M, Sheehan J, Eldor P. 2006. *Agriculture’s Role in Greenhouse Gas Mitigation*. Washington, DC: Pew Center on Global Climate Change.

Pollan M. 2002. Power steer. *The New York Times Magazine*, 31 March: 44.

Pollan M. 2006. *The Omnivore’s Dilemma: A Natural History of Four Meals*. New York: The Penguin Press.

PR Newswire. 2007. Smithfield joins the Chicago Climate Exchange. Available: <http://sev.prnewswire.com/food-beverages/20070226/CGM04426022007-1.html> [accessed 24 October 2007].

Silverstein K. 2007. The appeal of animal waste. *EnergyBiz Insider*, 10 August. Available: http://www.energycentral.com/centers/energybiz/ebi_detail.cfm?id=367 [accessed 8 October 2007].

Smith RA. 1998. Impact of disease on feedlot performance: a review. *J Anim Sci* 76:272-274.

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C. 2006. *Livestock’s Long Shadow: Environmental Issues and Options*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Storck AB. 2007. More farms find unlikely power source: manure. *Meatingplace.com* 30 July. Available: <http://www.meatingplace.com/MembersOnly/webNews/details.aspx?item=18539> [accessed 24 October 2007].

Sutherly B. 2007. Ohio farms planning to use cows, chickens to generate energy. *Dayton Daily News* (Dayton, OH), 22 June. Available: <http://www.daytondailynews.com/n/content/oh/story/news/local/2007/07/21/ddn072207farmenergy.html> [accessed 3 January 2008].

Thorne PS. 2007. Environmental health impacts of concentrated animal feeding operations: anticipating hazards – searching for solutions. *Environ Health Perspect* 115:296-297.

Topping Jr. JC. 2007. Summit aftermath: study by NASA and university scientists shows world temperature reaching a level not seen in thousands of years and raises grave concern of irreparable harm. Available: http://www.climate.org/programs/washington_summit_temperature_rise.shtml [accessed 24 October 2007].

UN (United Nations). 2007. Ban Ki-moon calls on new generation to take better care of Planet Earth than his own. Available: <http://www.un.org/apps/news/story.asp?NewsID=21720&Cr=global&Cr1=warming> [accessed 24 October 2007].

UNEP (United Nations Environment Programme). 2007. Sudan: post-conflict environmental assessment. Available: http://sudanreport.unep.ch/UNEP_Sudan.pdf [accessed 24 October 2007].

USDA. 2004. U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001. Washington, DC:U.S. Department of Agriculture.

U.S. EPA. 1998. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1996. Washington, DC:U.S. Environmental Protection Agency.

U.S. EPA. 2003. National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitation Guidelines and Standards for Concentrated Animal Feeding Operations (CAFOs); Final Rule. Fed Reg 68:7175-7274.

U.S. EPA. 2006. Methane: sources and emissions. Available: <http://www.epa.gov/methane/sources.html> [accessed 24 October 2007].

U.S. EPA. 2007a. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005. Washington, DC:U.S. Environmental Protection Agency.

U.S. EPA. 2007b. Ruminant livestock: frequent questions. Available: <http://www.epa.gov/methane/rlep/faq.html> [accessed 24 October 2007].

U.S. EPA. 2007c. U.S. government accomplishments in support of the Methane to Markets partnership. Available: <http://www.epa.gov/methanetomarkets/accompreport.htm> [accessed 4 October 2007].

Verge XPC, De Kimpe C, Desjardins RL. 2007. Agricultural production, greenhouse gas emissions and mitigation potential. *Agr Forest Meteorol* 142:255-269.

WWF (World Wildlife Fund). 2007a. Brazilian savannas. Available: http://www.panda.org/news_facts/education/best_place_species/current_top_10/brazilian_savannas_.cfm [accessed 24 October 2007].

WWF (World Wildlife Fund). 2007b. Facts about soy production and the Basel Criteria. Available: http://assets.panda.org/downloads/factsheet_soy_eng.pdf [accessed 24 October 2007].

Zhu Z, Minami K, Galloway J. 2004. Nanjing Declaration on nitrogen management, presented to the United Nations Environment Programme. Available: http://www.initrogen.org/fileadmin/user_upload/nanjing/nanjing_declaration-041016.pdf [accessed 24 October 2007].

The potential of livestock to reverse desertification and sequester carbon, mitigate global climate change and create enhanced rural livelihoods

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Introduction

Grassland soils of the world represent the largest, potential *single source*, terrestrial carbon sink known. Grasslands (arid, semi-arid and prairie type landscapes) represent roughly 60% of the earth's surface - an estimated 12 billion acres (4.9 billion hectares). Extensive pastoralism occurs in some 25% of the global land area and some 120 million pastoralists around the world are dependent on grasslands for their livestock and livelihoods (ILRI, 2002; WISP 2007). The IPCC (2007) has recognized that good grazing management has a strong mitigating potential on global climate change and its impact. Farmers have long recognized the benefit of improved grasslands in terms of fertility, organic matter, water retention, and productivity. The role grasslands (vegetation and soils in particular) could play in addressing global climate change is significant and should be included in any comprehensive approach to averting the impact of climate change.

Grazers/pastoralists, trained in Holistic Management planned grazing and monitoring - on four continents - have sound evidence that this improved grazing management produces:

- Increased soil cover – decreasing runoff and enhancing water retention;
- Increased plant diversity, age and structure;
- Increased soil organic matter;
- Increased water infiltration and retention – thus mitigating drought;
- Improved health and productivity of animals;
- Increased days of grazing;
- Increased carrying capacity;
- Improved wildlife habitat.

In some cases, livestock have been used to reclaim lands impacted (denuded) by mining, fire and other destructive human activities. In Australia, one farmer has documented an increase from 2% to 4% soil organic matter as a result of his changed animal management practices. In North Dakota, another farmer has documented an increase of water infiltration from .5 in/hour to 7.6 in/hour. In Zimbabwe, a farmer increased the yield from his fields by an estimated 1500% when he used a herd of animals (at very high density) to prepare the soil. And, herders at Dimbangombe College of Wildlife, Conservation and Agriculture are running 300% more livestock, producing abundant grasslands and restoring the rivers.

The experience of these farmers and documentation from their farms or communal lands has never been more important than now. Worldwide concern about not only Global Climate Change but also the effects (increased drought, disease, flooding, famine, etc.) on poor pastoral communities precipitates an urgent need to better understand the relationship between animal management, deteriorating land, human-induced drought and flooding, famine and social upheaval. In addition, greater understanding is needed of the relationship between land management practices that have destroyed 20-80% of the soil organic matter and practices that can replenish it and of the specific relationship between increased SOM, increased water infiltration and retention and carbon sequestration in grassland environments.

Based on 50 years of field work, study, implementation and monitoring, HMI's evidence indicates that livestock owners, including pastoralists, commercial operators, communal grazers, and family ranchers, have the best tool available to restore degraded grassland environments – their animals. Beginning with the basic premise that grassland environments of the world co-evolved with grazing animals and pack-hunting predators, Holistic Management planned grazing is designed to recreate the symbiotic relationship between grazing, trampling, plants, soils, minerals and water. The process, which is not “rotational grazing” is backed by 50 years of development, testing, monitoring, further development and implementation in a large variety of settings and environments.

Current studies in this field, which will be shared in this poster, include those looking at the relationship between improved grazing management and increased organic matter, carbon sequestration, and water retention/infiltration. Methodologies include comparisons of continuous graze, ungrazed, and high density short duration (including some Holistic Management planned grazing) plots using a variety of standard data gathering, monitoring and documentation approaches.

Data concerning the role terrestrial carbon loss has played in contributing to global climate change will be presented along with the potential role grasslands could play in sequestering carbon to address the legacy and annual load of emissions. Environmental, social and financial impacts and benefits of grassland restoration will be presented. Challenges in adoption of planned grazing, especially in communal settings, will be presented.

The wildfire in Sudan and its impacts on the natural rangelands

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Introduction

Sudan is the largest country in Africa occupying 8% of the African continent. Extending from latitude 3° 53' N in the equatorial zone to latitude 21° 55' in the Sahara desert. Sudan is bounded on the east by the Red Sea and bordered on the other sides by nine African nations. Sudan has a wide range of ecological zones, its dominant features being desert conditions in the north, and tropical and semi tropical condition in the south with large areas under swamps. Bush and grass fire occurs in the low rainfall savannah covering central Sudan, which is an inflammable environment because highly inflammable grasses such as *hyparrhenia pseudocymaria*, *pennisetum purpureum*, *sorghum halpense* and *cymbopogum nervatus*, occur in gaps within the stands and open grassland plains. These tall grasses dry up suddenly over extensive areas of land immediately after the last rain in October (Badi, 1999). In the high rainfall savannah ecosystem of southern Sudan fires kill certain fire sensitive trees e.g. *isoberlinia doka*, *daniellia oliveri*, etc. In an average year, fires affected about 70% of the open range lands (Bayoumi, 2008). Bush and grass fires are the most characteristic phenomenon in Sudan.

Causes of the fire

These fires are caused by man in his daily and seasonal life activities. Farmers and nomads are responsible for 81% of the incidents, while 13% are attributed to travellers. Deliberate criminal acts and picnickers bear the responsibility for the rest.

Fire incidence

Fires occur in October and reach their maximum occurrence in November, then slowing down towards February. An increase in incidents occurs in March concurrent with starting activity of the traditional rain fed cultivators, then slowing down to end of June.

Fire impacts

Fire causes serious damage to forest stands, burning the standing trees to ashes or weakening them and reducing growth. It destroys the seed bank in the soil and ruins the organic matter layer of the soil. Fire stimulates changes in species composition and encourages the spread of insects and fungi (Elhassan, 2000). Natural or intentional fires are claimed to regularly destroy up to 30 to 35% of annual grazing lands /forest forage production (Harris 1994). In an average year, fire affected about 70% of the open rangeland (Bayoumi, 2000). About 84% of nomads consider the consumption of grass as the major damage caused by fire. This is because fire destroys grasses used by both animals and the nomads themselves (Algamri 2007).

Fire database

Fire statistics for the period 1980 to 1999 are lacking except for limited incidents in Jebel Marra (Bayoumi, 2008).

Fire management in Sudan

The problem of the wild land fires is not well considered in Sudan, very limited actions are taken to prevent and suppress fire (Stauber 1995). The Range and Pasture Administration (RPA) is only able to build a limited number of fire breaks (Elgamri)

Organizational set-up

A fire management organization is not in place. However, the traditional system of constructing or maintaining forest fire lines (fire breaks) is adhered to through an annual budget programme, but funds are always short. In colonial times and up to the end of the 1960s the Native Administration, under the supervision of the Range and Pasture Department and in close collaboration with the Forestry Department, maintained a fire break network extending north - south over North Kordofan and North Darfur to protect grazing lands and gum gardens. No fire fighters are available but people and communities are obliged by the forest law report and help fight wildfire (Bayoumi, 2008).

Result and recommendations

This study has shown that very little research was done on the fires in the Sudan and those that were done are mainly on the forests. They show very little information about the impact on livestock, which is a very considerable sector in Sudan and mainly depends on the natural range lands. The situation is very dangerous and needs governmental intervention. Because elsewhere in Sudan no information is available on the wild land fire regime similar research is needed in all areas affected by wildfire.

If range lands continued to be encroached on by wild land fires the future of animal resources will be threatened.

References

- Badi, K.H. (1999) Diversity in forest ecosystems in southern Sudan, High council for the Environment and Natural Resources Khartoum, Sudan.
- Bayoumi, A (2000). Fire situation in Sudan.
- Bayoumi, A (2008). Fire situation in Sudan.
- Elgamri, M (1998). Assessment of fire management in Jebel Marra.
- Elgamri, M (2002). The use of remote sensing in defining and assessing the wild land fire regime and its impacts on forests and range management.
- Elhassan, N (2000) Stakeholders approach for suitable management of forest resources.
- Goldammer, J.G. and Crutzen, P.J. (1993). Fire in the environment: scientific rationale and summary of results of Dahlem Workshop. The ecological, atmospheric and climatic importance of vegetation fire, PPI.14. London: John Wiley and Sons Ltd.
- Harris, P (1994) Consultant report on grazing management in forest areas.
- Stauber, R.L., (1995) Consultant Report on forest fire management in the Sudan. FNC and FAO Boise Idaho, USA.
- Trigg, S (2002) towards improving the use of remote sensing for monitoring burnt vegetation in Africa Savannah. PhD thesis, University of Greenwich, UK.

The elaboration of pathways of methane emissions mitigation in atmosphere by cattle

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One of the processes which reduce the use of nutrients in the rumen of cattle is the formation of significant amounts of methane by symbiotic bacteria (more than 250 l per day in an adult animal). 10-15 % of forage energy is expended on the synthesis of this gas in the rumen. The methane emitted to the atmosphere by ruminants strengthens the green house gas effect and influences the climate of the earth. Therefore the challenge to reduce methane production in the rumen is an actual problem from both economic and ecological points of view.

The research investigations were carried out in vitro. It was established, that during incubation of rumen liquid in anaerobic conditions, the bacterial mass and total volatile fatty acids increased. In the gas phase the methane and hydrogen accumulated. After addition of live *Saccharomyces cerevisiae* cells to the medium, an increase in microorganism population and reduction in the ammonia concentration was observed. At that time the total level of volatile fatty acids rose significantly in comparison to the control, due to an increase in acetate production. The yeast cells exerted an inhibitory influence on methane formation, whereas their effects on molecular hydrogen production were not significant.

In the presence of monensin, sharp inhibition of methane formation and insignificant inhibition of microorganism growth in the rumen were noted. Simultaneously, total proteolytic activity of the microorganisms population and fatty acid formation in the rumen were diminished.

The greatest inhibition of methanogenesis in the rumen and intensification of acetogenesis, in comparison with the controls, were noted in bacteria under the simultaneous addition of yeast cells and monensin to the incubatory medium (a decrease ~ 60 %).

The results obtained suggest that the methane formation in the rumen of cattle is influenced by various factors, including different additives to the ration, which suppress the intensity of methanogenesis. However, it is necessary to take into account that the formation of methane in the rumen of cattle is an important biological process, directed at the decrease in the level of hydrogen, which suppresses other essential processes. Therefore, it is necessary to stimulate the alternative reductive reactions, when methanogenesis intensity diminishes. The intensification of acetogenesis in the rumen under the influence of the ionophore monensin and *Saccharomyces cerevisiae* cells may represent one such pathway.

Heifer International and Sustainable Livestock Development

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Introduction

Heifer International has a solid reputation of using an effective model of people-centered community development using livestock of many species. With its innovative approach, Heifer International has helped millions of people over the past 64 years in over 125 countries enhance family livelihoods, increase household food security and improve nutrition without exploiting their natural resource base.

In the US, the Heifer International Center has been awarded a Platinum certification rating from the U.S. Green Building Council. The Platinum certification is the construction industry's highest honour for buildings that demonstrate environmental responsibility. In this way, Heifer is also leading the way by demonstrating innovative management with minimum environmental degradation.

However, Heifer's programs are under the critical eye of some because of the perceived negative impact of livestock on the environment. The FAO publication entitled "Livestock's Long Shadow" has shed light on the impact that livestock have on increasing atmospheric emissions (carbon dioxide, methane and nitrous oxide) maintaining that in the agriculture sector, livestock constitute nearly 80 percent of all greenhouse gas emissions and 18 percent over all sectors. Hence, livestock are being blamed for contributing to the global climate change.

This paper will describe the many positive characteristics of Heifer's program that results in sustainable livelihoods for program participants that actually benefits the environment.

Heifer's Mission, Vision and Values

For more than 60 years, Heifer International has been working with communities to end hunger and poverty and care for the earth. The Heifer vision is for a world of communities living together in peace and equitably sharing the resources of a healthy planet. To achieve that, Heifer's work is guided by twelve cornerstones or values shared by the organization and program participants. These cornerstones include accountability, sharing and caring, improved animal management, gender and family focus, improving the environment and other values integral to true, sustainable development efforts. Each participant in the program *Passes on the Gift* of an animal offspring or training or other benefits that come with their project. Living these cornerstones, community groups support each other and develop new skills that result in the goal of improved nutrition and income while caring for the earth. .

Most often, Heifer works with farm animals raised on integrated small family farms. This focus affirms the mutual benefits of the relationship between farm animals and people. In exchange for labor, financial security, social status, milk, eggs, meat, manure or wool, farm animals receive protection from predators, clean water, and food, space for exercise, comfortable housing and humane slaughter.

Livestock, crops and training in an integrated farm management system drive economic activity in the communities of project participants. Innovative practices, such as zero grazing housing systems or improved grass management improve the growth and well-being of the animals and income from their production. Improved access to animal health services and training in disease control, improved nutrition, rational use of genetic resources, and improved marketing of livestock and livestock products add to the success of the program.

Dynamics of the Livestock Development

Livestock are a major source of livelihood and sustenance across the planet. The geography and economics of animal agriculture are changing with a trend toward concentrated, intensive production systems. These can be termed High External Input Agriculture (HEIA) or intensive animal production units (see Table1).

Heifer's projects can be classified as Low External Input Agriculture (LEIA) which is the major characteristic of sustainable livestock development and production systems. LEIA has a strong focus on integrated farming techniques where livestock produce nutrients for crops and the crops provide some of the sustenance for the livestock. In terms of resources utilization patterns, one can compare the advantages of the LEIA with the HEIA system on the chart below. The more objective parameters (The Hardware System Dynamics) and more subjective parameters (The Software System Dynamics) demonstrate the advantages of the very strong features of the Heifer International Values-Based approach.

Integrated farming systems contribute to the decrease in wastage and increase in sustainable systems in each beneficiary's house. Working together, whole communities can be integrated to use available resources to increase income, protect the environment and promote sustainable development. Passing on quality animals to other neighbors brings changes as this series of activities creates a growing circle of interdependent and healthy families.

Table 1 Comparison of Animal Agriculture among LEIA*, Heifer International and HEIA** Approach

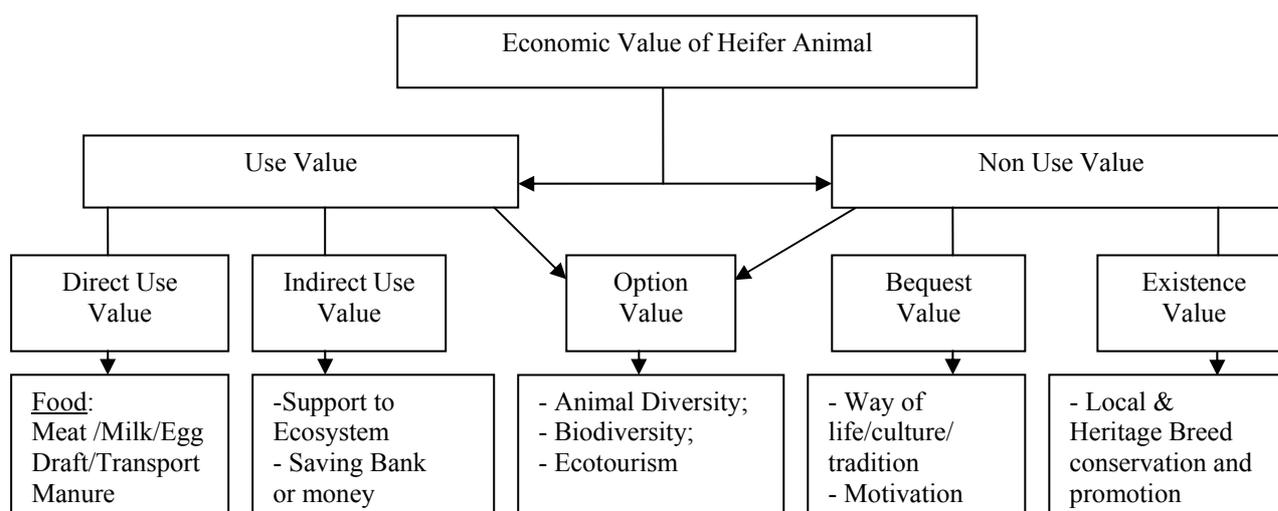
Parameters observation	LEIA	LEIA Integrated (Heifer)	HEIA
Hardware System Dynamics			
Animal Keeping	Not sure	Housing/Grazing	Housing/Grazing
Dung	Use	Use	Yes
Pasture/Fences	Little-yes	Yes	Yes
Urine	No	Yes	No
Use of crop residues	Yes	Yes	No
Fodder	Yes	Yes	Not sure
Scale	Small	Small	Large
Farm Dynamics	complex	Integrated	Simple
Animal Health	Not sure	Yes	Antibiotics/Hormones
Stability	Stable?	Stable	Yes/No
Rate	slow	Slow	Fast
Yield	Low	Low/Optimum	High
Formulated Ration	No	No	Yes
Problems due to waste	Not sure	No, everything used	Yes, if not managed
Ethno-veterinary	Yes/No	Promoted	No
Software System Dynamics			
Holistic approach	Not Sure	Yes	No
Animal Pass On	No	Yes	No
Family Harmony	Yes/No	Sure	Business oriented
Local Innovations	Yes/No	Promoted	No
Child Education	Neutral	Yes	Neutral
Spirituality -Cohesiveness	Does not care	Yes	Does not care

*LEIA: Low External Input Agriculture, **HEIA: High External Input Agriculture

Values of Heifer Animals

Heifer International is more than the provision of animals; it is the overall development of a community of families. The benefit from the animals is much more than the economic use value of the animal. It often translates into a child from Cambodia or from Tanzania having access to school - just from the pair of goats in the shed or a cow in the barn. Within the culture and tradition, the family may not think of this in terms of money. The socio-cultural changes brought about by the animal in the form of nutritious milk or improved vegetables from the kitchen garden directly relate to the decrease in symptoms to disease, such as HIV and AIDS or to fees for the children's school or an improved roof to keep the rain out of the home. This cannot be calculated simply in terms of money.

Figure 1 Values of Heifer Animals in the Communities



Indigenous breeds of animals are often selected by community members for unique uses. In Romania, a local breed of horse adds interest to their eco-tourism program and horse & buggy projects in the area. In Thailand, elephants have been used to provide touristic attractions for visitors and earn income for the villagers. Local breeds of livestock that are long-term adapted to the region provide a more economical animal to raise and extend the biodiversity of the animal species.

Multiple offspring of livestock often provide a living “savings account” for farm families and a hedge against economic downturns, natural disasters, crop failures and family health problems. When funds are needed, the animals in the farm yard can provide immediate cash for the family.

Animal source foods play a central role in human diets, providing excellent sources of protein, vitamins, minerals, and most micro-nutrients. Without meat, milk and eggs, readily available sources of amino acids for a complete diet are limited. People living with disease need ready sources of nutrients that are easily digested and many animal source foods offer that need.

Farm animals, such as cattle, water buffalo, sheep, goats and even chickens are useful in rural villages because they can graze rough and restricted areas where crops for human consumption cannot be grown. They convert forage found in grasses and leaves into milk, meat and muscle power. And they add nutrients back to soils for plant growth and bulk, allowing longer water retention and reducing compaction. Thus, animals not only provide food themselves, but also provide the means to grow other kinds of food and create income opportunities that steadily build food security at family and community levels.

Conclusion

Out of several concerns raised about the role of livestock in global warming, most of these issues actually find benefit from the way Heifer projects rear livestock and care for the earth. When animals are healthy and productive, they are beneficial to the families and have a beneficial impact on the environment. When the communities use the available by-products wisely, such as crop residues and animal wastes, there is an increase in farm crop productivity. Agroforestry, plantations of fodder, even in the alleyways between other crops and on terraces of sloping grounds bring positive benefits to the environment.

References

- Aaker J.2007.The Heifer Model, Cornerstones Values –Based Development. Heifer International, 1 world Avenue, Little Rock, AR 72202, USA.
- Steinfeld , H., P.Gerber , T. Wassenaar, V Castel, M. Rosales, C.D. Haan.2006. Livestock’s Long Shadow: environmental issues and options. FAO, Rome.

The effect of season on performance and blood metabolites of Holstein steers fed low or high grain diets in semi-arid climate

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Introduction

Extreme or rapid changes in environmental conditions can often be detrimental to cattle performance and well-being (Webster, 1973; Hahn, 1995). However, if climatic changes are not too abrupt, cattle can buffer effects of, and adapt to, changing environmental conditions through physiological and metabolic processes. Kamal and Ibrahim (1969) reported that thyroid gland activity in summer was 16% less than in winter allowing for a decrease in metabolic rate and muscle activity to occur and overall heat production to be reduced. In addition, when cattle were exposed to heat stress, blood urea nitrogen levels were found to decrease by 16% in lactating cows and by 28 to 30% in calves (Habeeb *et al.*, 1992). The depression in blood urea nitrogen appears to be a result of re-absorption from the blood to the rumen to compensate for the decrease in ruminal ammonia-N due to reduced feed intake (Habeeb *et al.*, 1992). When cattle are exposed to cold stress, gastrointestinal tract motility increases due to an elevated metabolic rate, resulting from an increase in thyroid hormone activity (Westra and Christopherson, 1976; Kennedy *et al.*, 1977). Thus, feed intake is often enhanced in cattle exposed to cold environments (NRC, 1996). There is evidence that when fed oestrogenic anabolic agents, IGF-I concentrations are increased (Breier *et al.*, 1988; Johnson *et al.*, 1998). Change in body temperature, particularly when cattle are under environmental stress, is another physiological characteristic that could be influenced by anabolic agents. However, no data are available regarding effects of anabolic agents on body temperature.

The aim of the present experiment was to determine the effect of season on feed intake, blood metabolites and body daily weight gain of Holstein steers fed diets providing different concentrate:lucerne hay ratios (C₆₀: L₄₀, C₈₀: L₂₀) in a semi-arid climate.

Materials and methods

The experiment was conducted in the east of Iran, during spring and summer, 2006; where average rainfall is 250 mm per year. Climatic conditions during the 2 seasons (spring and summer) were reported by weathercast centre of Iran. For the spring and summer periods, the ambient temperature averaged 18 and 33 °C, respectively, and ranged from a daily average of 15.2 to 25 °C for spring and 26 to 38 °C for summer.

Holstein steers (initial body weight 261±15 kg, n=30) were adapted to experimental diets for one week. Then, for 120 d, steers were fed diets differing in concentrate (155 g CP kg⁻¹ of DM; 30% maize, 34% barley, 8% soybean meal, 5% sugar beet pulp, 10% wheat bran, 12% cottonseed meal, 0.3% CaCO₃, 0.5% mineral and vitamin premix, 0.2% salt) to lucerne hay (155 g CP kg⁻¹ of DM) ratios as 60:40 (C₆₀: L₄₀) and 80:20 (C₈₀: L₂₀) in a completely randomized design. Steers were housed in individual pens, and fed the experimental diets as total mixed ration twice daily at 0800 and 2000 h. Refusals were removed before the morning feeding. Animals had access to drinking water at the all time. Daily weight gain was recorded every 4 weeks.

For both seasons, at day 60 (spring) and 120 (summer) of the experiment, blood samples were taken from the jugular vein at 2 and 4 h after the morning feeding. Blood samples taken were extracted for plasma by centrifugation (3000 rpm) for 20 min at 4 °C, and were stored at -20 °C until further analysis. Plasma samples were measured for glucose and urea N by Spectrophotometer (CE 1021, 1000 series, Cecil instruments Cambridge England). Duplicate analyses were performed on each sample for glucose and plasma urea nitrogen (PUN).

For Jugular blood pH, samples were collected using heparinized syringes approximately 4 h after the a.m. feeding. The syringes were chilled in an ice bath immediately and transported to the laboratory within 1 h. Blood pH was measured by Automatic blood gas system (AVL 995, Switzerland) adjusted for hematocrit and body temperature.

Data from sampling days were analyzed as repeat measures using the PROMIX of SAS ($y = \text{Mean} + \text{Treatment} + \text{Animal}(\text{Treatment}) + \text{Time} + \text{Treatment} * \text{Time} + \text{Residual}$) and the means compared by the Duncan test ($P < 0.05$).

Results

Feed intake and body weight gain are shown in Table 1. Jugular blood pH, and glucose and plasma urea nitrogen concentrations are shown in Table 2.

Table 1 Feed intake and body weight gain of Holstein steers fed diets differing in concentrate:lucerne hay ratios during spring and summer in semi-arid climate.

Item	Concentrate: Lucerne hay ratio ^{1,2}				Treatment effect		Season effect	
	C ₆₀ : L ₄₀		C ₈₀ : L ₂₀		SEM ³	P	SEM	P
	spring	summer	spring	summer				
Feed intake (kg/d)	10	9.8	9.8	9.65	0.10	0.55	0.11	0.8
Weight gain (kg/d)	1.50	0.99	1.49	0.89	0.11	0.60	0.03	0.01

¹When the difference between means in each row is greater than two times the SEM, it is considered as significant (P<0.05).

²Values were reported as the mean of 15 steers in each treatment.

³SEM= Standard Error of Mean

Table 2 Jugular blood pH, and glucose and plasma urea nitrogen concentrations of Holstein steers fed diets differing in concentrate: lucerne hay ratios during spring and summer in semi-arid climate.

Item	Time (h)	Concentrate: Lucerne hay ratio ^{1,2}				Treatment effect		Season effect	
		C ₆₀ : L ₄₀		C ₈₀ : L ₂₀		SEM ³	P	SEM	P
		60 d	120 d	60 d	120 d				
Blood pH	4	7.33	7.38	7.35	7.36	0.01	0.97	0.01	0.05
Glucose (mg/dl)	2	94.21	79.01	95.73	88.22	3.00	0.04	0.78	0.01
	4	98.78	88.93	103.83	88.93				
Plasma urea nitrogen (mg/dl)	2	13.85	13.21	12.70	12.57	0.52	0.60	0.28	0.9
	4	12.86	12.46	14.22	13.21				

¹When the difference between means in each row is greater than two times the SEM, it is considered as significant (P<0.05).

²Values were reported as the mean of 15 steers in each treatment.

³SEM= Standard Error of Mean

Dry matter intake was not significantly affected by the season. However, the amount of DMI was numerically lower in summer.

Weight gain values were not affected by the treatments. However, it was influenced by the season (P< 0.05) The results of this study showed that the weight gain values were lower in summer than spring (0.94 vs. 1.495 kg/day/steer).

The results of the present study demonstrated that the increasing of concentrate in diets did not significantly affected blood pH. However, blood pH was affected by the season and was ranged from 7.33 (spring) to 7.38 (summer).

Plasma urea N values were similar among diets, but blood glucose values were affected significantly by the treatments and season (P< 0.05). Overall, seasonal effects were not found for PUN concentrations. In addition, the results of this study indicated that the plasma urea N values were not significantly influenced by the concentrate to lucerne hay ratios.

Conclusions

In a semi-arid climate lower weight gain in summer than spring might be associated with body physiological changes. Kamal and Ibrahim (1969) reported that thyroid gland activity in summer was 16% less than in winter allowing for a decrease in metabolic rate and muscle activity to occur, and overall heat production to be reduced. Thyroid activity influences digesta passage rate and digestibility in ruminants (Christopherson, 1985). Thyroid gland responses are also influenced by level of feed intake (Yousef and Johnson, 1985). Positive relationships have been found between thyroid hormone concentrations and energy balance (Murphy and Loerch, 1994; Hersom *et al.*, 2004). Based on seasonal differences in body weight gain in the current study, it has been proposed to evaluate the thyroid activity in the next works.

In a semi-arid climate when steers were fed a high grain diet, the increase in the glucose concentration after realimentation was probably the result of a higher ruminal production of its precursor, propionic acid (Journet *et al.*, 1995).

In the current study, Peak PUN concentrations were found on day 60 (in the spring). In the spring, during the period when ambient temperatures were lower, feed intake was stimulated and was associated with greater PUN levels than were found on summer. In the summer, ambient temperature would be peaking around day 120, thus suppressing feed intake and contributing to a lower PUN. Similarly, a 16% decline in PUN in the summer compared with winter-fed ruminants was reported previously (Habeeb *et al.*, 1992). Habeeb *et al.* (1992) stated that this decline in summer PUN levels could be due to the decrease in DMI, thereby lowering ruminal nitrogen recycling, and causing reabsorption of nitrogen into the rumen from the blood. Kreikemeier and Mader (2004) reported the greatest and lowest DMI during d

36 to 69 in the winter and summer studies, respectively. Furthermore, Changes in PUN concentrations could be attributed to increases in protein synthesis, decreased protein degradation, or a combination of both.

Implications

This study examines the effect of season on feed intake, body weight gain and some blood metabolites of Holstein steers fed low or high grain diets during spring and summer in a semi-arid climate. An unfavourable effect of season on body weight gain and blood glucose concentration suggested that animals fed either diets had poor performance in summer compared with spring in the semi-arid climate.

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References

- Breier, B. H., P. D. Gluckman, and J. J. Bass. 1988. Influence of nutritional status and oestradiol-17 β on plasma growth hormone, insulin-like growth factors-I and II and the response to exogenous growth hormone in young steers. *Journal of Endocrinology*. 118:243–250.
- Christopherson, R. J. 1985. Endocrine systems and thermal environment. Pages 163–180 in *Stress Physiology in Livestock: Basic Principles*. CRC Press Inc., Boca Raton, FL.
- Habeeb, A. A. M., I. P. M. Marai, and T. H. Kamal. 1992. Heat stress. Pages 27–47 in *Farm Animals and the Environment*. C. Phillips and D. Piggins, ed. CABI Publishing, Wallingford, UK.
- Hahn, G. L. 1995. Environmental influences on feed intake and performance of feedlot cattle Pages 207–227 in *Proc. Symp.: Intake by Feedlot Cattle*. Oklahoma State Univ., Publ. no. P-942. F. N. Owens, ed. Oklahoma State University., Stillwater.
- Hersom, M. J., R. P. Wettemann, C. R. Krehbiel, G. W. Horn, and D. H. Keisler. 2004. Effect of live weight gain of steers during winter grazing: III. Blood metabolites and hormones during feedlot finishing. *Journal of Animal Science*. 82:2059–2068.
- Johnson, B. J., M. E. White, M. R. Hathway, C. J. Christians, and W. R. Dayton. 1998. Effect of combined trenbolone acetate and estradiol implant on steady-state IGF-I mRNA concentrations in the liver of wethers and the longissimus muscle of steers. *Journal of Animal Science* 76:491–497.
- Journet, M., G. Huntington, and J. L. Peyraud. 1995. Le bilan des produits terminaux de la digestion. In: R. Jarrige, Y. Ruckebusch, C. Demarquilly, M. H. Farce, and M. Journet (Ed.) *Nutrition des Ruminants Domestiques*. Ingestion et Digestion. pp 671-720. INRA, Paris.
- Kamal, T. H., and I. I. Ibrahim. 1969. The effect of the natural climate of the Sahara and controlled climate on thyroid gland activity in Friesian cattle and water buffaloes. *Int. Journal of Biometeorology*. 13:275–285.
- Kennedy, P. M., B. A. Young, and R. J. Christopherson. 1977. Studies on the relationship between thyroid function, cold acclimation and retention time of digesta in sheep. *Journal of Animal Science* 45:1084– 1090.
- Kreikemeier, W. M., and T. L. Mader. 2004. Effects of growth-promoting agents and season on yearling feedlot heifer performance. *Journal of Animal Science*. 82:2481–2488.
- Mader, T. L. and W. M. Kreikemeier. 2006. Effects of growth-promoting agents and season on blood metabolites and body temperature in heifers. *Journal of Animal Science*. 84:1030-1037.
- Murphy, T. A., and S. C. Loerch. 1994. Effects of restricted feeding of growing steers on performance, carcass characteristics, and composition. *Journal of Animal Science*. 72:2497–2507.
- NRC. 1996. *Nutrient Requirements of Beef Cattle*. 7th ed. Natl. Acad. Press, Washington, DC.
- Webster, A. J. 1973. Heat loss from cattle with particular emphasis on the effects of cold. Pages 205–231 in *Heat Loss from Animals and Man: Assessment and Control*. J. L. Monteith and L. B. Mount, ed. Butterworths, London, UK.
- Westra, R., and R. J. Christopherson. 1976. Effects of cold on digestibility, retention time of digesta, reticulum motility and thyroid hormones in sheep. *Canadian Journal of Animal Science* 56:699–708.
- Yousef, M. K., and H. D. Johnson. 1985. Endocrine systems and thermal environment. Pages 133–141 in *Stress Physiology in Livestock: Basic Principles*. CRC Press Inc., Boca Raton, FL.

Past and recent climate change in Northern and Western regions of Africa

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Most studies carried out on climate in sub-Saharan of Africa indicate more climate variability than an evolution of climate. Consequently, at the present time, no study has convincingly related the evidence of a modification of the climatic parameters to signs of climate change. Data available on climate evolution are compartmental and not very suggestive to engage a national mobilization in favour of climate protection.

This study identifies the evidence of past climate change and establishes the indicators of evolution of the current climate in Southern and Central of Benin.

The indicators of the past climate change were extracted from the available literature and were supplemented by study of the historical traces left by the climatic variations in the landscapes of the two regions.

In order to identify the current signs of a climate change, the climatological data for the 1941-1970 and 1971-2000 periods were analyzed and compared. The numbers of rainy days, the pluviometric means were used to determine the differences between the two periods considered. The data generated on the various scales were translated into relative values. The indicators of warming were found by the calculation of the variations between the periods (1941-1970 and 1971-2000).

Studies and field work reveal that the regions of study were marked by climate changes. The types of grounds, the presence of the flagstones, yellow sands, several lakes, etc. and certain geomorphological specificities in Benin costal zone, are the traces and the obvious signs of past climate change in the two regions of study.

The comparative study of the climatological data between the two periods 1971-2000 and 1941-1970, shows that precipitation dropped by 16 and 28% in the in Southern and central areas of Benin. In this same interval of time, overall temperatures increased by +1°C in the two regions.

Key words: *Southern and western region of Africa, past, recent, analysis, climate change*

Effect of increasing milking frequency on performance and physiological trait of Tunisia Holstein dairy cows under hot weather condition

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Introduction

The thermal comfort zone of bovines is between -13°C and +25°C and within this temperature range, animal comfort is optimal, between 38.4°C and 39.1°C (Lefebvre and Plamondon, 2003). Dairy cows show rapid and shallow breathing, profuse sweating and reduction in milk yield by 10% when the temperature is above or equal to 20°C, and the THI is equal or exceeds 72 (Gerald and Charles 1999). Severe heat stress (32°C and 100% RH) causes open mouth panting, hyperthermia and a 25% decrease in milk yield (Gerald and Charles 1999). Effects of heat stress on milk yield and milk composition of dairy cows have been extensively studied (Moran, 1989). Other studies (Bar-Peled *et al*, 1995; Erdman and Varner, 1995; Sanders *et al*, 2000) showed that milking frequency increases milk yield in dairy cows housed under moderate climate condition (THI<74) (Amos *et al* 1985). However, there are no known studies about the effect of milking frequency on milk production of heat stressed cows. For this reason, we studied the effect of increasing milking frequency in lactating Tunisian dairy cows during heat stress.

Materials and methods

The study was conducted at the OTD Farm of Ghezala (Mateur, 37° 3' 41" N and 9° 39' 45" E, Tunisia) during July, August and September 2006. A total of 48 multiparous lactating Holstein Friesian dairy cows were used. Cows (499 kg BW, 170 DIM and 17.5 L/d) were allocated to 2 treatment groups according to size of udder cistern measured by ultrasonography (LC, large cistern; SC, small cistern) and 2 milking frequencies (×2, twice a day milking; ×3, thrice a day milking) for 2 experimental periods (Period 1, August; Period 2, September). Cows were housed in free stalls with concrete surfaces, bedded with hay and fed ad libitum a TMR containing 4.5 MJ NEL and 15% CP (DM basis). Water was available *ad libitum*. All animals were machine milked twice daily (Alpha Laval, Netherlands) at 0400 and 1600 in a herringbone milking machine. Individual milk yield was recorded at each milking to a precision of 100 ml. Milk samples were collected aseptically during each experimental period in a 20ml vials, preserved with potassium dichromate and stored immediately in a portable refrigerator at 2°C. Upon arrival in the laboratory, milk samples were equilibrated to 40°C and analyzed for protein, fat and urea content. Routine milking included udder and teat cleaning, and teat dipping in an Iodophor sanitizer (Iodine, Veto Lab, Tunisia). At the start of the experiment all cows were diagnosed free of mastitis. Determination of the udder health was performed by CMT (Ukaltest, Ukal Canada) on milk samples collected aseptically on a CMT plate. Cistern area was measured by ultrasonography according to the methodology of Ayadi *et al*. (2003). Udder scans for the right front and rear quarters were performed in duplicate 08 to 10 h after the a.m. milking by using real time B-mode ultrasonograph (Ultra Sound Scanner B7v; Noveko Echograph Inc., Quebec, Canada) equipped with a Multi-frequency linear probes (7.5-2.6 MHz, 2 dB power; 80° scanning angle, 0.5-mm axial and 1.5-mm lateral resolution). Cistern areas were measured in duplicate using an image tool programme. Rectal temperature (RT), Respiratory and cardiac rate (RR, CR) were recorded in test days at monthly milk recording. RT was measured using a medical digital thermometer to a precision of 1/100°C, between 09:00 and 15:00, RR (Breaths/minute) and CR (Beats/minute) were counted, between 10:00 and 15:00, using a medical stethoscope. Ambient temperature (AT) (°C) and relative humidity (RH) (%) were measured using a thermohygrometer (HI 91610C, Hanna instrument). Data are expressed as means and subjected to analysis of variance-covariance with repeated measures and the pre-experimental period (p0) was used as covariates. Pearson's correlation coefficients among physiological, production and meteorological parameters were calculated. Repeated measurements were analyzed by ANOVA (mixed model procedure for repeated measurements in SAS) Missing data were estimated by least squares procedures with appropriate reduction of degrees of freedom for residual. The level of significance was taken as $\alpha=0,05$.

Results

Average (AT), (RH) and THI at the Ghezala dairy farm of the OTD (Tunisia) are presented in Table 1. It should be pointed out that THI during the experiment exceeded the critical value of 72 at which milk yield is reduced, suggesting that cows were continuously exposed to heat stress. Such THI has been shown to reduce milk yield in cows (Johnson, 1987). Igono *et al.*, (1992) reported that when the number of hours where the (AT) was less than 21°C fertility was not affected. However, milk yield was reduced when (AT) was over 27°C.

Table 1 Temperature, Relative humidity and THI at the 'Ghezala' dairy farm of the OTD in Tunisia

Item	Period		
	Pre-exp. (P0) July	Exp. 1(P1) August	Exp. 2(P2) September
Ambient temperature, °C (T)	29.3 (26.5-33.0)	33.4 (27.6-36.8)	29.2 (28.2-30.1)
Relative humidity, % (RH)	53.1 (47-65)	59.3 (46-80)	51.9 (49-56)
THI*	79 (75-81)	84 (81-87)	77 (77-78)

*Temperature-humidity index according to Thom (1959), $THI = 1.8 \cdot T - (T - 14.3) \cdot (100 - H) / 100 + 32$

Table 2 shows milk yield, milk composition, and udder cistern size. Correlation between milk yield and cistern size was low but positive at the beginning of the experiment ($r = 0.33$; $P = 0.018$) and increased when expressed as fat corrected milk at 4% ($r = 0.43$; $P = 0.002$). Daily milk yield per unit (Table 2) of cisternal area was equal to 482 mL/cm² and daily milk yield was 16.9 L/d, which was in the range of the values obtained by Ayadi *et al.*, (2003) and Caja *et al.*, (2004) which varied from 332-551 mL/cm². Our results support the repeatability of the methodology used, as well as the representativity of the cow sample used and indicate that an alveolar to cisternal milk partitioning of approximately 70 to 30%, respectively, can be assumed.

Correlation between rectal temperature, and heart girth or body weight was low and negative ($r = -0.24$; $P = 0.017$), indicating that the heavy cows had a lower metabolic rate. On the other hand, we observed that heavy cows tended to lose more milk than lighter ones during heat stress ($r = 0.28$; $P = 0.113$). Correlation between milk yield and ambient temperature at the day of milk recording was low but positive ($r = 0.29$; $P < 0.05$). No significant correlations between other parameter and milk yield were observed ($P > 0.05$).

Table 2 Lactational performances of Holstein cows during the experiment at the ‘Ghezala’ dairy farm (Tunisia)

Item	Period		
	Pre-exp. (P0)	Exp. 1(P1)	Exp. 2 (P2)
Cows, n	78	67	45
Age, mo	72.5	73.5	74.5
Body weight, kg* (BW)	498.8	502.5	512.4
Days in milk, d	170	201	232
Milk yield 3, L/d	18.0 (100%)	15.3 (85%)	13.3 (74%)
Milk fat 3 (%)	3.31	3.19	4.00
Milk protein, (%)	3.06	3.12	3.06
ECM4, L/d	17.6 (100%)	14.7 (84%)	14.1 (80%)
Udder cisterns size, cm2	32.9	-	-

* Estimated according to Heinrichs *et al.* (1992), $BW = 4.134 \cdot (HG - 318.51)$

THI equal or greater than 75 ($P < 0.05$) increased rectal temperature, respiratory and heart rates. Each unit increase in THI is followed by an increase of 0, 2°C, 5 breaths/min and 1beat/min. Under field conditions body temperature increases as (AT) increases above 21°C (McDowell, 1958). Figure 1 indicates that (RT) increases as (AT) increases and agrees with that of Igono and Johnson, (1990). This correlation is high ($R^2=0.85$) and indicates that the upper critical ambient temperature for dairy cows is 25°C. Above 25°C management to relieve heat stress is required to minimize the rise in body temperature (Berman *et al.*, 1985).

Moreover our results show that (RR) and (RT) are highly correlated ($r > 0.9$) on test days. This result suggests that RR is sensitive to RT. This finding agrees with that of Brown-Brandl *et al.*, (2005), whom suggest that RR is a good indicator of heat stress. It should be pointed out that RR was observed when $THI > 75$ (Figure 2).

In the present study, heat stress reduced daily corrected milk yield by 16% as the THI increases from 79 to 84 (Table 2). Bouraoui *et al.*, (2002) reported that milk yield decreased by 21% when THI increased from 68 to 78. Estimated milk yield reduction was on average equal to 0.32kg per unit increase in THI (Ingraham *et al.*, 1979). Johnson *et al.*, (1963) reported that milk yield decreased when RT exceeds 38.9°C, and for each 0.55°C increase in RT, milk yield decreased by 1.8kg. Ravagnolo *et al.*, (2000) concluded that THI can be used to estimate the effect of heat stress on milk production.

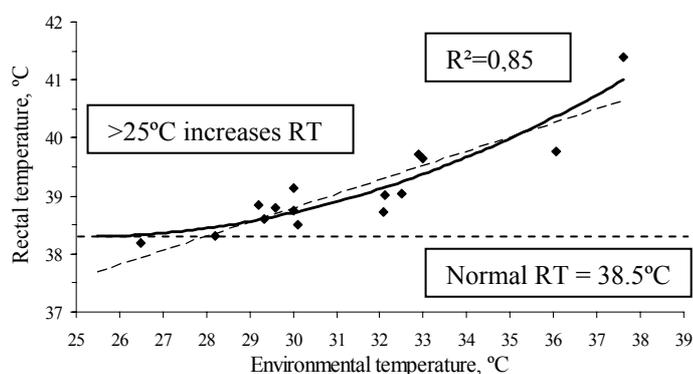


Figure 1 Regression between environmental and RT of Holstein Friesians raised in Tunisia.

Decreases in milk yield were accompanied by a decrease in milk fat (16%; $P < 0,01$) but no effect on milk protein was found ($P = 0,385$) (Table 2). Heat stress reduced milk fat content from 3.31% to 3.19%. Heat stress has been associated with depressions in milk fat percentages (Rodriguez *et al.*, 1985). However, Knapp *et al.*, (1991) and Roman-Ponce *et al.*, (1977) found no significant decrease in fat milk for cows under heat stress. Bouraoui *et al.*, (2002) and Rodriguez *et al.*, (1985) found that milk protein content decreased as a result of summer heat stress. Milk urea decreased by 22% on average during the experimental ($P < 0,01$). No interaction between cistern size and milking frequency was detected for milk yield (Figure 3).

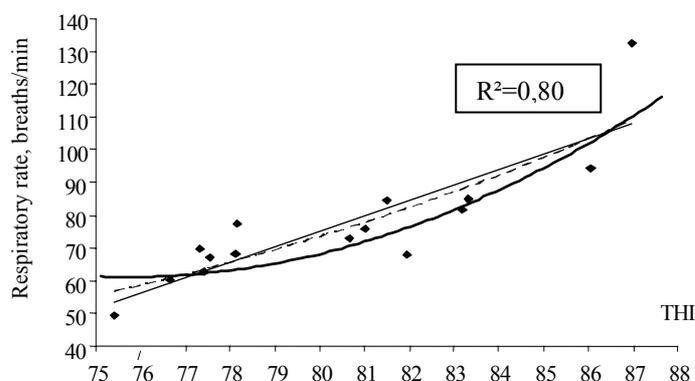


Figure 2 Regression between the THI and RR of Holstein Friesians raised in Tunisia.

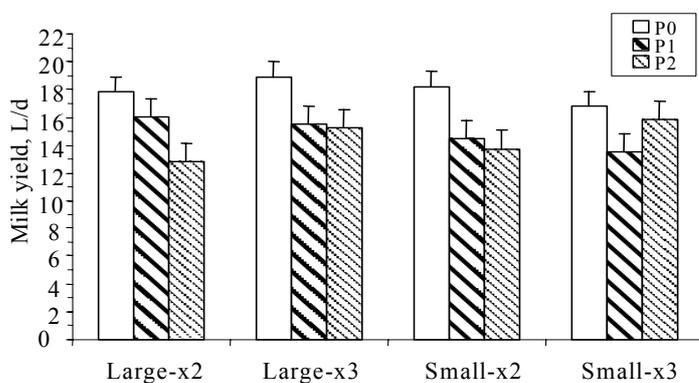


Figure 3 Milk yield according to cistern size and milking frequency in Holstein Friesians in Tunisia.

Milk yield decreased under heat stress and lactation stage ($P < 0,001$) (Figure 4), however milk losses in x3 cows were half those of x2 cows (-2,3 vs. -4,7L/d, $P = 0,08$). As a result, only a 5% decrease in energy corrected milk was observed in x3 cows at the end of the experiment (Figure 4 and 5).

Increasing the frequency of milking dairy cows, increased milk production (Amos *et al* 1985). Bar-Peled *et al.*, (1995) and Hale *et al.*, (2003) have reported an increase in milk yield by 7.7; 10.9; and 16.1 l/d when cows were changed from 2x to 3x, 2x to 4x, 3x to 6x respectively in milking frequency, with no effect on milk composition. In addition to the positive milk yield responses, higher milking frequency reduces heat stress.

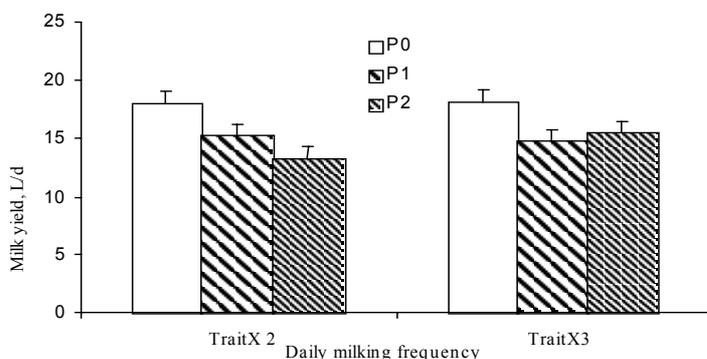


Figure 4 Milk yield according to milking frequency in heat stress Holstein Friesians in Tunisia

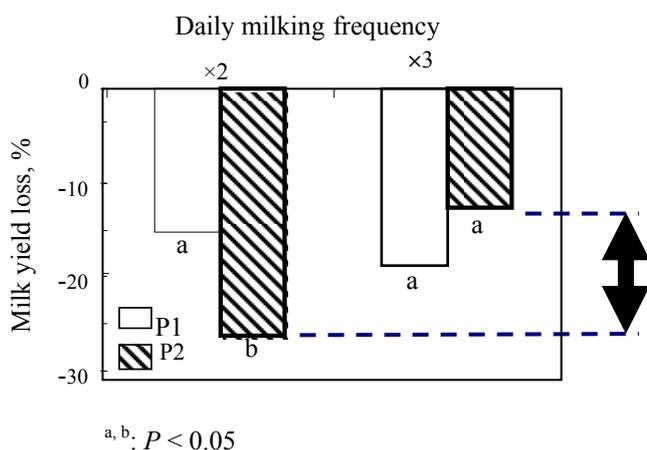


Figure 5 Milk yield according to frequency in heat stress Holstein Friesians in Tunisia

Conclusion

Heat stress was detected when $THI > 75$ in Holstein Friesian cows raised in Tunisia, THI induced a decrease in milk yield, milk fat but have no adverse effect on milk protein. Respiratory rate was found to be the best indicator for heat stress. Heat stress was observed from mid June to the end of September at Mateur (Tunisia), THI ranged from 70 to 80. In addition thrice a day milking may alleviate heat stress.

Implications

This study discusses strategies that can be used on commercial dairies to reduce the effects of heat stress on milk yield, milk composition, RT and RR. Thrice a day milking may alleviate heat stress and improve milk yield.

Acknowledgements

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References

- Amos S.E., Kiser T and Loewenstein M. 1985. Influence of milking frequency during on productive and reproductive efficiencies dairy cows. *J. Dairy Sci.* 68: 732-739.
- Ayadi M., Caja G., Such X, and Knight C.H. 2003a. Use of ultrasonography to estimate cistern size and milk storage at different milking intervals in the udder of dairy cows. *J. Dairy Res.* 70: 1-7.
- Bar- Peled U., Maltz E., Bruckental I., Folman Y., Kali Y., Gacitua H, and Lehrer A.R. 1995. Relation ship between frequent milking or suckling in early lactation and milk production of high producing dairy cows. *J. Dairy Sci.* 78: 2726- 2736.
- Berman A., Folman Y., Karim M., Mamen M., Herz Z., Wolfenson D., Arieli A., Graber Y. 1985. Upper critical temperatures and forced ventilation effects for high yielding dairy cows in a subtropical climate. *J. Dairy Sci.* 68: 1488-1495.
- Bouraoui R., Lahmar M., Majdoub A., Djemali M., Belyea R. 2002. The relation ship of temperature-humidity index with milk production of dairy cows in a Mediterranean climate. *Anim. Res.* 51: 479- 491.
- Brown- Brandl T.M., Eigenberg R.A., Hahn G.L., Nienaber J.A., Mader T.L., Spiers D.E., and Parkhurst A.M. 2005. Analyses of thermoregulatory responses of feeder cattle exposed to simulated heat waves. *Int. J. Biometeorol.* 49: 285-296.
- Caja G., Ayadi M., and Knight C.H. 2004. Changes in cisternal compartment based on stage of lactation and time since milk ejection in the udder of dairy cows. *J. Dairy Sci.* 87: 2409- 2415.
- Erdman R.A. and Varner M.A. 1995. Fixed yield responses to increased milking frequency. *J. Dairy Sci.* 78: 1199-1203.
- Gerald M.J. and Charles C.S. 1999. Reducing heat stress for dairy cattle. Virginia cooperative Extension. Dairy Publication Number 404-200.
- Hale S.A., Capuco A.V., and Erdman R.A. 2003. Milkyield mammary growth effects due to increased milking frequency during early lactation. *J. Dairy Sci.* 86: 2061-2071.
- Igono M.O. and Johnson H.D. 1990. Physiologic stress index of lactating dairy cows based on diurnal pattern of rectal temperature. *J. Interdiscipl. Cycle Res.* 21: 303-320.
- Igono M.O., Bjotvedt G., and Sanford-Crane H.T. 1992. Environmental profile and critical temperature effects on milk production of Holstein cows in desert climate. *Int. J. Biometeorol.* 36: 77-87.
- Ingraham R.H., Stanley R.W., and Wagner W.C. 1979. Seasonal effects of tropical climate on shaded and non shaded cows as measured by rectal temperature, adrenal cortex hormones, thyroid hormone, and milk production. *Am. J. Vet. Res.* 40: 1792- 1797.

- Johnson H.D., Ragsdale A.C., Berry I.L., Shanklin M.D. 1963. Temperature- humidity effects including influence of acclimation in fet and water consumption of Holstein cattle, University of Missouri, Research Bulletin, N° 846.
- Johnson H.D. 1987. Bioclimate effects on growth, reproduction and milk production. Page 35 in Bioclimatology and the adaptation of livestock. H.D. Johnson, ed. Elsevier, Amsterdam, the Netherlands.
- Knapp D.M., and Grummer R.R. 1991. Response of lactating dairy cows to fat supplementation during heat stress. *J. Dairy Sci.* 74: 2573-2579.
- Lefebvre D., and Plamondon P. 2003. Le producteur de lait Quebecois, Juin 2003.
- MC Dowell R.E. 1958. Physiological approaches to animal climatology. *J. Hered.* 49: 52-61.
- Moran J.B. 1989. The influence of season and management system on intake and productively of contained dairy cows in a Mediterranean climate, *Anim. Prod* 49: 339-344.
- Ravagnolo O., Misztal I., and Hoogenboom G. 2000. Genetic component of heat stress in dairy cattle, development of heat index function. *J. Dairy Sci.* 83: 2120-2125.
- Rodriguez L.W., Mekonnen G., Wilcox C.J., Martin F.G., Krienk W.A. 1985. Effects of relative humidity, maximum and minimum temperature, pregnancy and stage of lactation on milk composition and yield. *J. Dairy Sci.* 68: 973-978.
- Roman- Ponce H., Thatcher W.W., Buffington D.D., Wilcox C.J., Van Horn H.H. 1977. Physiological and production responses of dairy cattle to shade structure in a subtropical environment. *J. Dairy Sci.* 60: 424- 430.
- Sanders A.H., Varner M.A., and Erdman R.A. 2000. The effects of six times a day milking in early lactation on milk yield, milk composition, body condition and reproduction. *Am. Dairy Sci. Annual Meeting*, Baltimore, July. *J. Dairy Sci.* 83(supp1):242(Abstr).
- Thom E.C. 1959. The discomfort index. *Weather wise* 12:57

The effect of body condition score and some body measurements on milk production and milking flow in Friesian cows in Yemeni cold areas

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The experiment studies the influence of the body condition score of the Friesian cows on milk production (day time \ night and 305 days) and milk flow. The study was carried out in Rusaba cows' station, 85 km from Sana'a and 15 km from Thamar governorate. Then the body condition score (BCS) is estimated after calving.

Data were analyzed using least squares. The day / night milk production, body weight ($p < 0.01$) and milking flow ($p < 0.05$) were influenced by the body condition score. There was also a high significant influence of the teat shape on the body measurement, day /night milk production and milk flow. All considered traits influenced parity significantly except body weight. The udder shape had no significant influence on any of the traits. The udder texture had a significant influence on day production, milking low and on 305 day milk yield ($p < 0.01$), ($p < 0.05$) respectively.

There was a highly significant correlation between (BCS) and body weight (0.78).

Crop growth limitations in arid region in Tunisia

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Introduction

In Mediterranean countries, agriculture plays a vital role in rural development and people's livelihoods. Furthermore, agricultural development is the main factor affecting livestock and animal production. However, in arid regions in Tunisia, these animals face a complex of factors affecting their growth and improvement. Severe climate changes, on one hand, and limited water resources on the other, are the most important factors limiting agricultural progress in arid regions.

Due to its socio-economic importance, the olive tree (*Olea europaea* L.), the major tree crop in arid regions in Tunisia, is being extended to irrigated lands. However, the current decrease in water resources in Mediterranean ecosystems and the increased need for good water quality for urban and industrial sectors use have led to the use of large quantities of saline water for olive tree irrigation. Nevertheless, in arid regions in Tunisia, the use of saline water is not the only factor on which agricultural development depends. Indeed, Ben Ahmed *et al.* (2006; 2007) have showed that, even under irrigation, plant activity is affected by severe environmental conditions characterizing the Mediterranean climate, particularly in the south of Tunisia, where the mean of air temperature can exceed 37°C during the summer period. The same authors have stated that the complementary of water irrigation at 66% ETc did not led to a significant increase of olive yield, if compared to that corresponding to 33% ETc of water supply. Hence, to select cultivars tolerant to salt stress and to manage water resources is an important step to enhance olive cultivation under salt stress conditions and to exploit saline soils being extended in these areas.

Several papers have considered olive tree as moderately tolerant to salinity (Therios and Misopolinos, 1988; Ben Ahmed *et al.*, 2006; Ben Rouina *et al.*, 2006). However, olive salt tolerance is cultivar (Chartzoulakis *et al.*, 2002, Ben Ahmed *et al.*, 2008a), climate environment and salinity level (Chartzoulakis *et al.*, 2002; Ben Ahmed *et al.*, 2008b) dependent.

There are a variety of papers showing the responses of different varieties of olive trees to deficit irrigation strategies and studying the relationships between drought stress conditions and olive production (d'Andria *et al.*, 2004; Tognetti *et al.*, 2004; Moreno *et al.*, 2006). They have stated that fruit weight development and olive production are not only related to water quality treatment but are also cultivar dependent. Moreover, the genetic diversity in olive trees is high and there are large differences in salt tolerance among genotypes and cultivated varieties (Chartzoulakis *et al.*, 2002; Loreto *et al.*, 2003; Ben Ahmed *et al.*, 2008a).

The main purposes of this paper are (1) to investigate the effects of long term salt stress on water relations, growth characteristics and olive production of this species and to determine some physiological responses developed by this perennial crop to tolerate salinity conditions under arid climate of Tunisia.

Materials and methods

The trial was carried out during two crop seasons, on the Chemlali olive trees planted in 1990 at the experimental site of the Olive Tree Institute in Sfax, Tunisia (34°43N, 10°41E). The region is characterized by an arid climate with an average of winter rainfall of about 250 mm of water annually and a temperature average of 23°C. The major climatic conditions of the experimental site (Average of air temperature, precipitation (rainfall) and global solar radiations) were recorded from a meteorological station installed near to the Institute.

Two blocks of 20 trees, with four replications of 5 trees each, per treatment were used. All the plants were spaced 4 x 6m, drip irrigated with the same amount of water and subjected to the same fertilization and common olive cultivation practices.

The Chemlali olive trees were subjected to the following treatments: irrigation with fresh water, 1.2 dS m⁻¹ EC (Control plants, CP); and irrigation with saline water, 7.5 dS m⁻¹ EC (Stressed plants, SP). The water used was either that supplied by the Tunisian National Water Carrier, or saline water from the local reservoir situated in the area of the Olive Tree Institute. Taking rainfall into account, total water supplied to mature olive trees was 4000 m³ / ha / year.

Growth characteristics were characterized via the determination of shoot elongation rates (SER). SER were measured every two weeks on 4 randomly selected shoots, from the different directions (north, south, east and west), from ten plants per treatment.

Control of fruit weight (FW) was made four times per month. In every control, 60 olives from six plants per treatment were collected for characterization. The harvest of the olive tree has been made manually to guarantee the accuracy. All the olives harvested from each tree were weighed to obtain olive production.

The data were subjected to analysis of variance (ANOVA) and treatment means were compared using Least Significant Differences (LSD) test at $p < 0.05$. At least three replicates were used for each field test.

Results

Table 1 summarizes the most important environmental parameters recorded during the experimental period. During both crop seasons, the rainfall pattern was characterized by a scant rain in spring (from March to May) and in autumn and a dry summer (from June to August). During the 2004/2005 period, it was of 94.6 and 169.5 mm, respectively in spring and autumn. The most important quantity was recorded in the winter season (from December to February). The climatic conditions were characterized by a moderate temperature average during spring time (28°C), a high temperature average from June to October (35.2 and 34.6°C, respectively during the first and the second crop season) and a moderate average during November – December period. Indeed, in arid area like the south of Tunisia, the summer period does not last only 3 months (from June to August). It practically continued to October with high temperature and less precipitation. The maximums for photosynthetic active radiations was registered during the summer period in coincidence with high temperature.

Table 1 Environmental parameters of the experimental site during the trial period

Period		F	M	A	M	J	J	A	S	O	N	D	J
2004/	T(°C)	19	25	28	31	34	38	38	34	32	26	21	18
2005	P(mm)	210	35	45	14.6	1.6	0.5	0.8	81	56	32.5	125	145
	PAR	720	890	995	1154	1250	1486	1520	1210	921	780	650	620
2005/	T(°C)	18	25.4	27.2	32.1	33.4	37.5	37.9	33.8	31	24.6	22.1	19.1
2006	P(mm)	145	220	64	12.5	2.1	1.1	0.4	74	85.6	241	220	247
	PAR	690	852	964	1021	1278	1469	1495	1364	1054	812	641	610

Each value represents a monthly mean. T: temperature average; P: precipitation average (mm of water per month); PAR: photosynthetic active radiations intensity ($\mu\text{mol m}^{-2} \text{s}^{-1}$)

Salt stress has altered photosynthetic activity and leaf relative water content of stressed plants (Fig. 1). Indeed, the relative reduction of net photosynthesis average in stressed plants ranged from 55 to 76% during June in the first and the second crop season, respectively if compared to CP. However, during the partial vegetative growth phase of the olive tree (from September to November), the relative reduction ranged from 32 to 57% for the first and the second crop season, respectively. The more severe the salt stress was, the lower the net photosynthesis was. The lowest values of relative reduction of net photosynthesis, in salt-stressed plants in comparison with the control ones, were recorded during summer and winter seasons coinciding with the plant rest phases, adapted by the olive tree in order to avoid damaging its survival mechanisms.

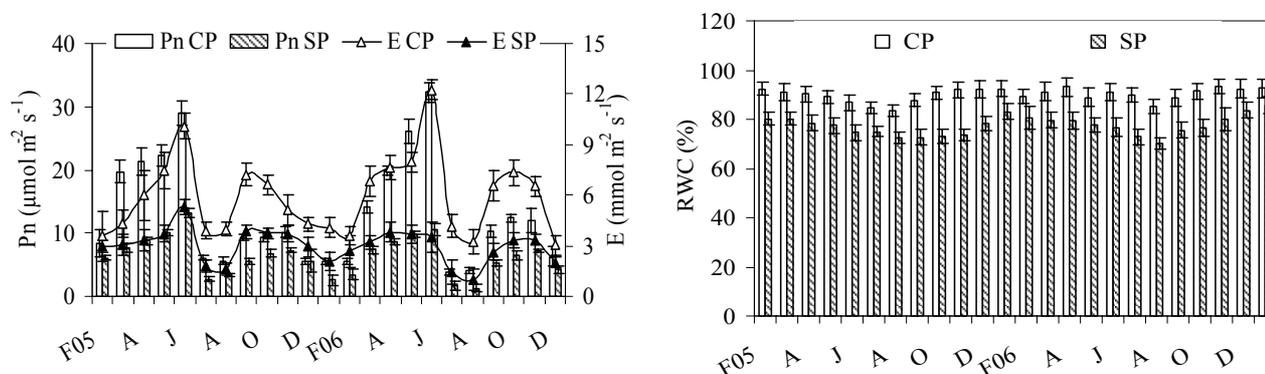


Figure 1 Time course of changes in net photosynthesis (Pn) and transpiration (E) (on the left) and relative water content (on the right) in both treatments during two crop seasons (2004/2005 and 2005/2006). Bars indicate S.E.

In general, the highest reduction was observed in summer period coinciding with severe climatic conditions characterizing the arid climate of the south of Tunisia. These observations indicate that the deleterious effects of salt stress on RWC and Pn were reinforced by severe environmental conditions. The occurrence of more moist times (autumn and winter) was accompanied with better water status levels in comparison to those recorded in the summer period. Indeed, even salt-stressed, Chemlali olive trees were able to establish better hydration status under more favourable climatic conditions. This behaviour displayed, at the same time, the resistance of the Chemlali Sfax olive tree to salt stress and its ability for recovery under more climate environmental conditions (low air temperature, high precipitation,). The reduction of photosynthetic performances (Pn, Gs and E rates) in salt stressed plants, and to a lesser extend in control plants, during the summer period in both crop seasons, constitutes for the Chemlali Sfax olive tree an adaptive mechanism, developed by this cultivar to maintain its hydration status and to avoid damaging plant survival mechanism (Ben Rouina *et al.*, 2006). The large depression of Pn in CP during the winter and summer seasons leads one to conclude that the availability of water is insufficient to induce maximum photosynthetic activity if other environmental conditions are not favourable. During this critical period, characterized by severe climatic conditions

(high air temperature, high light intensity, cold,...), the Chemlali Sfax olive tree has to reduce its activity and to enter in a rest phase to prevent damaging its survival mechanism (Ben Ahmed *et al.*, 2007; Ben Rouina *et al.*, 2007).

Table 2 shows the patterns of shoot elongation rates during both crop seasons for different plant directions. For both treatments, the intense shoot elongation rate was recorded during the intense vegetative growth phase coinciding with maximum photosynthetic activity. During both crop seasons, differences between shoot elongation rate (SER) of CP and SP were statistically significant ($p < 0.05$) with differences noticed during the second crop season being larger than those recorded during the first one. The relative reduction of SER of SP was of 12 and 37%, respectively during the first and the second crop season, if compared to CP. The highest relative reduction of SER was observed during the intense vegetative growth phase. It ranged from 19.3% and 43% during the first and the second crop season, respectively. However, during the partial vegetative growth phase (SER2), the relative reduction was of 15.5% and 16%, respectively. Furthermore, for both treatments, the highest shoot elongation rate was recorded for the south direction and to a lower extent the west one. The lowest rate was determined in the north direction and to a slight higher extent for the east one, as well during the first, as during the second crop season. The best shoot elongation process occurred on well exposed shoots.

Table 2 Shoot elongation rate (cm month⁻¹) for different directions of the tree in the irrigation treatments studied during 2004/2005 and 2005/2006 crop seasons

		2004/2005			2005/2006		
		SER	SER1	SER2	SER	SER1	SER2
CP	North	1.28±0.025	1.55±0.029	0.91±0.012	1.42±0.015	2.20±0.025	1.03±0.025
	South	1.48±0.036	2.29±0.019	1.34±0.018	1.98±0.014	2.45±0.024	1.24±0.019
	East	1.41±0.041	1.93±0.028	1.05±0.065	1.84±0.026	2.28±0.013	1.10±0.024
	West	1.44±0.052	1.95±0.017	1.21±0.025	1.91±0.015	2.36±0.014	1.16±0.036
SP	North	1.19±0.014	1.44±0.025	0.71±0.014	1.09±0.025	1.19±0.056	0.82±0.042
	South	1.29±0.026	1.73±0.026	1.08±0.036	1.16±0.014	1.45±0.015	1.03±0.029
	East	1.21±0.065	1.46±0.018	1.01±0.015	1.1±0.025	1.29±0.025	0.96±0.047
	West	1.25±0.028	1.6±0.058	1.01±0.024	1.12±0.022	1.36±0.015	0.98±0.038
Rred in SP (%)		12	19.3	15.5	37	43	16.3

Values represent means ± S.E. values of two measurements per month for 10 plants per treatment. SER: relative growth rate (cm/month) for 9 months per year (from March to November including summer period), SER1: shoot elongation rate (cm/month) during spring period (March – June), SER2: shoot elongation rate (cm/month) during autumn period (September – November); Rred in SP: relative reduction of shoot elongation rate in SP in comparison to CP.

The reduction in growth characteristics and leaf gas exchange properties of salt – stressed Chemlali Sfax olive tree indicate a close relationship between carbon acquisition and whole plant growth under saline conditions. The relationship between photosynthetic assimilates and growth process can be justified by the fact that the most important shoot elongation rate has occurred during the period characterized by the intense photosynthetic activity (from March to June); and the partial vegetative growth phase (from September to November) was characterized by both low levels of photosynthetic and shoot elongation rates. Several researches have reported that the extent of plant growth reduction was related to the period of salt exposure and the cultivar (Loreto *et al.*, 2003). The same results have been signalled by Kozłowski (1997). The same author has attributed the growth alteration to the effects of excessive salt uptake which affects the production or the synthesis of some metabolites controlling directly the growth process. The difference in shoot elongation rates between the different directions of the plant (south, north, east and west) could be related to the intensity of solar radiations to which the plants were exposed. The direction subjected to a longer period of sunning presents the higher rates of shoot elongation.

The olive production data of the experimental olive orchard studied expressed as the average weight of fruits per olive tree per treatment during the 2004/2005 and 2005/2006 crop seasons for both treatments are listed in Table 3.

Table 3 Olive production in the different irrigation treatments studied during 2004/2005 and 2005/2006 crop seasons.

Crop season	Olive production (Kg tree ⁻¹)	
	CP	SP
2004/2005	47±3.2	32±2.8
2005/2006	38±2.9	22±3.1
Mean	42.5	27

Values represent means ± S.E. values of olive production for 10 plants per treatment.

The average olive production of salt stressed plants (27Kg tree⁻¹) was much lower if compared to that obtained in CP (42Kg tree⁻¹) with a reduction of 36%. Indeed, the relative reduction of olive production in SP ranged from 32 to 42%, respectively during the first and the second crop season, if compared to CP. During both crop seasons, differences between control and stressed treatments were statistically significant. However, the oil produced under salinity conditions showed higher phenolic compounds than that obtained from control plants and it was classified as “extra virgin” oil (unpublished data).

Implications

In Tunisia, as in other African countries, livestock is dependent on agriculture development and vegetable growth. The improvement and extension of olive plantation will have a direct positive consequence on animal production especially on sheep. Each year it is the olive yield which determines the sheep production because most animal producers manage their production on the basis of olive production which is dependent on climate change and water resources. People in arid regions are interested not only in the management of water resources but also in the selection of most olive salt tolerant cultivars to be extended in arid regions and so limit desertification, to provide an animal food source, to maintain a green landscape in arid regions and in so doing, to improve the livestock, particularly the sheep production in southern Tunisia.

References

- Ben Ahmed, C., Ben Rouina, B., Athar, H.R., and Boukhris, M., 2006. Olive tree (*Olea europaea* L. cv. "Chemlali") under salt stress: water relations and ions content. *Pakistan Journal of Botany*, 38(5) Special issue: 1777-1784.
- Ben Rouina, B. Ben Ahmed, Ch. Athar, H.R., Boukhris, M., 2006. Water relations, proline accumulation and photosynthetic activity in olive tree (*Olea europaea* L cv Chemlali) in response to salt stress. *Pakistan Journal of Botany*, 38(5) Special issue: 1397-1406.
- Ben Ahmed Ch., Ben Rouina, B., Boukhriss. M., 2007. Effects of water deficit on olive trees cv. Chemlali under field conditions in arid region in Tunisia. *Scientia Horticulturae*. 133: 267-277.
- Ben Ahmed Ch., Ben Rouina, B., Boukhriss. M., 2008a. Comparative responses of three tunisian olive cultivars to salt stress: from physiology to management practices. Nova Science Publishers. In "Agricultural Irrigation Research Progress " Edited Book (in press)
- Ben Ahmed Ch., Ben Rouina, B., Boukhriss. M., 2008b. Changes in water relations, photosynthetic activity and proline accumulation in one - year - old olive tree (*Olea europaea* L. cv Chemlali) in response to NaCl salinity. *Acta Physiologia Plantarum*. 154 (in press).
- Ben Rouina, B., Trigui, A., d'Andria, R., Boukhris, M., Chaïeb, M., 2007. Effects of water stress and soil type on photosynthesis, leaf water potential and yield of olive trees (*Olea europaea* L. cv Chemlali Sfax). *Australian Journal of Experimental Agriculture*, 47 (12): 1484-1490.
- Chartzoulakis, K., Loupassaki, M., Bertaki, M., Androulakis, I., 2002. Effects of NaCl salinity on growth, ion content and CO₂ assimilation rate of six olive cultivars. *Scientia Horticulturae*. 96: 235-247.
- d'Andria, R., Lavini, A., Morelli, G., Patumi, M., Terenziani, S., Calandrelli, D., Fragnito, F., 2004. Effects of water regimes on five pickling and double aptitude olive cultivars (*Olea europaea* L.) *Journal of Horticultural Science and Biotechnology*. 79: 18-25.
- Kozłowski, T.T., 1997. Responses of woody plants to flooding and salinity. *Tree Physiology Monograph* No.1, 1997.
- Loreto, F., Centritto, M., Chartzoulakis, K., 2003. Photosynthetic limitations in olive cultivars with different sensitivity to salt stress. *Plant, Cell and Environment*. 26: 595-601.
- Moreno F, Conejero W, Martin- palomo MJ, Giron IF, Torecillas A (2006) Maximum daily trunk shrinkage reference values for irrigation scheduling in olive trees. *Agricultural Water Mangement*. 84: 290-294.
- Therios, I.N., Misopolinos, N.D., 1988. Genotypic responses to sodium chloride salinity of four major olive cultivars (*Olea europaea* L.). *Plant and Soil*. 106: 105-111.
- Tognetti R, d'Andria R, Morelli G, Calandrelli D, Fragnito F (2004) Irrigation effects on daily and seasonal variations of trunk sap flow and leaf water relations in olive trees. *Plant and Soil*. 263 (1): 249-264.

Effect of feeding discarded dates on milk yield and composition of Saudi Ardhi goats on hot climate

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The effect of feeding discarded dates (not edible for human consumption) on milk yield and composition of Ardhi lactating does was studied under Al-Qassim conditions in Saudi Arabia. Ten Ardhi dairy does were equally divided into two groups and they were offered two diets; one diet contained 30% discarded dates and the other one served as the control diet (without discarded dates). Yield, pH, and acidity of milk, gross composition and nitrogen distribution and minerals in milk were evaluated. No significant differences in yield and acidity of milk were observed between the two diets. Milk obtained from does fed the diet with dates was significantly higher in protein and solids-not fat contents but was comparable, with respect to its other constituents, with does fed the diet without dates. The difference in non-protein nitrogen of milk was significant between the two diets studied. Milk obtained from does fed the diet with dates had higher casein nitrogen and non-casein nitrogen than those does fed the diet without dates. With respect to milk mineral content, no significant differences in K, Na, Mg, Ca, Fe, and Zn contents were detected between the two diets, whereas the contents of Mn and Cu in milk of does fed the diet without dates were higher than that of does fed diet with dates.

Key words: Goats, dates, milk yield, milk composition, pH, nitrogen in milk, milk minerals.

Can methane emissions of ruminant animals be reduced by altering composition of feed oats?

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Introduction

Greenhouse gas (GHG) emissions from agriculture are a major contributor to climate change. The Stern review 2006 identified that agriculture accounted for ~14 % of GHG with an additional 18% of emissions due to deforestation to provide more agricultural land. In the UK about 7% of GHG is contributed by agriculture (AEA Technology plc, 2007). The main greenhouse gases are nitrous oxide (N₂O), methane (CH₄) and carbon dioxide (CO₂). Of these N₂O is ~300 times more potent GHG than CO₂ and CH₄ is 21 times more potent than CO₂. In the UK agriculture is the major contributor to N₂O and some 70kt N₂O is emitted annually equivalent to 21.7Mt CO₂. Enteric fermentation contributes greatly to methane emission and there is evidence that feed composition and inclusion of oil in the ration can reduce CH₄ emissions by ruminants (Beauchemin and McGinn, 2006).

In the UK, oats have traditionally been used as an animal feedstuff. Conventional husked oats have a similar feed value to wheat and oats have a higher energy value due to the increased oil content. At IGER naked oats have been developed mainly for use as a feedstuff for monogastrics. In addition, oats as a crop usually receive less fertiliser than other feed cereals (RB209) which means they can play a valuable role in mitigating some of the agricultural contribution to GHG emission. Firstly by reducing the use of N fertiliser compared with other cereals and secondly the increased oil content may reduce methane emission.

Naked oats have the highest energy available of cereals crops (Valentine 1995) although their yield is 25-30% lower than that of conventional husked oats. Currently, Ragoon, a high oil naked oats is used as a feed stuff for poultry. Since ruminants can utilise fibre we sought to identify a possible “ideal” ruminant feed, an oat which has a low lignin husk surrounding a groat with a high oil and the impact of this oat on GHG emissions in comparison with conventional oats and other cereals. The *in vitro* gas production technique (Theodorou *et al* , 1994) was used to measure both digestibility and the evolution of the gases CO₂ and CH₄ gases from a range of oat and wheat feedstuffs.

Materials and methods

Samples of the following oat varieties and selection lines were used in the experiment: Gerald, Chris, Fatso , 96-140Cn 1, Ragoon, Hendon , N327-6 and Ac Assiniboia the source of low lignin husk. Two feed wheat varieties Consort and Robigus were also included for comparison purposes.

All the husked oats were dehulled mechanically and the two fractions groat and husk retained. Sub samples from all groat samples were analysed for oil using cold soxtec method STM021. Samples were milled through a 1mm rotary sieve and stored until weighed out into treatments described in Table 1. Treatments 5-8 were prepared to simulate a normal husked oat with a kernel content of 75% groat and 25% husk.

Three 1g samples were incubated in *in vitro* rumen simulation media to assess for total gas production using established techniques (Theodorou *et al* , 1994) A time course of pressure and gas readings were taken and the sampled gas passed through a IRGA infrared gas analyser (ADC 5000 series) to obtain CH₄ and CO₂ production profiles (Davies *et al*, 1998). The apparatus and method of gas production was described by Theodorou *et al* (1994). The incubation was carried out for 121 hours at which time most of the fermentation was completed.

Table 1 Oil content of groat and husk of oat lines used in the experiment

Treatment	Oil content %
1 normal groat Gerald (ng)	6.95
2 high oil groat Chris (hg)	10.75
3 normal husk Gerald (nh)	
4 low lignin husk Assiniboia (lh)	
5 mixture 75%/25% normal groat /normal husk (ng/nh) “Gerald”	
6 mixture 75%/25% normal groat /low lignin husk (ng/lh)	
7 mixture 75%/25% high oil groat /normal husk (hg/nh)	
8 mixture 75%/25% high oil groat /low lignin husk (hg/lh)	
9 consort (wheat)	2.9
10 robigus (wheat)	2.5
11 high oil groat N327-6	15.01
12 high oil groat Fatso	12.37
13 high oil groat 96-140Cn1	10.53
14 high oil groat Ragoon	10.22
15 normal groat Hendon	7.44

Results

Table 2 shows that the normal husk (Treatment 3) is highly indigestible compared to the groat. The low lignin husk (Treatment 4) was almost three times more digestible than the normal husk.

Table 2 Results of gas production corrected to gas produced per g dry matter digested.

Treatment	%dry matter digested	Gas volume (ml) produced per g dry matter digested		
		Total gas	CO ₂	CH ₄
1 normal groat Gerald (ng)	95.21	295.01	232.68	31.04
2 high oil groat Chris (hg)	93.41	295.95	229.55	29.66
3 normal husk Gerald (nh)	23.60	379.77	247.59	35.90
4 low lignin husk Assiniboia (lh)	73.16	392.29	294.57	49.12
5 mixture 75%/25% normal groat /normal husk (ng/nh) "Gerald"	72.17	340.56	259.06	36.22
6 mixture 75%/25% normal groat /low lignin husk (ng/lh)	86.71	331.01	264.45	39.03
7 mixture 75%/25% high oil groat /normal husk (hg/nh)	74.38	281.77	230.48	30.23
8 mixture 75%/25% high oil groat /low lignin husk (hg/lh)	83.45	328.01	257.03	33.34
9 consort (wheat)	93.55	363.12	277.71	45.34
10 robigus (wheat)	93.83	356.28	267.96	44.79
11 high oil groat N327-6	97.91	277.83	220.75	23.97
12 high oil groat Fatso	96.20	296.96	230.54	26.85
13 high oil groat 96-140Cn1	94.34	302.76	237.53	29.40
14 high oil groat Racoon	96.30	300.10	233.96	28.92
15 dwf groat Hendon	95.70	325.65	252.09	36.09

The remaining groats, both high oil and normal oats, as well as the wheat were all highly digestible with more than 93% digested confirming they are a good energy source. Treatment 5, which is essentially a husked oat, had approximately 72% digestibility but with a reduction in the amount of methane produced from digestion compared to the wheat varieties. Treatment 6, the inclusion of low lignin husk, showed a slight increase in methane production, but this was still below that of wheat, and a 14 % increase in digestibility which in practice would translate to more efficient animal growth. Treatment 7 the high oil groat with normal husk, showed 74% digestibility and a 15ml reduction in methane compared to wheat. Treatment 8 the high oil low lignin oat showed 83% digestibility with a 12 ml reduction in methane compared to wheat.

For the designed oats (Treatments 5-8), the increase in digestibility and generally lower methane emissions suggest that development of varieties with such characteristics and their inclusion in ruminant diets would be beneficial in terms of converting the feed more efficiently and less methane production.

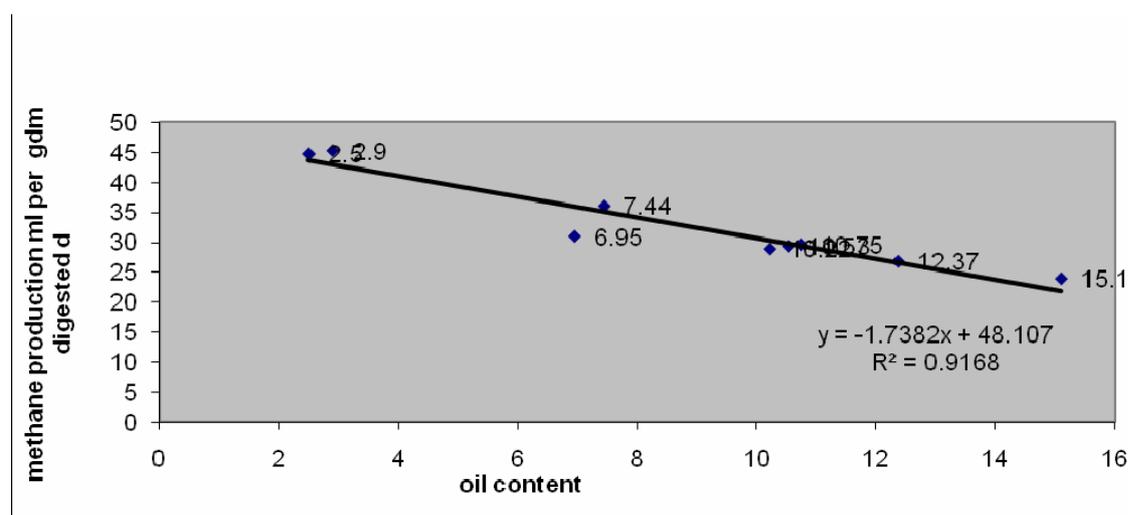


Figure 1 Effect of oil content on methane production

Figure 1 shows that a higher oil content reduced methane production ($R^2 = 0.9156$). This is in agreement with Beauchemin and McGinn 920060 who observed that adding canola oil to ruminant diet reduced methane emission by 32 %. However Johnson *et al* (2002) also investigated addition of various oils with no reduction in methane emissions.

Although the oil composition was not examined in this study, Peterson and Wood (1997) indicated a high proportion of oat oil is present as unsaturated fatty acids and these are likely according to Beauchemin and McGinn (2006) to be the recipients of hydrogen ions that would otherwise be released as methane. These are preliminary results and further chemical analysis of the oats will be required to confirm that it is the oil content and profile which is responsible for the methane reduction. We intend further studies to validate these apparent beneficial effects.

Conclusion

This initial study has shown that methane emissions of ruminants can be reduced by increasing the oil content of oats *in vitro* studies. The increased energy value of the low lignin husk compared to normal husked oats would also be beneficial to livestock feeding regimes.

Breeding effort will be concentrated to produce experimental lines of oats which have these characteristics and which can then be tested *in vivo* experiments on livestock.

Implications

These results show the potential of using oats, an oil rich cereal as a feedstuff for ruminants. Developing a new feed oat incorporating a higher oil groat and low lignin husk would enhance these benefits. The addition of the husk would increase the yield of oats to approximately 8t/ha over the alternative high oil winter naked oats (5t/ha yield). The benefits of growing oats as feed on farm would be many: -reduction in the transport cost of feed, improve traceability of feedstuff, and varied environmental benefits, oats are a low input crop and can increase the yield of subsequent wheat crops by up to 10%.

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References

- AEA Technology plc 2007. Greenhouse Gas Inventories for England , Scotland, Wales and Northern Ireland 1990-2005. AEA Energy and Environment, Didcot. UK.
- Beauchemin K.A. McGinn S.M.. 2006. Methane emissions from beef cattle : Effects of fumaric acid , essential oil and canola oil. *Journal of Animal Science* 84:1489-1496.
- Davies, D. R. , Bakewell, E. L. , Merry, R. J. 1998. The effect of bromoethanesulphonic acid on gas production during an *in vitro* rumen fermentation *In vitro Techniques for Measuring Nutrient Supply to Ruminants, British Society of Animal Science Occasional Publication No 22 (BSAS Meeting, Reading, 8-10 July 1997)* Deaville, E. R. , Owen, E. , Adesogan, A. T. , Rymer, C. , Huntingdon, J. A. , Lawrence, T. L. J., eds. 193-194 BSAS, Reading
- Johnson, K.A., Kincaid R.L., Westberg H.H., Gaskins C.T., Lamb B.K., and Cronrath J.D. 2002. The Effects of Oilseeds in Diets of Lactating Cows on Milk Production and Methane emissions. *Journal of Dairy Science* 85: 1509-1515.
- Fertiliser recommendations for agricultural and horticultural crops (RB209): Seventh edition (2000) <http://www.defra.gov.uk/farm/environment/land-manage/nutrient/fert/rb209/index.htm>
- Peterson D.M., Wood D.F. 1997 Composition and structure of high oil oat. *Journal of Cereal Science* 26:121-128
- Theodorou, M.K., Williams B.A., Dhanoa M.S., McAllan A.B. and France J.1994. A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feeds. *Animal Feed Science and Technology* 48: 185-197.
- The Stern Review
http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm
- Valentine, J. Naked Oats, 1995. In: *The Oat Crop: Production and utilization*. Ed. Robert W. Welch. Chapman and Hall, London. ISBN 0 412 37310 6

Livestock and carbon sequestration in the Lacandon rainforest, Chiapas, Mexico

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Introduction

One of the principal land use changes experienced in Latin America has been the transformation of forests into pasture (Szott, *at al.* 2000). In south eastern Mexico, the area of land devoted to bovine livestock farming has increased dramatically due to the increase of regional meat prices and an economic deterioration of staple crop cultivation. These land use changes are mainly associated with extensive livestock farming systems that negatively impact environment and rural society at both local and global scales. One such environmental impact is the generation of greenhouse gases.

Silvopastoral systems are a type of agroforestry system (AFS) whereby trees are managed in pasture areas and are characterised by product diversification, biodiversity conservation and the provision of environmental services. Regarding greenhouse gases, agroforestry systems store an average of 95 Mg C ha⁻¹ in tropical zones (Murgueitio, 2005; Albrecht and Kandji, 2003).

The inclusion of trees in pastures is a strategy which is currently being implemented in order to reverse the trend towards extensive cattle farming, diversify production units and offer environmental services. In Chiapas, Mexico, the Scolel'te ("growing trees" in the Tzeltal Indian language) project has sold the environmental service of carbon sequestration through a voluntary market since 1994 (Soto-Pinto *at al.*, 2004; Montoya *at al.*, 1995). The established systems are "taungya", coffee with trees, improved fallow and recently (in 2006) trees in pastures; 42,053 tons of carbon were negotiated during 1997-2006 (Ambio, 2007).

On a global scale, most C estimation studies have focused on temperate woodlands, forests and agroforestry systems. However, in cattle farming landscapes there are few studies on C stocks and strategies such as environmental service payments and their contribution to rural development.

The aim of this study was to characterize cattle pasture areas and estimate carbon stocks in monoculture and silvopastoral pasture systems within cattle farming landscapes.

Materials and methods

The research was carried out in 2006. Eighteen cattle farming plots were included in La Corona ejido (16° 19'50" N-90° 41'51"W and Reforma Agraria (16° 15'24" N-90° 51'34" W) in the Marques de Comillas within the Lacandon rainforest, Chiapas, México. Interviews, transects and participative workshops were used in order to describe pasture systems (IIED, 1994). The following carbon reservoirs were estimated: live tree biomass, grasses, roots (thick and fine) and soil organic matter in a) monoculture pastures, b) pastures with live fences and c) pastures with dispersed trees. Soil organic carbon (SOC) was calculated using the method proposed by Amezquita *at al* (2004). Soil samples were taken from each system to determine the SOC at three depths (0-20, 20-40 and 40-60 cm.). The SOC was determined by the wet combustion method described by Walkley y Black (1934). To measure the amount of organic carbon the formula described by Ruiz (2002) was applied. The amount of carbon in the arboreal biomass was determined using the methodology suggested by McDicken (1997). An allometric model developed by Chave *at al.* (2005) was used in order to estimate the tree biomass. Biomass was multiplied by 0.5 to estimate carbon content (IPCC, 2003). The biomass of thick and fine roots in each plot was estimated according to the method suggested by Castellanos *at al.*, (1990). The analysis of herbaceous and fine root carbon was performed using Leco CHN 1,000 ®. A variance analysis and a Tukey comparing of means test were applied using SAS (2001).

Results

In the studied communities land use is determined by three central activities: a) staple crop cultivation (maize-beans), an activity that is being replaced by more profitable crops such as chilli, vegetable gardens and the oil palm which is used for the growing bio-energy market, b) forest conservation as environmental service among other uses, and c) pasture areas cattle raising for sale to local and regional markets.

The majority of land use changes are due to forest conversion into pasture as cattle farming is the most profitable activity within the Lacandon rainforest region. Although people are aware of the importance of conserving forest areas, crop and cattle farming is exerting pressure and threatening the few remaining conserved areas. These areas play a strategic role in communities as they are part of environmental service payment programmes and are also important for ecotourism. In this region cattle farming is extensive, subject to little technological investment and technical assistance and lacks financial support. In both communities the majority of producers (95%) adapt their livestock systems to the production of calves that are sold at local markets.

Table 1 Characteristics of cattle farming units in two communities of Marques de Comillas, Chiapas, Mexico

Characteristics	La Corona	Reforma Agraria
Mean temperature (°C)	18	18
Rainfall (mm)	2500	2500
Climate	wet humid	wet humid
Ethnic group	Choles	Mestizos
Inhabitants	266	188
Cattle producers	52	33
Land per producer (ha)	43	74
Land holding	Ejidal ¹	Ejidal
Total area of the locality (ha)	2252	2665
Crop cultivation area (ha)	126	122
Conservation area (forest) (ha)	1752	2096
Cattle farming area (ha)	374	447
Monoculture pasture (ha)	275	315
Pastures with live fences (ha)	50	50
Pastures with trees (ha)	49	82
Heads of cattle	446	797
Livestock breed	Cebu x Swiss	Cebu x Swiss
Stocking rates (AU/ha)	1.19	1.78

¹Individual tenure in a community

The following pasture systems were identified in relation to the presence of trees: a) Monoculture pastures (MS), b) pastures with disperse trees (PTS), and c) pastures with live fences (LFS). In MS there were no trees present. These areas which are the result of slash and burn practices were predominant in the cattle farming landscape. Traditionally, all the trees are felled in the pasture areas; however, this practice is now being questioned as it does not provide any additional benefits to the producer. These areas are divided by “dead fences” instead of live fences. The most common pasture grasses are: *Cynodon plectostachyus*, *Brachiaria decumbens*, *Brachiaria humidicola*, *Brachiaria brizantha* and *Andropogon gayanus*. Native grasses are rare. Pastures with disperse trees is a common practice amongst farmers in the Lacandon area. These trees are remnants of the original forest that the producer deliberately let stand during slash and burn clearing. In the studied communities between 14 and 26 trees per ha were recorded. The predominant species were: *Blepharidium guatemalensis*, *Sabal mauritiformis*, *Vatairea lundellii*, *Guarea glabra*, *Albizia adinocephala*, *Bursera simaruba* and *Spondias mombin*. Several palm species such as *Sabal yapa* and *Acrocomia aculeata* are also grown so that the leaves can be used for rural construction. Some timber species such as “popiste” (*Blepharidium mexicanum*) are favoured by producers in pasture areas as the wood is used for beams for their own houses or on the local market where they fetch a high price. Pastures with live fences is a practice of planting trees on lines widely known amongst cattle producers. However, farmers do not use to establish living fences because of economic costs derived from scarcity of trees providing vegetative material. Producers that plant 2.5m-between-trees lines of *Gliricidia sepium*, *Erythrina* sp and *Bursera simaruba*.

With regards to total carbon stocks, the highest value was obtained in PTS with 82.88 Mg C ha⁻¹, followed by LFS with 77.08 Mg C ha⁻¹. The lowest value was recorded in MS with 62.61 Mg C ha⁻¹. The soil organic matter was the largest reservoir. There were no significant differences among systems ($p = 0.104$) or by soil depth (Table 2). When compared with other agricultural systems in Chiapas, Mexico, Roncal (2007), recorded values in Taungya, traditional milpa (maize field), enriched fallow and natural fallow systems of 109.4, 127.9, 150.1 and 177.6 Mg C ha⁻¹, respectively. The most recent estimations of carbon in cattle farming landscapes of Central America and Colombia are reported by Ibrahim *at al.*, (2007). These authors researched degraded pastures, natural pastures, pastures improved with trees, fodder banks and secondary forest, recording 72.5, 97.3, 115.13, 130.6 y 162.17 Mg C ha⁻¹ respectively. Planting disperse trees on pastures is possible to sequester approximately 24 Mg C ha⁻¹ during 10 years.

Table 2 Carbon reservoirs of different components in monoculture pasture systems (MS), live fence systems (LFS) and pasture with trees systems (PTS) in Marques de Comillas, Chiapas México.

Reservoirs (Mg C ha ⁻¹)	pasture systems	live fence systems	pasture and trees systems
C in live biomass (LB)			
Trees	1.99 ^a	10.40 ^b	5.99 ^{ab}
Pasture	0.00 ^a	7.60 ^b	4.23 ^{ab}
Total roots	1.33 ^a	0.91 ^a	0.64 ^a
	0.66 ^a	1.88 ^a	1.12 ^a
C in soil (depth in cm)			
0-20	60.62 ^a	66.68 ^a	76.89 ^a
20-40	34.57 ^a	39.12 ^a	40.04 ^a
40-60	12.04 ^a	15.14 ^a	20.63 ^a
	14.0 ^a	12.42 ^a	16.21 ^a
Total system C	62.61 ^a	77.08 ^{ab}	82.88 ^b

Means followed by the same letter in each column are not statistically different according to the Tukey test ($p < 0.05$).

Conclusion

The incorporation of agroforestry practices in livestock systems is a viable strategy for productive diversification in the Lacandon rainforest region of Chiapas. Pastures with trees as important carbon sinks can act as carbon sequestration pools with potential to offering environmental services as well as providing a variety of other goods and services for the local population. Evidence from this study suggests that higher complexity in livestock systems results in higher C accumulation as reported in other regions of Chiapas. This provides an opportunity for producers to implement silvopastoral projects and design plans in order to sell environmental services and enter the voluntary carbon market.

Implications

In the Scolel' Te project most of the carbon sales originate from coffee agroforestry systems, "Taungya" and conservation areas (forests and woodland). This study allows us to establish a baseline from which we can work and thus develop "Silvopastoral and Environmental Services Projects" with the eventual aim of implementing long term carbon sale programmes in silvopastoral systems within areas such as the Lacandon rainforest in Chiapas, Mexico where biodiversity conservation and improvement is imperative.

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References

- Albrecht, A., Kandji S.T. 2003. Carbon sequestration in tropical agroforestry systems. *Agric. Ecosys. Environ.* 99:15-27.
- AMBIO, 2007. Informe tecnico Anual. San Cristóbal de las Casas, Chiapas, México, 25 p.
- Amezquita, M.C., Ibrahim, M., Buurman, P. 2004. Carbon sequestration in pasture, agropastoral and silvopastoral systems in the American Tropical Forest Ecosystems. In: Mannetje, L.T., Ramirez, L., Ibrahim, M., Sandoval, N., Ojeda, Ku J. eds. The importance of Silvopastoral systems in rural Livelihoods to Provide Ecosystems Services (2, 2004, Merida, Yuc, MX). Memoria. Merida Yucatan, Mexico. pp 303-309.
- Andrade, J., Ibrahim, M. 2003. Como monitorear el secuestro de carbono en sistemas silvopastoriles. *Agroforesteria en las Américas*. Vol 10, (39)-40. 109 – 116.
- Avila, V. G. 2000. Fijación y almacenamiento de carbono en sistemas de café bajo sombra, café a pleno sol, sistemas silvopastoriles y pasturas a pleno sol. Tesis Mag. Sc. CATIE, Turrialba, Costa Rica. 102 p.
- Castellanos, J., Maass M., Kummerow, J. 1991. Root biomass of a dry deciduous tropical forest in Mexico. *Plant and Soil*, 131: 225-228.
- Chave, J., Andola, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J., Nelson, B. W., Ogawa, H., Puig, H., Riéra, B., Yamakura, T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*. 145(1): 87-99.
- IIED. 1994. Rapid Rural Appraisal (RRA). Special issue on livestock. Notes N° 20. International Institute for Environment and Development. London, UK. 173 pp.
- MacDicken, K.G. (1997) A Guide to Monitoring Carbon Storage in Forestry and Agroforestry projects. Winrock Internacional Institute for Agricultural Development. Arlington, EEUU. 87 p.
- Montoya, G., Soto, L., de Jong, B., Nelson, K., Farias, P., Pajal, Y., y Taylor, J. 1995. Desarrollo forestal sustentable y captura de carbono en las zonas tzeltal y tojolabal del estado de Chiapas. INE, México 79 p.
- Muhamad, I., Chacon, M., Cuartas, C., Naranjo, C., Ponce, G., Vega, P., Casasola F., Rojas J. 2007. Almacenamiento de carbono en el suelo y la biomasa arborea en sistemas de usos de la tierra en paisajes ganaderos de Colombia, Costa Rica y Nicaragua. *Agroforesteria de la Américas*, 45:27-35.
- Murgueitio, E. 2005. Silvopastoral systems in the Neotropics. In: Mosquera, M.R, McAdam, J, Rigueiro-Rodriguez A, editors. *International Silvopastoral and Sustainable Land Management*, Lugo (Spain): CAB Int. pp. 24-29.
- Roncal-Garcia, S. 2007. Almacenamiento de carbono en sistemas agroforestales en Chiapas, México. Tesis de MC. El Colegio de la Frontera Sur (Mex), 75 p
- Ruiz, G.A. 2002. Fijación y almacenamiento de carbono en sistemas silvopastoriles y competitividad económica en Matiguás, Nicaragua. Tesis de Mc, CATIE. Turrialba Costa Rica. 106 p.
- Soto-Pinto, L., Jimenez-Ferrer, G, Vargas-Guillen A, De Jong-Bergsma B, Esquivel-Bazan E., (2004). Experiencia agroforestal para la captura de carbono en comunidades indígenas de México. *Rev. For. Iberoamer.* 1: 44-50.
- Szott, L., Ibrahim, M. and Beer, J. 2000. The Hamburger Connection Hangover: Cattle, Pasture Land Degradation and Alternative Land Use in Central America CATIE-DANIDA-GTZ, Turrialba, Costa Rica
- SAS, 2001. SAS Institute Inc. SAS Campus Drive, Cary, NY, North Carolina, Estados Unidos.
- Walkley, A, Black T.A. 1934. An examination of the Degtjarett method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37: 29-38.

Maize and amaranth fodders as dry season feed for sheep in the southwest of Nigeria

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Introduction

The dry season presents a problem of shortage of quality feed for ruminants in the southwest of Nigeria. Changing climatic conditions has further complicated this problem due to increased incidence of crop failure, zero pasture production and water scarcity during the dry season. Conservation of high yielding and quality fodder for ruminants during this period is one way of mitigating the effects of negative climatic change on these animals. Maize and amaranth fodders contain a relatively high concentration of soluble carbohydrates and yield a high quality biomass within a short period, making them attractive as hay and silage crops for tropical areas (Coors and Lauer, 2000; Sleugh et al., 2001). These fodder crops grown on a small portion of the pasture and conserved for dry season feeding have the potential to bridge the gap in feed supply to ruminants at this period.

Whole plant maize has been used extensively as a silage crop in both temperate and tropical climates (Phipps, 1996; Njoka et al., 2005). The main limitation of maize as a livestock feed is its low protein content. Typical maize forage has a crude protein content of 8-9% (Carruthers et al., 2000; Darby and Lauer, 2002). This makes it necessary to supplement ruminants fed this basal diet with large quantities of expensive oilseed cakes.

The amaranth plant is gaining attention as a fodder crop. Most literature available relates to its use as a grain or vegetable in human foods. Its potential as a forage for ruminants was reported by Sleugh et al. (2001). Although the biomass yield is reported to be high (Svirskis, 2003), the main attraction to this crop as livestock feed is the high content and quality of its protein. The crude protein content of amaranth fodder ranges from 15-24% (Kadoshnikov et al., 2001; Pizarikova et al., 2006). The protein quality of this plant is quite high. It is rich in lysine and sulphur-containing amino acids which are limiting in cereal crops (Sleugh et al., 2001; Svirskis, 2003). It is also suspected that this plant has a high by-pass protein (Cheeke and Bronson, 1980) which is of great value in ruminant nutrition. The protein content and quality of amaranth, and its growth habit suggest that it can play a complementary role to maize in traditional crop-livestock systems in the southwest of Nigeria.

This study tested the hypothesis that intercropping amaranth with maize would improve fodder yield, land use efficiency and nutrition of ruminants fed a combination of these fodders in a crop-livestock system.

Materials and methods

This study consists of agronomic and animal digestibility trials. In the agronomic trial, yield, land use efficiency and chemical composition of sole maize and sole amaranth were compared with four maize-amaranth intercrop mixtures in two growing seasons. The treatments consist of, sole maize (SM), sole amaranth (SA), 50:50 maize amaranth mixture (MA50:50), 60:40 maize amaranth mixture (MA60:40), 70:30 maize amaranth (MA70:30), and 80:20 maize amaranth mixture (MA80:20). Plant populations were 80,000, 80,000, 160,000, 133,333, 114,286 and 100,000 plants per hectare for SM, SA, MA50:50, MA60:40, MA70:30 and MA80:20 respectively. A randomized complete block design was adopted. Plots received 91kg N/ha and 45 kg P/ha and 45 kg K/ha. Yield and land equivalent ratio (Balasubramanian and Sekayange, 1991) were determined for each treatment. Proximate and detergent fibre composition of the whole plant was determined using AOAC (1995) methods. Data were subjected to analysis of variance and Duncan's multiple range tests using SAS (1995) procedures.

In a digestibility study, the nutritive value of sun-dried or ensiled maize, amaranth or maize-amaranth mixture was estimated using 18 male West African dwarf sheep approximately 12 months old with mean weight 17.33 ± 2.70 kg. Treatments correspond to six experimental diets as follows: sun-dried maize (SDM); sun-dried maize-amaranth (SDMA); sun-dried amaranth (SDA); ensiled maize (EM); ensiled maize-amaranth (EMA); ensiled amaranth (EA). Animals were put in metabolic cages with facility for feeding, watering and separate collection of faeces. The animals were divided into three groups according to their weights and randomly assigned to one of the six diets. Experimental diets were offered *ad-libitum* for 14 days. Feed offered, feed refused and faeces voided were weighed and recorded in the last 7 days. Feed intake and faecal output were determined. Ten per cent of feeds and faeces voided were taken daily, dried at 65°C to constant weight, milled and kept in airtight containers until required for analysis. Dry matter and chemical composition of feed and faeces were determined using AOAC (1995) methods. Apparent digestibility of the diets was calculated as the difference between nutrient intake and excretion in the faeces, expressed as a ratio of nutrient intake. Data were subjected to analysis of variance and Duncan's multiple range tests using SAS (1995) procedures.

Results

Fodder yield and land equivalent ratios for sole maize, amaranth and four intercrop mixtures are summarized in Table 1. Dry matter yield of the whole plant ranged from 7.01 - 11.86 t/ha. There were significant differences ($P < 0.05$) in dry matter yield of sole maize and sole amaranth with maize having the higher yield. Intercropping had a negative effect on yield components of maize fodder while amaranth yield was little affected. Amaranth seemed to cope better with competition than maize. There were no significant differences ($P > 0.05$) in dry matter yield among the various

intercrop mixtures and sole maize. Intercropping showed advantage over sole amaranth crop in terms of yield but it had no advantage over sole maize. Land use efficiency generally improved with intercropping. However, it should be noted that this improvement is in relation to amaranth and not maize.

Table 1 Mean fodder yield and land equivalent ratios for maize, amaranth and their intercrop mixtures

Yield component	SA	MA 50:50	MA 60:40	MA 70:30	MA 80:20	SM	SE
Yield (t/ha)							
Ear/seedhead	3.14 ^b	4.13 ^a	4.73 ^a	5.00 ^a	4.60 ^a	5.43 ^a	0.43
Stover	3.87 ^b	5.65 ^a	6.40 ^a	6.33 ^a	5.50 ^a	6.43 ^a	0.54
Wholeplant	7.01 ^b	9.78 ^a	11.13 ^a	11.33 ^a	10.10 ^a	11.86 ^a	1.19
Land equivalent ratios							
Ear/seedhead	1.00	1.05	1.16	1.16	1.09	1.00	-
Stover	1.00	1.19	1.22	1.15	1.00	1.00	-
Wholeplant	1.00	1.14	1.19	1.17	1.04	1.00	-

SM: sole maize crop, SA: sole amaranth crop, MA: maize-amaranth intercrop, SE: standard error
^{a, b}: means with different superscripts within the row are significantly different (P < 0.05)

Chemical composition of fodders from sole maize, sole amaranth and intercropped maize-amaranth plots are given in Table 2. Dry matter content of fodders ranged from 21.63 - 35.20 g/100g while crude protein content ranged from 9.88 - 22.68 g/100g. Dry matter content of whole plant fodders reduced with increasing proportion of amaranth in the mixture while crude protein content increased. Crude fibre content of all the fodders were similar although neutral detergent fibre and acid detergent fibre were much higher in maize than in amaranth fodder.

Table 2 Chemical composition (g/100g) of maize and amaranth fodders

Components	SA	MA 50:50	MA 60:40	MA 70:30	MA 80:20	SM
Dry matter	21.63	25.5	26.1	27	28.1	35.2
Crude protein	22.68	16.47	15	13.45	12.38	9.88
Crude fibre	22.52	23.47	22.1	22.28	22.45	24.01
Neutral detergent fibre	36.24	43.55	46.1	47.45	49.28	52.14
Acid detergent fibre	20.53	25.53	27.35	28.85	30.05	30.58

SM: sole maize crop, SA: sole amaranth crop, MA: maize-amaranth intercrop

Table 3 presents the chemical composition of conserved fodders used in the digestibility study. Crude protein content of conserved fodders ranged from 9.25 - 22.40g/100g. For the sun-dried fodders, protein content increased with increasing level of amaranth in the forage, however, protein content was similar for ensiled maize, amaranth and maize-amaranth fodders. Much of the protein in amaranth was lost during the ensiling process. This could be due to putrefying losses. Maize fodders had higher fibre content than amaranth fodders while the mixed fodders were intermediate between maize and amaranth fodders.

Table 3 Chemical composition (g/100g) of conserved maize, amaranth and maize-amaranth fodders

Component	SDM	SDMA	SDA	EM	EMA	EA
Dry matter	88.79	88.81	87.36	30.80	26.10	21.60
Crude protein	9.56	17.47	22.40	9.38	9.27	9.25
Crude fibre	26.08	25.21	24.55	25.56	24.92	23.54
Neutral detergent fibre	53.30	52.02	50.80	51.04	48.00	47.74
Acid detergent fibre	30.80	29.80	29.15	30.10	27.55	27.20

SDM: sun-dried maize, SDMA: sun-dried maize-amaranth, SDA: sun-dried amaranth, EM: ensiled maize, EMA: ensiled maize-amaranth, EA: ensiled amaranth

Apparent digestibility of sun-dried or ensiled maize, amaranth or maize-amaranth mixture is shown in Table 4. Dry matter digestibility of sun-dried fodders was generally higher than that of ensiled fodders although ensiled maize had a higher digestibility than sun-dried maize. In spite of the higher protein content in amaranth, maize fodders were better digested than amaranth fodders or their mixture. Presence of anti-nutritional factors in amaranth seed-head may be responsible for the lower digestibility observed for amaranth and maize-amaranth fodders. This needs to be further investigated. Protein loss in amaranth during the ensiling process may also have contributed to the lower digestibility observed for ensiled amaranth and maize-amaranth fodders.

Table 4 Apparent digestibility (g/100g) of conserved maize, amaranth and maize-amaranth fodders

Component	SDM	SDMA	SDA	EM	EMA	EA	SE
Dry matter	71.82 ^a	60.68 ^b	57.33 ^{bc}	73.74 ^a	55.26 ^{bc}	52.58 ^c	2.68
Crude protein	56.15 ^a	53.90 ^a	46.49 ^b	59.31 ^a	41.72 ^{bc}	37.10 ^c	2.00
Neutral detergent fibre	72.87 ^a	61.22 ^b	60.63 ^b	73.85 ^a	59.13 ^b	58.73 ^b	2.07
Acid detergent fibre	67.51 ^a	56.15 ^b	53.13 ^b	67.12 ^a	54.08 ^b	54.10 ^b	2.20

SDM: sun-dried maize, SDMA: sun-dried maize-amaranth, SDA: sun-dried amaranth, EM: ensiled maize, EMA: ensiled maize-amaranth, EA: ensiled amaranth

Conclusions

Results from this study showed that intercropping had a negative effect on yield of maize fodder but had little effect on yield of amaranth. Intercropping also improved land use efficiency for amaranth but had no advantage for maize. Protein content of total forage increased when maize was intercropped with amaranth but this did not translate to improved digestibility for sheep. In spite of the higher protein content in amaranth, sun-dried or ensiled maize fodder were better digested by sheep than amaranth or maize-amaranth fodders, showing that sole cropping of maize is a better option than intercropping with amaranth for feeding of sheep during the dry season. These results disprove the hypothesis that intercropping amaranth with maize will improve yield, land use efficiency and nutrition of ruminants fed a mixture of these fodders.

Implications

This study demonstrates that under the prevailing conditions in the southwest of Nigeria, sole cropping of maize is a better option than intercropping with amaranth when these crops are grown as fodders for feeding ruminants during the dry season.

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References

- AOAC, 1995, Official Methods of Analysis. 16th Ed. Association of Official Analytical Chemists, Washington, DC.
- Balasubramanian V and Sekayange L, 1991. *IITA Research*. Vol.1 No.2, pp 16-19.
- Carruthers K, Prithiviraj B, Fe Q, Cloutier D, Martin RC and Smith DL, 2000. *Journal of Agronomy and Crop Science* 185:177-185.
- Cheeke PR and Bronson J, 1980. Proceedings 2nd Amaranth Conference, Rodale Research Center, Kutztown, PA. 13-14 September 1979. Rodale Press, Emmaus, PA, pp 5-11.
- Coors, JG, and Lauer JG, 2000. Specialty Corns. A.R. Hallauer (ed.) CRC Press, Boca Raton, FL. pp 347-392.
- Darby HM and Lauer JG, 2002. *Agronomy Journal* 94:559-566.
- Kadoshnikov SI, Martirosian DM, Kadoshnikova IG and Chernov IA, 2001. LEGACY. The Official Newsletter of the Amaranth Institute. Vol. XIV, No 1, 2001.
- Njoka EM, Muraya MM and Okumu M, 2005. *Australian Journal of Experimental Agriculture* 44(12): 1215-1219.
- Phipps R H, 1996. *Journal of the Royal Agricultural Society of England* 157: 103-115.
- Pisarikova B, Zraly Z, Kracmar S, Trckova M and Herzig I, 2006. *Veterinarni Medicina* 51 (7): 399-407.
- SAS Institute, 1995. SAS/STAT User's Guide. Version 6, 4th Ed. Vol. 1 and 2. SAS Inst. Inc., Cary, N.C.
- Sleugh BB, Moore KJ, Brummer EC, Knapp AD, Russell J and Gibson L, 2001. *Crop Science* 41: 466-472.
- SSSA, 1996. Methods of Soil Analysis, Part 3- Chemical Methods. Soil Science Society of America, Madison, WI, USA.
- Svirskis A, 2003. *Agronomy Research* 1(2): 253-264.

Summer solar radiation and reproductive performances in Barbarine sheep raised in semi-arid conditions

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The objective of the work was to examine the reproductive performances of male and female Barbarine sheep exposed to solar radiation. The study was conducted during the hot month of August. 112 ewes and 10 rams were used for the experiment. Animals were divided into 2 homogenous groups. Group 1 was kept outdoors without shade, whereas group 2 was kept indoors with adequate ventilation. Both groups received the same diet. Heat detection was undertaken twice daily. Endoscopy was carried 12 days after heat expression to measure ovulation rate. Fertility and litter size were calculated. Sperm quality was evaluated by measuring volume, concentration, motility and percentage of live spermatozoa on samples taken early, in the middle and at the end of the month. Similarly, heart and respiration rates and rectal temperature were measured on all animals. Results showed that animal exposure to summer radiation did not affect either the percentage of females in oestrus during the 25 days following ram introduction or the return rate (95% vs 100% and 21% vs 22% respectively for indoors and outdoors groups). Moreover ovulation rate, fertility and litter size were similar for both groups (1.12 ± 0.33 vs 1.16 ± 0.37 ; 80% vs 79,6 and 111 ± 13 vs 114 ± 11 respectively for indoors in outdoors groups). Solar radiation significantly increased respiration and heart rates (respectively 52.7 ± 8.5 vs 100 ± 30 and 83.3 ± 5.5 vs 92.7 ± 2.5 for indoors and outdoors; $p < 0,05$). Rectal temperature was, however similar for both groups. In males, exposure to solar radiation had no significant effects on sperm volume (1.12 ± 0.11 ml vs 1.11 ± 0.12 ml), concentration ($2,903 \pm 247 \times 10^6$ ml vs $3,020 \pm 251 \times 10^6$ ml), motility (2.10 ± 0.17 vs 1.71 ± 0.18) or percentage of live spermatozoa (40.6 ± 3.98 vs 32.0 ± 4.06).

These results indicate the wide adaptation of Barbarine sheep for permanent exposure to solar radiation as indicated by the absence of significant effects on breeding activities and reproductive performance.

Key words: ewes, rams, reproduction, stress, solar radiation

Animal feeding constraints in steppic rangelands of North Eastern Morocco

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The pastoral system of the High Plateaus of North Eastern Morocco is characterized by extensive livestock systems primarily dependent on the availability of rangeland fodder. During the past few decades, tendencies for changes to such systems have been associated with the regression of rangeland fodder resources that are very dependent on climatic conditions.

This regression of the fodder resources is the combined result of many factors, including both climatic (unfavorable climate change and low precipitation with an unfavourable distribution over time and space) as well as anthropozoic factors (clearing and cultivation of good lands, overgrazing and violation of protected spaces).

The available pastoral fodder resources do not match the number of feeding animals, even in good years.. Thus, malnutrition is frequent especially in periods of food shortage, generating low flock productivity.

To meet the needs of their livestock, herders use feed supplements, mainly barley and cereal bran, production costs for the dominant livestock, sheep, has increased dramatically because of the feed supplementation that has become a common practice throughout the year. The competitiveness of the sector has therefore become marginal for the large flock owners, whilst small herders are abandoning their profession and migrating elsewhere.

To mitigate this situation, we recommend that:

- i) rangeland rehabilitation be reinforced in degraded areas through plantations and rotational rest;
- ii) Reproducing ewes be rationally allowed to use collective rangelands while benefitting from an adequate feed complementation during critical physiological periods;
- iii) Collective or individual fattening units be encouraged in order to reduce the pressure on natural resources and to improve red meat availability and quality;
- iv) Users be made more sensitive to, and aware of the need for the sustainability of the natural resources through the engagement of pastoral cooperatives in the management of protected as well as open pasture lands.
- v) An early warning system for drought be established to enable better natural resource management and a timely safeguard action of threatened livestock.

The adaptation strategies to drought of rural communities in southern Tunisia

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Water resources, ecosystems, livestock and thus food security are the main vulnerable sectors to climatic variability and changes in southern Tunisia. The risks are not only of a climatic and ecological nature since the incidence of conflicts (inter and intra communities), poverty as well as the migration may also increase with perceptible consequences at a local, sub-national and national scale.

In southern Tunisia, drought is a common phenomenon which, over the years, local pastoral communities have developed several strategies to mitigate it. The organization of the herd's mobility is the main component of these strategies. The existing old local community based organizations played a key role in identifying the suitable humid areas for their transhumance. Such organizations may also order a decrease in the flock size in the face of feed scarcity. Their role has also been of great importance in organizing the temporal and spatial harvest campaigns of the "Gueddim" (hay of *Stipa tenacissima*). The conservation and storage of any excess production, of either weeds or farm by-products, in the good years is also used to mitigate the following severe dry years.

The increase in drought frequency, the privatization of rangelands, the disappearance of the old community based organisations and particularly the appearance, since the 1980s, of Governmental subsidies for complementary animal feeding have increased the vulnerability to drought. The later policy has probably led to the loss of much local indigenous know-how and to an increase in the dependence of the agropastoral communities on the feed resources market, particularly of barley, and consequently to the unpredictability of the future of the livestock sector in southern Tunisia.

A drought management strategy, the maintenance of old grazing practices in southern Tunisia such as herd mobility, a reduction in flock size and local feed storage all need to be maintained as they are part of the rural landscape. The re-establishment of community based organizations such as the Agricultural Development Groups (ADG) and the introduction of appropriate technical options such as rangeland rest techniques, fodder shrub planting and livestock feed blocks may help to alleviate the effect of droughts associated with climatic change and associated increases in animal feed costs.

Epidemiological investigations of sheep pox in eastern regions of Sudan

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Summary

As the eastern states of Sudan were known to be enzootic with sheep pox (SP), the present study was conducted to investigate the precise situation of this health problem in Kassala state. Both participatory approaches and a serological survey of animals in the various localities of the state were employed. A questionnaire survey among sheep herders and consultations of veterinary records in the state were made. The agar gel immuno-diffusion (AGID) test was used to detect the antibody (Ab) responses in sera of non-vaccinated sheep. The study outcomes showed that most of the sheep owners have a good knowledge about SP as an epizootic disease in the state. Moreover, 80% of the owners confirmed the presence of the disease in their sheep flocks. Fifteen outbreaks of SP were reported in the state over the last five years. Out of the 502 serum samples tested for Abs against SP virus (SPV), 63.55% of them were positive. A high prevalence of antibodies against SPV was noted in samples from Algash (69.57%, n=115) followed by Kassala (66.89%, n=151), Nahr Atbara (63.79%, n=116) and Setiet (53.33%, n=120). Results of risk factor analysis with respect to age groups and sex of sampled animals revealed no statistical significance between disease prevalence and age or sex ($\chi^2= 2.3751$, P -value= 0.498) and ($\chi^2= 0.2039$, P -value= 0.652), respectively. However, the highest level of prevalence was observed in female animals (64.05%, n=253) and among the age group of less than one year old (65.63%, n=233). In conclusion, the findings elucidated the situation of the disease in that endemic area and recommended that strategic control programmes should be designed and applied.

Keywords: Sheep pox, eastern Sudan, Participatory epidemiology, Antibody

Introduction

Sheep pox (SP) is a contagious viral infection causing mortality in lambs and mastitis and abortion in ewes (Losos, 1986). It is one of the most economically important and endemic diseases of sheep in northern and central Africa, Southwest and central Asia and the Indian subcontinent (Carn, 1993; Esposito and Fenner, 2001). Sheep pox virus (SPV) is an epitheliotropic DNA virus belonging to the genus *capripoxvirus* which represent one of eight genera within the subfamily *chordopoxvirinae* of the family *Poxviridae* (Fenner *et al.*, 1999). SPV is antigenically and physicochemically related to goat pox virus (GPV) and lumpy skin disease virus (LSD) (Kitching, 1986; Kitching, 2003). The disease manifests itself in pyrexia, cutaneous and lung lesions and lymphadenopathy (Esposito and Fenner, 2001; Munz and Dumbell, 1994). The gross and histological appearance of the disease lesions were recently described by Gulbahar *et al.* (2006). Live attenuated SPV and subunit formulations have been used experimentally and in enzootic, as well as outbreak areas, as vaccines against SP, GP and LSD (Capstick and Coackley, 1961; Carn, 1993).

In Sudan, the first report on SP was made by Bennet *et al.* (1944). They confirmed that the disease is endemic in many parts of the country and seasonal in occurrence. It was established that high prevalence of clinical cases of SP were usually associated with cold winters. However, during the last few years outbreaks of the disease were observed at different times of the year (Sheikh-Ali *et al.*, 2004).

The modern participatory epidemiological approaches were conducted to address some animal health problems in southern Sudan and showed high levels of validity and reproducibility (Catley *et al.*, 2001; Catley *et al.*, 2002). In the present study, these technologies were adopted to determine the situation of SP in Kassala state, eastern Sudan. Many serological assays were previously used to detect the Abs against SPV including the agar gel immunodiffusion test (AGID) (Kitching *et al.*, 1986), counter immuno electrophoresis (Sharma *et al.*, 1988), passive haemagglutination test (PHA) (Tiwari *et al.*, 1995), serum neutralization test (SNT) (Kitching and Carn, 1996) and enzyme linked immunosorbent assay (ELISA) (Tiwari *et al.*, 1996). AGID test was used in this study to detect the Abs against SPV in sera collected from non-vaccinated animals in the area of study, as this test proved reasonably sensitive and applicable for the purpose (Sheikh-Ali *et al.*, 2004).

Materials and methods

The study was conducted in Kassala state which is located in the eastern region of the Sudan. The state is divided into five administrative localities, Kassala, Algash, Nahr Atbara, Setiet, and Hamshkoreib. It borders another four states and Eritrea in the east. According to the estimates of the general directorate of the animal resources in the state, the sheep population is about 1,383,840 distributed over the state as follows: 400,585 in Nahr Atbara; 360,527 in Setiet; 267,057 in Algash; 200,293 in Kassala and 155,378 in Hamshkoreib. Nomadism is the normal system for the animal owners in the state where they adopt a cyclic seasonal movement of their flocks depending on the rainfalls to meet their animals' demands for water and pasture.

The questionnaire was designed and distributed to 50 pastoralists in the different localities to come up with information related to SP symptoms, its impacts on their flocks, their acceptability of vaccination, effect of animals' movement on the spread of the disease and to cover the pastoralist understanding of the disease in the state.

Passive retrospective data was also derived from the state veterinary records for the last five years. The necessary data were collected using the monthly and annual available reports of the general directorate of animal resources of the state. Detailed information about the personnel, infrastructure, previous outbreaks of the disease and its control by means of vaccination were also collected.

A total of 502 blood samples were randomly collected from apparently healthy sheep in four localities of the state. It was not possible to collect samples from Hamshkoreib due to the constraint of unrest in the area. All animals sampled had no vaccination history against SP recorded for the last three years.

A hyper immune serum (HIS) against 0240 strain of SPV was essentially prepared as described by Subba Rao and Malik (1979) to be used as a positive control in AGID. The SPV, strain 0240, was also used as the antigen following preparation of the stock virus in cell cultures as described by Jassim and Keshavamurthy (1982). 2% of freshly prepared sodium deoxycholate (SDC) was mixed with an equal volume of diluted antigen prior to the test to enhance antigen/antibody binding. The AGID was carried out according to Kitching *et al.* (1986). 15 µl of the reference antigen was put in the central well of each group of wells. The HIS was placed in a determined well for each group of wells as the positive control. The test sera were placed in the remaining wells. The dishes were then incubated in a humid incubator at room temperature for 24–48 hours before the results were read using an illuminated chamber.

Microsoft Excel (Windows 2000) and Stata 6.0 for Windows 98/95 /NT were used for data analysis. The significance in the differences between some factors and data obtained was determined using chi-square test.

Results

The passive data obtained following application of the questionnaire survey among the sheep herders in the various localities of the state demonstrate that 38% of the sheep owners in the state informed that SP constitutes the most important disease in their areas. 80% of them confirmed that they experienced the disease in their animals in previous times. 90% of them proved to be aware of SP signs. 34%, 28% and 18% of both ages (adult and young), adult and young animals respectively are susceptible to the disease. 80% of the sheep owners confirmed that the morbidity of SP is higher than mortality attributed to the disease. 44% confirmed the association of abortion to the disease. The majority (56%) of the sheep owners in the state attributed the economic loss of SP due to the reduction in the animals' productivity while only 4% attributed its effect to the death of infected sheep. Only 14% of the sheep owners in the state vaccinated their animals against SP while 86% did not.

15 SP outbreaks are registered in the records of the Federal General Directorate (FGD) of animal health and epizootic disease control in the state. Table 1 shows the SP outbreaks reported in the state during the five years (2001- 2005). The number of outbreaks reported, their effect on the animals in the area and interventions made for the disease control are presented.

Table 1 Outbreaks of sheep pox reported in Kassala state during the last five years

Year	No. of outbreaks	No. of AAR	Morbidity (%)	Mortality (%)	CFR (%)	Intervention
2001	2	877	49 (5.59)	0 (0.00)	0.00	Treatment & isolation
2002	3	unknown	24 (NA)	3 (NA)	12.5	Treatment & isolation
2003	7	936	149 (15.92)	24 (2.56)	16.11	Treatment
2004	2	1084	3 (0.28)	1(0.09)	33.33	Isolation
2005	1	1100	5 (0.45)	0 (0.00)	0.00	Vaccination
Total	15	NA	230 (NA)	28 (NA)	12.17	

AAR = animal at risk; CFR= case fatality rate; NA= not applicable as the number of animals at risk in 2002 is not known since it is not appeared in the records.

Generally, 63.55% of the sera samples tested are positive for Abs against SPV in the state at large. Varying prevalence of SP in the different localities of the state, as detected by AGID test, were found. A high prevalence of SP is observed in Algash at 69.57% (n=115). In contrast, the prevalence of the disease in Kassala, Nahr Atbara, and Setiet is noted 66.89% (n=151), 63.79% (n=116), and 53.33% (n=120), respectively.

The correlation of the prevalence of the disease and different age groups of animals is shown in Table 2. Based on the Chi-square test, no significant association between different ages of animals and the prevalence of the disease (Chi-square= 2.3751, *P*-value= 0.498) was noted. However, high prevalence of SP is observed in the less than one year age group (65.63%, n= 233).

Table 2 The distribution of Ab responses to SPV among different age groups of sheep in Kassala state

Test result	Age (months)				Total
	1- 12	13- 24	25- 36	37- 48	
Positive	233* (65.63)	51 (57.59)	30 (60.00)	5 (55.56)	319 (63.55)
Negative	122 (34.37)	37 (42.05)	20 (40.00)	4 (44.44)	183 (36.45)
Total	355 (100.00)	88 (100.00)	50 (100.00)	9 (100.00)	502 (100.00)

* Data represent the number of positive and negative samples to Abs against SPV, as detected by AGID, among the different age groups of sheep in Kassala state (%).

No statistical significance (Chi-square= 0.2039, P -value= 0.652) was also found between the presence of Abs in serum samples and sex of animals tested. The AGID positive cases were 66 (61.68%) for males and 253 (64.05%) for females.

Discussion

Only limited documented reports about sheep pox in Sudan are available. An outbreak of goat pox which showed experimental cross pathogenic reactivity with sheep was reported by Mohamed *et al.* (1982) in central Sudan. Recently, some outbreaks were also reported and studied by Sheikh-Ali *et al.* (2004) in the vicinity of Khartoum state. There are some claims that eastern regions of Sudan are highly endemic with the disease without solid reports being available. This study was planned to determine the situation of the disease in Kassala state, the state which is highly sheep-populated as compared to the other eastern states of Sudan. The participatory epidemiological approaches involve questionnaire application and passive retrospective data collection from the veterinary authorities reports coupled with the serological survey of the disease among non-vaccinated animals. The awareness of the sheep herders of the disease is targeted in the present study. It was proved that a significant number (68%) of animal keepers in the state who were interviewed own sheep. It was also evident that the majority of them are nomads and confirmed that sheep pox constitutes a major concern among their herds' health problems. This finding may refer to the quick build up of sheep flocks attributed to the demand of the nomads to increase their income to face their accelerating family needs. The perpetuation and transmission of SPV among animals of nomadic keepers is basically attributed to the hardness of the virus and its resistance to desiccation (Esposito and Fenner, 2001). This is additionally enhanced by the lack of quarantine measures and restriction of sheep movement practiced in the border station with other neighbouring states. The majority (80%) of the sheep owners who responded to the questionnaire in this study, confirmed the occurrence of the disease in their flocks as well as being highly familiar with the disease clinical picture. The clinical signs of the disease they described are highly adherent to those mentioned in the scientific literature. This is an indication of the presence of the disease in the area of study since a long time back. It was also revealed that the economic effects of the disease are not due to death of the animals but the disease is mainly associated with reduced production and reproduction. This again pointed out the existence of the disease in the area with endemic shape and the animals exhibited the better protective immunity against the lethal effect of the virus. This is compatible with the previously published results of Losos (1986) who reported the very low mortality of SP in enzootic areas. However, high mortality rates for SP may be encountered in disease free areas especially for more genetically susceptible breeds of animals as reported by Mondal *et al.* (2004). Most of the sheep owners (86%) do not vaccinate their animals against SP, probably due to inadequate vaccine doses being available as well as to some tribal traditions leading to refrain from vaccination.

The passive data obtained from consultation of the state records indicated that many outbreaks of SP had occurred during the five years (2001-2005). Interestingly, there were no reports of the disease outbreaks in Algash in the records despite the highest levels of Ab responses in non-vaccinated sheep being detected for that locality in this study as well as some clinical cases for the disease being observed.

The serological survey for SP conducted in this study revealed that the disease is spreading in all localities of the state by significantly higher rates especially when considering the total population of animals at risk. The high prevalence rate of the disease noted in Algash was expected as it borders the Red sea state which proved to have high levels of Ab responses against the disease as recently reported by Ali *et al.* (2004). This is because free movements of animals between these eastern states of Sudan occurred due to herders seeking good grazing pastures and water sources. No statistical significance in correlations between SP with age and sex was observed during this study. These findings are similar to those of Woldemeskel and Ashenafi (2003) who also verified the absence of statistical association of SP with age and sex of the sheep. The high prevalence of infection obtained, in this study; among animals of age less than one year is previously documented by Losos (1986). It is generally known that females are more stressed than male animals due to their physiology especially during pregnancy when having a compromised immune status, and hence are more susceptible to infectious diseases.

Conclusions

From the data obtained in the present study, it can be concluded that SP is a real health problem in Kassala State, eastern Sudan and a threat to the animals throughout the region. The reliability of participatory epidemiology in extracting knowledge about infectious diseases can also be confirmed.

Implications

From the data obtained, a strategic control and eradication programme can be suggested including massive vaccination moves using homologous virus strain of SP.

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References

- Ali, Y.H., Wegdan, H.Ali., Amira, M. Elhassan. and Intisar, K. 2004. Sudan Journal of Veterinary Science and Animal Husbandry 43(1&2): 123-131.
- Bennet, S.C., Horgan, E.S. and Hasseb, M.A. 1944. J. Comp.Pathol. 54: 131-160.
- Capstick, P.B. and Coackley, W. 1961. Res. Vet.Sc. 2: 362-375.
- Carn, V.M., 1993. Vaccine 11(13): 1275-1279.
- Catley, A., Okoth, S., Osman, J., Fison, T., Njiru, Z., Mwangi, J., Jones, B.A. and Leyland, T.J. 2001. Preventive Veterinary Medicine 51(3-4): 161-81.
- Catley, A., Osman, J., Mawien, C., Jones, B.A. and Leyland, T.J. 2002. Preventive Veterinary Medicine 53(4): 275-84.
- Espósito, J.J. and Fenner, F. 2001. Poxvirus. In: Veterinary Virology (Fields, B.N, D.M. Knipe, P.M. Howley, R.M. Chanock, J.L. Melnick, T.P. Monath, B. Roizman and S.E. Straus) 4th ed. Lippincott, Williams and Wilkins, Philadelphia, USA. pp. 2885-2921.
- Feener, F.J., Gibbs, E.P.J., Murphy, F.A., Rott, R., Studdert, M.J. and White, D.O. 1999. Poxviridae In: Veterinary Virology; 2nd ed. Academic press UK. pp. 369-389.
- Gulbahar, M.Y., Davis, W.C., Yuksel, H., Cabalar, M. 2006. Veterinary Pathology 43(1): 67-75.
- Jassim, F.A. and Keshavamurthy, B.S. 1982. Acta Virologica 26(3): 190-200.
- Kitching, R.P. 1986. Research in Veterinary Science 41: 247-250.
- Kitching, R.P. 2003. Developmental Biology (Basel).114: 161-167
- Kitching, R.P. and Carn, V. 1996. In Manual of Standards Diagnostic and Vaccine (OIE). 119-127.
- Kitching, R.P., Hammond, J.M. and Black, D.N. 1986. Journal of General Virology 67: 139-148.
- Losos, J.G. 1986, Infectious tropical diseases of domestic animals. First edition, Longman. pp. 559-580.
- Mohamed, K.A, Hago, B.E, Taylor, W.P, Nayil, A.A. and Abu-Samra, M.T. 1982. Tropical Animal Health and Production 14(2): 104-108.
- Mondal, B., Hosamani, M., Dutta, T.K., Senthilkumar, V.S., Rathore, R. and Singh, R.K. 2004. Revue of Scientific Technique 23(3): 943-949.
- Munz, E. and Dumbell, K. 1994. Sheeppox and goatpox, In: Infectious diseases of livestock (Coetzer, J.A.W., Thomson, G. R. and Tustin, R.C.) Vol. 1, Oxford University Press, Cape Town, South Africa. pp. 613-615.
- Sharma, B., Negi, B.S., Pandey, A.B., Bandyopadhyay, S.K., Sharma, H. and Yadav, M.P. 1988. Tropical Animal Health and Production 20(2), 109-113.
- Sheikh-Ali, M.A., M.E. Hamad, B.H. Ali, A.S. 2004. Veterinarski arhiv 74: 341-350.
- Subba Rao, M.V and Malik, B.S. 1979. Acta Virologica 23(2): 165-716.
- Tiwari, A.K., Nadi, S. and Negi, B.S. 1995. Indian Journal Virology 11(2): 35-37.
- Tiwari, A.K., Singh, R.P. and Negi, B.S. 1996. Journal of Animal Science 11(1): 129-130.
- Woldemeskel, M. and Ashenafi, H. 2003. Dtsch Tierarztl Wochenschr 110(1): 20-22.

Success stories of the Masherq and Maghreb Projects in assisting farmers in Central Tunisia to adapt to global climate change and drought

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Livestock are the main source of income of most rural populations in central Tunisia. Until the 1970s, range vegetation contributed most to the nutrient supply for ruminants. However, due to several reasons, including climate change and drought, rangelands are prone to degradation and the potential of cereals and roughage cropping are decreasing. Therefore, animals raised in these areas are more and more dependant upon concentrate feeds and purchased feedstuffs mainly oaten hay. Thus under these conditions, farmers consider that production costs have become beyond their financial capacity. A wide range of techniques and technologies have been developed to overcome this situation or at least to alleviate the impact of drought. The Mashreq and Maghreb (M&M) Project, a technology transfer-based project coordinated since 1995 by ICARDA, has developed a participatory approach which has been efficient in transferring and facilitating the adoption of a technology package by farmers. The success stories of this project include the manufacturing and utilization of feed blocks and pellets, shrub plantation, mainly cactus, the establishment of adapted cultivars of gramineae and legume forage species and the adjustment of feeding calendars. Benefits from feed blocks, as reported by target farmers, include the simple way of their preparation and their replacement value for common and expensive concentrate feeds (i.e. barley and wheat bran). The cactus-barley alley cropping technique which has been tested in some farms has also proved efficient in increasing grain and straw yields and in controlling erosion especially on sloppy lands. The examination of feeding calendars adopted by farmers revealed nitrogen/protein deficiency in livestock diets. The introduction of a new cultivar of *Vicia* (Mguila) and its positive impact on the performance of lactating ewes convinced farmers of the role of legume cropping in animal feeding. The positive impact of transfer techniques and technologies among a focal group enhanced the process of farmer-to-farmer transfer. Producers benefit from the adoption of technology through opportunities to lower production costs, either by increasing outputs from the same inputs or by maintaining the same output from reduced inputs. The success of such an approach is probably due to the involvement and negotiated cooperation between rural communities, scientists and extension specialists. This would facilitate the refinement and promotion of technologies and policies that could help ensure sustainable livelihoods and enhance the productive capacity of target farms. The key step of the participatory approach developed within this project is the deep characterization of the community conditions and the good understanding of mechanisms regulating activities of the target population. Finally, local institutions (farmers' associations, agricultural development groups, etc.) could facilitate the adoption of strategies for drought mitigation.

Key-words: *drought, Central Tunisia, technologies, participatory farmer approach.*

Sheep herders of steppe areas facing climatic change: Consequences and adaptation strategies – The Case of Algeria

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During the past three decades, sheep have faced a climatic hazard that is instrumental to the degradation of natural forage resources, making the production of animal feed increasingly marginal. Indeed, it has been shown that the frequency of dry years has considerably increased in arid and semi-arid areas.

To shed light on how sheep herders in steppe areas have managed to sustain their ancestral profession in an unfavorable environment, a systemic community-based approach was adopted to analyze their strategies of adaptation. Two criteria, based respectively on land tenure (land owners versus landless herders) and mode of herd movement, enabled the identification of the following types of sheep herders: nomad, semi-nomad, transhumant, semi-transhumant and sedentary.

To prevent total capital loss, all land owners take preventive measures (such as feed storage, lease of cultivated lands, use of modern-reproduction techniques, irrigation, etc.) in order to mitigate drought effects. However, the most common option noted in our sample is the purchase of barley or bran-based feed concentrates. Results also showed that clearing natural pastures and overgrazing natural resources (through high stocking rates on a fragile resource base) are at the root of the decline in forage production potential, thus threatening the sustainability of livestock farming activities. Indeed, the analysis of satellite imagery, for 1985 and 2003, reveals a 136% increase in the tilled area, resulting in a 42% loss in rangeland area.

Key words: steppe, climatic change, degradation, herder, strategies, sustainability

Inter-relationships between human reproductive health and livestock keeping in contributing to livelihoods security in the climatically vulnerable region of Nyanza in West Kenya

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Introduction

This paper reviews some of the complex inter-relating factors between climate change and livelihoods with particular attention to the Nyanza region of Western Kenya. This is an area which is potentially very vulnerable to climate change, with a high incidence of poverty and an associated high incidence of human reproductive health problems. These are reviewed and the potential of livestock to improve livelihoods explored.

Climate change

The exact nature of any change in climate remains unclear but has been well reviewed elsewhere in this conference. The likeliest scenario is one of increased variability, particularly at the extremes with overall increases in mean temperature and overall decreases in mean rainfall being likely. Climate change is now, somewhat belatedly, being taken seriously at a global, political level. By way of example, FAO Headquarters in Rome will host the High-Level Conference on World Food Security and the Challenges of Climate Change and Bioenergy from 3 to 5 June 2008. The Conference will build upon the work initiated at the Expert Meetings of January-April 2008. All FAO member countries, relevant inter-governmental and non-governmental organizations and other institutions will attend. The overall purpose of the Conference is to address food security and poverty reduction in the face of climate change and energy security. More specifically, the objective is to assess the challenges faced by the food and agriculture sectors from climate change and bioenergy in order to identify the steps required to safeguard food security within the broader context of action being recommended to address climate change and bioenergy at the global, regional and national levels. It should thus contribute to the UN system efforts in the field of climate change which are much needed. Whilst these discussions, and the hoped for action coming out of the discussions, have global relevance they are likely to have a particular impact on many climatically marginal areas within the tropics.

Livestock and livelihoods

Many of the poorest people in the world live in rural areas of tropical developing countries. Most keep farm animals. Cattle, buffalo, sheep, goats, pigs and poultry are among the most important assets of the poor and are the mainstays of their farming. Livestock bring the poor income, food and fertiliser. These sustain their livelihoods, assets, health and environments. Demand for livestock foods in developing countries is expected to more than double over the next twenty years. This 'livestock revolution' offers several hundred million people opportunity to raise themselves out of absolute poverty. The increasing demand for milk and meat makes livestock development an imperative for a more equitable and sustainable future. Conditions in the tropical developing world are often harsh for animals and people alike and these challenges may be further exacerbated by climate change.

Livestock production efficiency in the developing countries is just one-quarter that of developed regions. Limiting factors for the small-scale farmers and pastoralists in developing countries are a dearth of livestock feeds, a devastating disease burden – both human and animal, rapidly eroding livestock and forage biodiversity, poor access to markets, unresponsive policy environments, and degradation of natural resources.

So why are livestock so integral to this situation? The fight against poverty starts with rational use of available natural resources. Among those most readily available to the world's poor are farm animals. One-third of the world's 6 billion people depend on animals. Of the 1.3 billion people living in absolute poverty, 80% live in rural areas and of these, two-thirds—some 678 million poor—keep livestock. Livestock matter because their products matter. Their high-quality food nourishes families that eat too little and too poorly. Their milk, eggs and meat bring cash into households with no other means of earning money. Their manure fertilises soils exhausted by continuous cropping. Their importance as sources of power is critical for cultivation and transport of farm produce to markets where mechanised traction does not yet exist.

Cattle and other ruminants in developing countries are efficient food producers. They eat grass and shrubs instead of grain. They forage for food along roadsides and consume the stalks of harvested maize and the wastes of the vegetable garden. Ruminant animals transform biomass unavailable to humans into high-quality protein, fat and micronutrients. These are essential for human health and development. Half the world's population is malnourished in 'micro-nutrients'; three billion people are deficient in iron, 400 million in vitamin A. The most vulnerable are women of reproductive age and children. Women become anaemic, children stunted. A considerable number go blind, fall sick and die. This 'hidden hunger' is successfully combated by supplementing small quantities of milk or meat to the starchy staple diets of the poor.

Gender Issues

As ILRI say in their Global Challenge Dialogue on Women and Livestock – “Poverty has a woman’s face”. Women do two thirds of the world’s work, and produce half the world’s food, yet earn only a tenth of the world’s income and own less than a hundredth of the world’s property. Of the 600 million poor livestock keepers in the world, around two thirds are women and most live in rural areas. There is a special relationship between women and livestock. Poor women can own livestock when they are denied land. Looking after livestock fits well with their work of running households and raising families. Hundreds of millions of women livestock farmers daily tend sheep, goats and chickens, milk cows, buy and prepare food, plant and harvest crops, weed their plots, look after children, clean their home, fetch and carry water and firewood, prepare every meal for the family, care for the sick and elderly, while often simultaneously running small informal businesses – selling milk, eggs, fruits and vegetables – in market centres and along roadsides. Women are the great unsung heroes of agricultural development. They are the farm and market managers who make agriculture, and particularly livestock keeping, viable. They are often also referred to as “the glue that holds families and communities together, the stewards who safeguard their environments for the generations to come”.

Kenya

The World Food Programme information on Kenya lists the following as risks to food security:

- Endemic poverty
- Low economic growth, coupled with high population growth
- Arid and semi-arid lands in northern and eastern parts of the country; droughts are common
- HIV/AIDS

Kenya is a low-income food-deficit country with a GDP per capita of around US\$460 (2004 World Bank). The 2006 UNDP Human Development Report put Kenya among the “low human development” countries of the world, ranking it 152nd out of 177 countries. In Kenya, endemic poverty, low economic growth, drought-prone arid and semi-arid lands and high population growth cause increasing hunger. The country is also disaster prone, with floods following hard on the heels of a succession of crippling droughts. Poverty and vulnerability to food insecurity are highest in urban slums and among pastoralists and marginal agriculturalists in remote, arid and semi-arid lands, which comprise 80 per cent of Kenya’s land mass. Many households in these areas are chronically poor and there are persistently high malnutrition rates among children under five. Western Kenya and the Nairobi slums have very high HIV/AIDS prevalence and growing destitution.

Kenya and poverty distribution

An article by Okwi *et al* (2007), investigates the link between poverty incidence and geographical conditions within rural locations in Kenya. Evidence from poverty maps for Kenya and other developing countries suggests (Thornton *et al* 2007) that poverty and income distribution are not homogenous. They used spatial regression techniques to explore the effects of geographic factors on poverty. Slope, soil type, distance/travel time to public resources, elevation, type of land use, and demographic variables proved to be significant in explaining spatial patterns of poverty. However, differential influence of these and other factors at the location level shows that provinces in Kenya, including the west, are highly heterogeneous; and hence different spatial factors are important in explaining welfare levels in different areas within provinces, suggesting that targeted pro-poor policies are needed.

Livestock and livelihoods in Western Kenya

Richards and Godfrey (2003) reported on a multi site study looking at the importance of urban livestock in Sub-Saharan Africa. One of the case studies focused on Kisumu in W. Kenya. They reported that there were at least 14 different kinds of livestock in the Kisumu area: cattle, goats, sheep, pigs, poultry and rabbits being of most importance but also including ducks, quails, guinea pigs, fish and bees.

Only 3% of cattle in the city were exotics whereas 60% of pigs and 64% of turkeys were exotics. Most exotic cattle were kept by the richer individuals. The main impediment to livestock keeping included the high cost of housing and drugs. Although cattle numbers were much lower than poultry, they are much more significant in terms of biomass. Livestock housing was a major constraint on livestock keeping in the city. The majority of sheep and goats (78%) were housed at night, but 73% of these scavenge. Pigs were also housed at night but scavenge. Most respondents started rearing livestock in the last 20 years. For all types of livestock apart from poultry and rabbits, husbands owned more than wives who owned more than anyone else. The exceptions were poultry where wives owned almost double the amount that husbands owned and rabbits where school-going sons owned two thirds of the rabbits. It is important to note that both the adult daughters and school going daughters virtually own no livestock. This is setting a very weak investment base for the daughters.

As well as the considerable numbers of livestock associated with mixed farming systems a number are also owned by nomadic pastoralists. The erosion of the material base of pastoralism has accelerated due to an adverse climatic trend in the region, which has increased the incidence and duration of drought, bringing famine and disease to humans and livestock. Loss of animals has impoverished households, forcing them to seek supplementary or alternative sources of income. Migration, often leading to settlement and part-time cultivation, are the preferred options, and a massive shift to agropastoralism has occurred throughout the region. Migration has proved to be a major source of conflict among

pastoralists, and between them and settled cultivators. Dispersal, migration and poverty have further eroded the fabric of pastoralist society, weakening its solidarity and potential for political assertion at a national level. Furthermore, these developments have had a serious impact on women pastoralists, most of whom continue to have little say in their communities' decision-making and few have rights to land. Recently, with the appearance of democratic practice in the region, pastoralists have gained a degree of representation at the national level. This is a promising start, although it has yet to bear fruit. The potential to influence state policy is greater at local government level, especially where there is a significant degree of decentralization and local autonomy.

Reproductive Health Programmes

Kenya faces a reproductive health care crisis caused by two converging trends—increased demands for care due to a young population, and the HIV epidemic. After decades of improvement, child mortality rates have recently been worsening. And fundamental changes in how Kenyans receive health care are needed. In Kenya's Nyanza province, Nyanza Reproductive Health Society and other partners are working to improve and expand sustainable HIV and tuberculosis prevention, treatment, care and support services, along with integrated reproductive health, safe motherhood, family planning, malaria, and selected child survival services. The Project supports Kenya's Ministry of Health, as well as faith-based and community-based organizations and cooperates with other agencies working in the province, such as APHIA (Aids, Population and Health Integrated Assistance) to reach its goal to reduce the risk of HIV transmission and the fertility rate in Nyanza by the following measures:

- Improving and expanding sustainable facility-based services for HIV, TB, reproductive health, family planning, malaria and maternal child health;
- Improving and expanding civil society activities in order to increase healthier behaviors, including prevention programs that target at-risk populations;
- Linking health services to the community;
- Improving home and community support programs for people and families infected and affected by HIV and AIDS, including orphans and other vulnerable children;
- Reducing the stigma associated with HIV.

Livestock in Reproductive Health Programmes

An example is KIPE (Kisumu Initiative for Positive Empowerment). KIPE consists of about 200 core members plus another 600 casual members, most of whom are living with HIV/AIDS. KIPE is a post-test club to provide counselling and support for those who tested positive at the Nyanza Reproductive Health Society circumcision project, but it is open to HIV negative people as well. Since it has been operating for nearly 6 years, many of the members are now on ARVs or in need of getting on treatment. Most members are unemployed and very poor. Many do not have the means to maintain proper nutrition and this is especially a problem for those on treatment, since taking the medication on an empty stomach causes nausea and reduces the effectiveness of the drugs.

All the members have been adversely affected by the recent violence. Those who had some small employment have lost their jobs. Some have had their houses burned. All are facing increased costs of food and other essentials. A number of projects are under consideration, including a number involving livestock:

- i. Chicken scheme. Construction of a chicken coup at KIPE; purchase 100 small chicks, raise them and sell them as broilers (six weeks from chick to the frying pan). This would be a sustainable activity that would provide ongoing income for the members and could be expanded over time. Cost: \$1050.
- ii. Goat milk scheme. Purchase 5 small females and one buck, which would then be reared to provide milk for sale. It would require building a shed, buying the goats and buying the feed. It would provide income for members and should be sustainable. It looks economically viable. Initial investment: about \$4,000.

Conclusions

It is clear from this paper that many of the issues under discussion impinge on each other. It is therefore important that scientists from the various disciplines are aware of each others work. This is likely to be increasingly true in the future as climate change affects climatically marginal areas. This will adversely influence livelihoods and it will be important to consider the potential of livestock to alleviate poverty – particularly of the economically and medically disadvantaged

References

- Markakis, J. (2004) Pastoralism on the margin. Minority Rights Group, London, UK ISBN 190458423 3
- Okwi, PO, Ndeng'e, G, Kristjanson, P, Arunga, M, Notenbaert, A, Omolo, A, Henninger, N, Benson, T, Kariuki, P & Ouwor, J. (2007) Spatial determinants of poverty in rural Kenya Proc Natl Acad Sci USA 104, 16769–16774
- Richards, J.I. and Godfrey, S.H. (Eds.) (2003) Urban livestock keeping in sub-Saharan Africa: Report of a workshop held on 3-5 March 2003 in Nairobi, Kenya.
- Natural Resources International Ltd, Aylesford, Kent, UK. ISBN: 0-95329274-9-0
- Thornton PK, Jones PG, Owiyo T, Kruska RL, Herrero M, Kristjanson P, Notenbaert A, Bekele N and Omolo A, with contributions from Orindi V, Otiende B, Ochieng A, Bhadwal S, Anantram K, Nair S, Kumar V and Kulkar U 2006. Mapping climate vulnerability and poverty in Africa. Report to the Department for International Development. pp 171.

Sheep management for drought mitigation: Fat-tailed sheep breed, a solution for difficult conditions, still needs preservation of breed adaptive qualities

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Sheep is a major livestock resource throughout North Africa and the Near East region. The fat-tailed breeds represent the greatest majority of sheep breeds in this region. Fat-tail breeds are mostly found in non-temperate regions, and are therefore subject to feed shortages due to large seasonality in vegetative production. During scarcity periods, ewes face, at least partially, the seasonal feed deficit by a mobilization of their body reserves. This ability of fat-tailed sheep to cope with periods of feed shortage is the result of a long evolutionary process in natural harsh conditions. The body condition score (BCS) and tail measurements (TM) are simple and reliable indicators that reflect the nutritional status of ewes and lamb growth rate. The objective of this work is to develop an alternative management to enhance drought mitigation for sustainable sheep production.

1. In common management, suckling period is large with lamb weaning at the age of 4-6 months. During suckling, nutritional requirements are very high. Earlier weaning (45-60 days) enables both an early release of ewes and an assured lamb survival. Fat-tail ewes can survive for a relatively long period on poor feeding (meager grazing and limited amount of straw). After weaning, fat-tail Barbarine ewes survive on 350 g of daily straw intake during 100 days, reaching a BCS value of 0.75 and a TM value of 1.25.
2. Six weeks before the next mating season, ewes should be scored and given feed supplements which will assure an acceptable fertility rate, even for ewes in poor body condition (BCS of 1-1.5).
3. Fattening weaned lambs until market live weight of 25 kg at 5 months with feed concentrate leads to better growth rate than in suckled lambs, for the same period and the same amount of concentrate.
4. For replacement, lamb selection based on TM enables the early identification of promising lambs. Results show a better correlation of early tail-growth rate (during the period 10-30 days) with lamb body average daily gain at advanced age (30-70 days) than at early age (10-30 days). Lambs that have higher TM during the suckling period (10-30) express the best body growth performance at later ages.

However, in difficult years, and especially in medium or small flocks, the best animals are sold to secure feed resources for the remaining animals. Such management works against selection of breed adaptive qualities and leads to genetic erosion.

Keywords: *sheep, drought, drought mitigation, management, feed, selection.*

Effects of heat stress on dairy cows in Tunisia and potential management strategies for its alleviation

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Tunisia has a Mediterranean climate characterized by hot temperatures for an extended period of time. Thus one of the big challenges facing dairy producers is heat stress and the negative effects it has on Holstein cows. The objectives of this work are to characterize the environmental conditions to which dairy cows are exposed in Tunisia, examine the effects of heat stress on performances of lactating cows using the Temperature Humidity Index (THI), which incorporates the combined effects of temperature and relative humidity, and discuss managements strategies which are available to producers to minimize the effects of heat stress. First, to calculate THI values and define heat stress intensity, average monthly temperature and relative humidity data were collected over a 10-year period from different weather centers located throughout the country. The trends for milk per cow and major reproductive indices were then examined using data from 4 selected herds located in north and central parts of the country. For each herd, available milk production and reproduction data were analyzed and relationships between milk yield, reproduction parameters and THI values were examined. Herd management practices were also investigated. Our results showed that climatic conditions in Tunisia are such that the hot season is relatively long, there is summer heat stress for 4 to 5 months each year going from May trough September with THI values greater than 72. The highest THI values were recorded for summer and fall which are unfavorable to optimum production of dairy cows. In fact; lactation peaks were lowest for the fall and the summer (21.3 and 21.4 vs. 22.7 and 22.8 kg/cow/d for fall, summer, winter and spring, respectively). On average milk production per cow dropped by about 10% between March and September. First conception rate (CRI₁) and overall conception rate (CR) were lowest in the summer for (25 and 32 % for CI₁ and CR respectively for the month of August). The highest values (58.9 for CRI₁ and 51 % for CR) were observed for the month of February. Regression equations between THI and CRI₁ and THI and CR showed high R² values (0.7 and 0.9, respectively) suggesting a strong relationship between heat stress and these reproductive indices. Calving to conception and calving intervals were the longest for cows calving during the summer and the shortest for those calving during the winter. Field investigations revealed that the observed effects of heat stress are often aggravated by current management practices and uncontrolled environmental conditions. It was concluded that the entire country is subject to extended periods of heat stress which affects milk production and reproductive efficiency and ultimately cow's productivity. Maintaining cow performance under hot weather conditions in the future requires the adoption of environmental control techniques, such as shades and cooling systems, the use of appropriate feeding strategies and improved nutritional practices, and the need for genetic improvement which may include cross breeding which enhance heat tolerance. This is particularly true given the continuous changes associated with global warming.

Keywords: *heat stress, dairy cows, production, alleviation*

Long term changes of live weight and metabolic hormones and associated reproductive performance of Barbarine maiden ewes bred in dry, hot conditions

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The aim of the present work was to investigate the nature of the relationship between long-term changes in live weight following weaning, the reproductive capacity of Barbarine ewes and their plasma concentrations of insulin and leptin. A total of 171 weaned Barbarine ewe lambs (mean live weight \pm s.d. 34.7 \pm 3.1 kg and mean age \pm s.d. 196 \pm 10 days at weaning) were used. Live weight curve over the 200 days following weaning (about 1 year of age) and corresponding to the driest and hottest season were analysed using the gamma model of Wood. The mathematical adjustment allowed to class the ewes into three different levels of live weight changes (LWC) based on the slope of the live weight curve; LWCI (n=46), LWCII (n=91) and LWCIII (n=34) with live weight loss being highest in LWCI and lowest in LWCIII. At 13 months of age, the proportion of ewe lambs cycling in LWCIII (85.3%) was higher in comparison to animals in LWCI (43.4%, $P<0.001$) and those in LWCII (61.5%, $P<0.05$) but similar between LWCII and LWCIII ($P=0.07$). At 18 months, the animals entered the mating season and live weight was still different between the 3 classes (LWCI: 41 \pm 0.7, LWCII: 39.7 \pm 0.5, LWCIII: 38.5 \pm 0.8 kg, $P<0.01$) but the proportion of females exhibiting oestrus at least once or returning to oestrus was not different between the classes ($P>0.05$). Fertility rates were also similar between the three classes (LWCI: 80.5%, LWCII: 79%, LWCIII: 79.2%, $P>0.05$). Over the six months preceding the 1st mating (18 months), plasma insulin and leptin concentrations, measured every two weeks, were positively correlated to live weight ($r = +0.31$ and $+0.29$, $P<0.001$ respectively). However, insulin levels did not differ between classes of live weight while leptin concentrations were affected by time ($P<0.001$) and class of live weight ($P<0.05$). Our results show that, in Barbarine ewes a desert adapted breed, decrease in live weight after weaning retards the onset of puberty, but that improvement of the level of nutrition, even without full recovery in bodyweight, allows the animals to reach similar fertility at the age of 18 months.

Keywords: Maiden ewes, Live weight, Leptin, Insulin, Reproduction

Land degradation and desertification in Libya

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This paper is intended to provide a brief background on available information concerning processes that cause and effect land degradation and desertification in Libya, with more emphasis given to the Mediterranean Coastal Zone, where relatively higher potential lands for agriculture are found and more than three quarters of the population are concentrated. The national actions and measures that have been taken to combat desertification in the last four decades, and the further work that is required will be reviewed. An application of Remote Sensing and Geographic Information System (GIS) to study land degradation of areas situated in northwestern zone of Libya is also included in this paper.

This paper indicates that scarcity of water (aridity), overgrazing, and changing the range land to rainfed agriculture have caused destruction of natural vegetation cover (reduction of bio-productivity and invasion of non palatable species) and induced wind and water erosion. Increased human pressure on the use of localized underground aquifers causes sea water intrusion in the Coastal Zone. In irrigated areas, imbalance between excessive irrigation and inefficient drainage causes water logging and secondary salinization. A monitoring study on El- Witia area (as a Pilot project) which was conducting in our Research Unit, at the Libyan Center for Remote Sensing and Space Sciences in 1997 showed the severe state of natural resource degradation in rangelands of the Coastal Zone of Libya (33.3% reduction in vegetation cover and 15.6% increase in the formation of sand dunes during the 10 year period from 1986 to 1996) . Many measures and acts have been applied to combat desertification in Libya in the last decades. These have included water development and conservation, wind and water erosion control, land reform, reclamation and development, and several social and legal actions. Some of the past and on-going anti-desertification measures applied in Libya succeeded; others are not suitable. Therefore these measures must be evaluated in order to provide clear prospectives for future programmes. The paper also concentrates on the importance of modifying water resources polices taking into account the growing water scarcity in Libya, and of the role of research, education, training and extension in order to combat desertification and stop land degradation more efficiently.

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