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REVIEW PAPER

The Development of Tractors and Other Agricultural Vehicles

H. GÖHLICH*

Consideration is given to the improvement of farm production including the problems of energy shortage and the possibility of replacing some fossil energy through the conversion of biomass. The tractors of today and their future development are considered within three areas:

information monitoring and power transfer to give low soil compaction, operating costs and purchase price;

the possibilities of versatile application and convenient implement coupling systems and

increased driver comfort and improved protection.

To improve the economy of field production, better information on the tractor and implement operating system is required. The sensing and evaluation of information will become a helpful procedure for tractor operators. The total weight of field machines should be as low as possible in order to reduce soil compaction, operating costs and purchase price. The most universal application of tractors will be achieved by improved front and rear implement coupling systems. The convenience of hydraulic power transfer will lead to an extended application of hydraulics and electro-hydraulic control circuits. So-called system tractors may replace some of the standard tractors of today in certain applications. Driver comfort requires further improvement for all vehicles. These improvement will be concerned mainly with reducing vibration on agricultural tractors designed for higher speeds, particularly for transport purposes. Total cab suspension systems and front axle suspensions will provide increased comfort and safety. Complete solutions for replacing the driver are not to be expected in the near future.

1. Introduction

1.1. *General agricultural aspects*

During the last 50 years or so, agricultural production has increasingly depended on the universal application of the tractor. It operates as a power unit for most field machines as well as providing power for loading and transport purposes in the field, on the farm and on the road. The versatility of its application has led to some compromises in design and construction but, nevertheless, the farmer has been able to live with such compromises and he has operated more-or-less successfully and economically.

Today, however, we might raise the question of whether this will be applicable in the future or whether new design criteria are on the horizon, which will set new directions or changes caused by structural or technical alteration in our agriculture. For example, to reduce soil compaction might require new concepts for tillage operations or new products, perhaps "energy plants" might demand new agricultural production systems.

Will food production remain the only task of agricultural producers or will there be a change in agriculture caused by the decrease of fossil oil reserves? Because of the increase in productivity of our agriculture we produce a considerable surplus of food. At present most of the industrialized

*Department of Agricultural Engineering and Construction Machinery, Technical University Berlin, Zoppoter Strasse 35, D-1000 Berlin 33, West Germany

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nations have to support their agricultures, and overproduction of food is stimulated by guaranteed prices for products. In the long term, present support measures are not likely to solve the problems of production surpluses.

Agricultural products serve as an effective solar energy storage medium. It is relevant to question whether these products will serve only as food for the people or if they have potential to store solar energy in the form of biomass. The steady decrease of fossil oil reserves may make it realistic to give greater consideration to agricultural crops in our energy balance in the future.

The latest considerations of the office of the European Economic Community in Brussels have resulted in the following perspectives.

In the next two decades within the EEC, 75 million tons of fossil fuel could be substituted by renewable energy sources such as biomass. So, in the year 2000 roughly 5% of the EEC's primary energy requirements could come from these sources, and that is an amount greater than today's total agricultural consumption of energy.

Instead of producing a surplus of food, it may be more economic to direct this production towards the growing of biomass for use as an energy substitute.

With a further increase in the price of fossil fuels, renewable energy sources might become competitive on the raw energy product market.

These considerations may have some effect on the economics of agriculture in the future, although they do not seem likely to prompt changes in production processes in the shorter term. Rather, other circumstances in agriculture may affect the development of machines and tractors to a greater extent.

It is unlikely that the growth in power and weight of tractors and machines will continue in the future at the same rate as in the past. One reason might be the decreasing growth of farm size in most European countries. Farm size will be stabilized by the decreasing land availability, by the general employment situation and by the limited market. For example, *Fig. 1* shows the change in farm size that has occurred during the last two decades in West Germany. The trend of farm size stabilization is recognizable and similar trends can be observed in other European countries.

Another important objective in the highly mechanized agriculture of the future will be the conservation and also restoration of a considerable soil area. The objective of maximizing crop yields has led to the application to the soil of more mechanical energy than was really necessary. Only a part of this energy contributed to soil cultivation and hence to growth and yield of the plants. The other part has caused structural damage to the soil in the form of compaction and smearing, and much of this has taken place below the normal ploughing depth. Again, more power and energy will be needed to restore these damaged deeper layers of the soil. These considerations have implications for the tractors of the future.

1.2. *Courses of design*

The foregoing considerations raise the question as to whether the agricultural tractor of today will remain the key production tool on the farm or whether considerable changes in agricultural production will lead toward other designs. The trend towards special tool carriers or power units (*Figs 2* and *3*) which came to the surface in the past, particularly in the period between 1955 and 1970, did not succeed. The idea was not successful, largely because the time required to mount the implements on the power unit was unacceptable. This mounting process had to be done during the time when field work was most important. Hydraulic mounting systems were not well-developed at that time and the process of assembling tools, mainly between the axles, required too much effort to carry out.

A few attempts have been made to combine the tractor with the harvesting unit. A recent design example is shown in *Fig. 4.* Such a harvesting machine is divided into two sections. Each of them has its own threshing and separating units which are mounted on both sides of the tractor, which

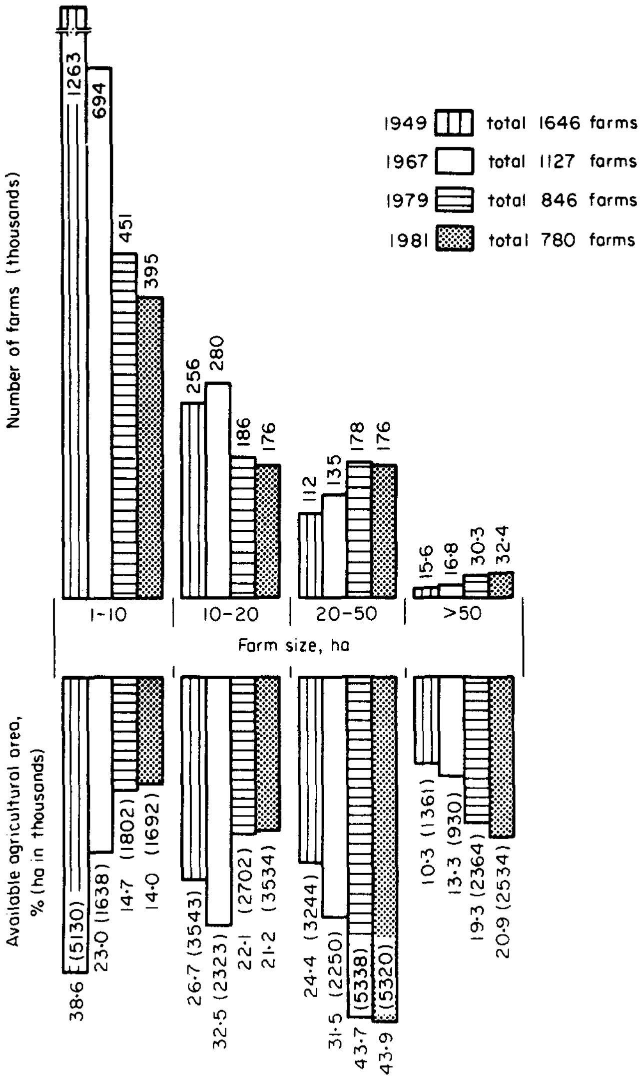

Fig. 1. Size distribution of farms in West Germany 1949–1981

operates backwards. Despite the fact that the mounting procedure is relatively simple the system has not achieved popularity with farmers.

Self-propelled machines such as the grain combine harvester need no, or very little, preparation work for their operation and they have proved to be successful worldwide. Other harvesting machines, such as sugar beet harvesters and forage harvesters, have been taken successfully in two different design directions, one self-propelled and the other tractor-powered. The reason for this originates from the needs of different farm structures: for example, contractors and some large farms use self-propelled machinery almost exclusively whereas the smaller farmer with limited financial resources more often uses tractor-powered implements.

There is little doubt that a versatile tractor will continue to be needed as a power unit for a wide range of applications in future agricultural production. Some indications are recognizable that the growth in power and weight is beginning to slow down. More attention will be paid to the

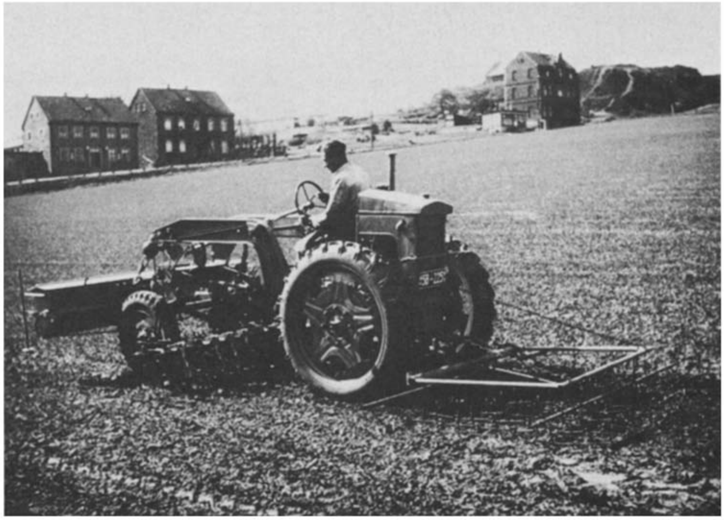

Fig. 2. Tool carrier, Ruhrstahl 1951

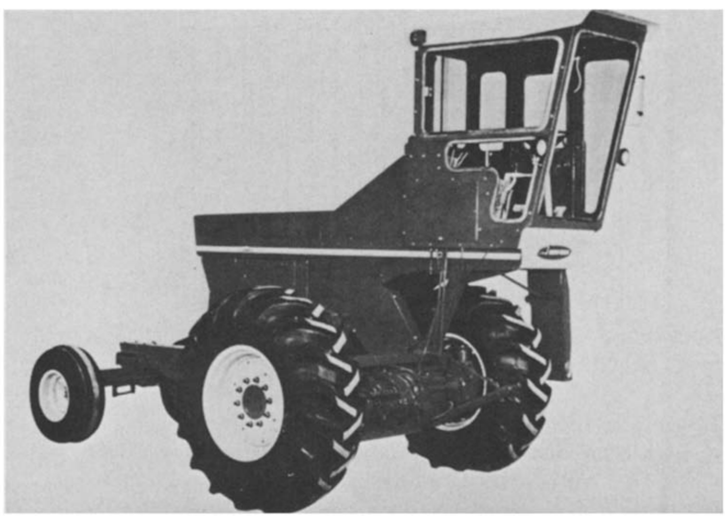

Fig. 3. Tool carrier, New Idea 1961

total weight needed for different field operations as well as the ground pressure caused by the wheels. The growth of tractor size in West Germany in the past two decades is illustrated in *Fig. 5.* In this connection it is of interest to comment on the development of the weight-to-power ratio of tractors. This ratio did not decrease as much as one might have expected with increase in tractor power, mainly because of the weight added by the front drive-axle assembly, on four-wheel drive tractors, and by cabs. The combination of these two add approximately 1000 kg to the total weight. *Fig. 6* illustrates the trend of the weight to power ratio depending on the engine power.[1]

In the following, the design criteria of the tractor, as viewed by the farmer, are discussed through the following points.

Fig. 4. Combination of tractor and grain harvesting unit

Optimum power transfer with low soil compaction and a low operating cost as well as a low purchase price.
The possibility for further universal application with convenient implement coupling systems.
Increased driver comfort and improved operator protection.

2. Optimization of power use

2.1. *Weight to power ratio*

One requirement for optimum power transfer would mean that each particular field operation should be performed with the lowest weight-to-power ratio and the optimum size of tyre and inflation pressure. The work should be performed with a low fuel consumption at the highest possible work-rate (in hectares per hour). A minimum weight-to-power ratio can be realized only when the basic weight of the tractor is relatively low, and when adding additional weight is either simple or fully-mechanized. Some new ideas are needed to make it easier to change axle loads, and it is possible that axle load transducers may help to realize an optimum balance. A low basic weight will lead to a low purchase price because the present cost of the material used in a tractor makes up more than 50% of its production costs.

Increasing the draught through further tyre improvements is unlikely, and much research has already been conducted in this area.[2,3] In spite of the fact that the ground pressure could be maintained at a constant level through choice of tyres and inflation pressure, the soil deformation at greater depths[4] is influenced not so much by the pressure as by the total weight, as shown in *Fig. 7.* The ever-increasing use of machinery has brought new problems, along with its many benefits. Soil compaction is being recognized as a problem on certain soil types. It reduces the pore spaces in the soil, thus inhibiting plant root development, reducing water storage capability and causing waterlogging if water cannot escape. In turn, these lead to lower yields and an additional energy requirement for reclaiming the compacted soil horizon.[5]

2.2. *Field performance*

Rolling resistance and wheel slip are sources of power losses, as well as producing unfavourable soil effects. There is a loss of efficiency, particularly when operating with powerful heavy tractors on soft freshly-tilled soil using implements which require only low traction. In particular, p.t.o.-

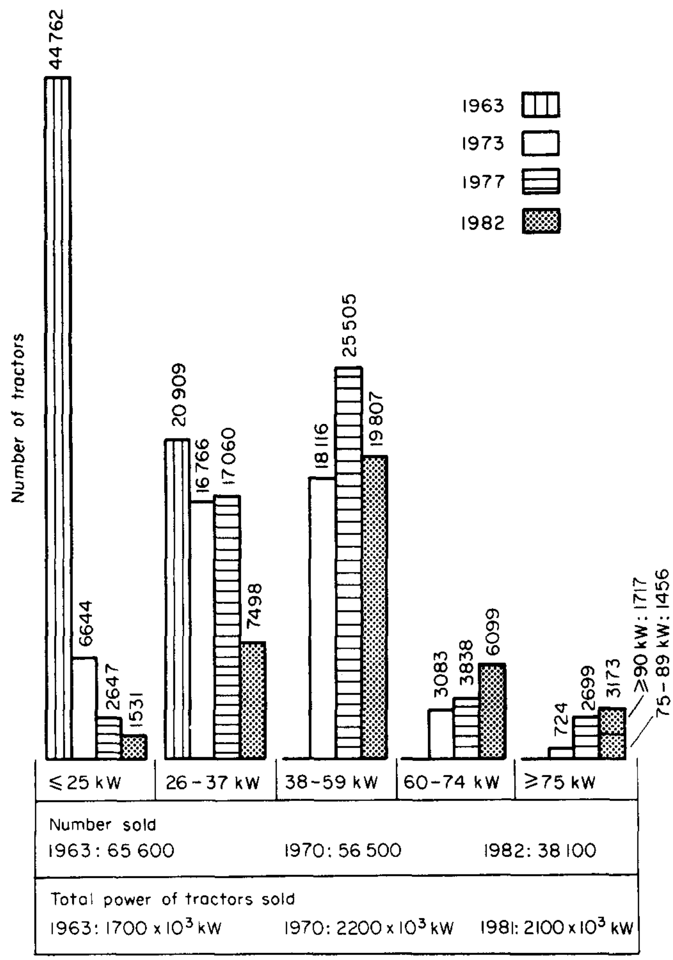

Fig. 5. Tractor size distribution in West Germany 1963–1982

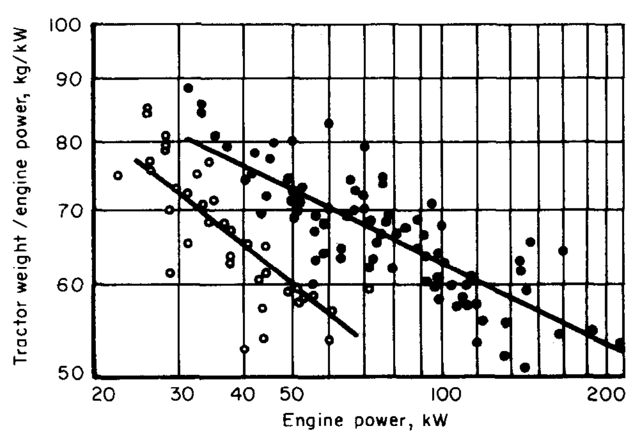

Fig. 6. Tractor weight-to-power ratio of new tractors. ○, Two-wheel drive with overall frame; ●, four-wheel drive with integral cab

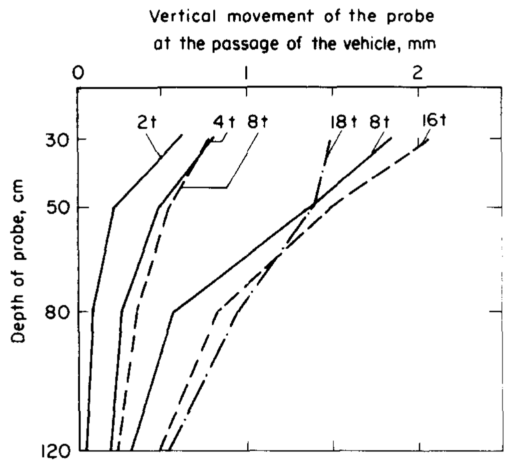

Fig. 7. Vertical movement of a probe measuring soil compaction at various depth under vehicles of different weight. ——, *Single axle;* — —, *tandem wheels;* —·—, *crawler tractor*

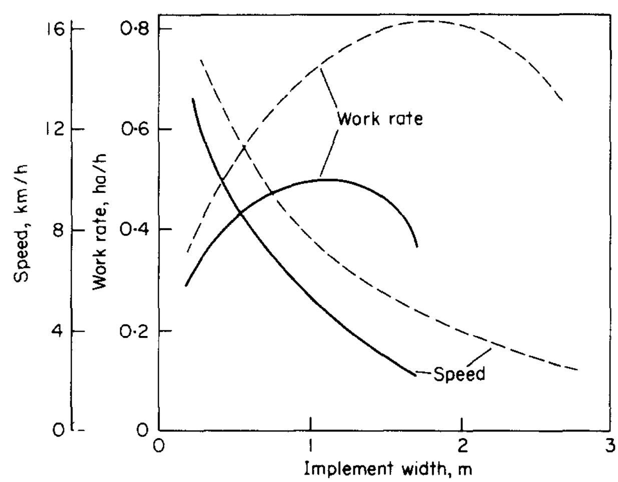

Fig. 8. Work rate and ground speeds vs *implement width.* ——, *Loamy clay;* – – –, *sandy loam*

driven implements for light tillage work emphasize the need for lightweight tractors. The question has been raised of whether it is possible to use "controlled traffic" methods instead of our present random field traffic, which require the tractor to travel on average 30–60 km/ha in one season.[6] Pathways are often used for fertilizer and spray applications and represent a first approach to controlled field traffic. The gantry proposal,[5] spanning some 12 m, capable of travel in any direction but restricted to certain pathways in the field, is another possible step in that direction.

An optimization of the relationship between the field work performed, as expressed in hectare per hour, and the fuel cost is the wish of every farmer. For some farmers, field work performed will take the first priority, while other farmers will consider the reduction of fuel cost to be more important. Today, the relationship between the work done and the fuel used is solely dependent upon the experience and capability of the driver. *Fig. 8* gives an example of the dependence of the work rate and the ground speed on working implement widths for different soils.[7] Considerable developments are under way to improve information about the entire operation provided

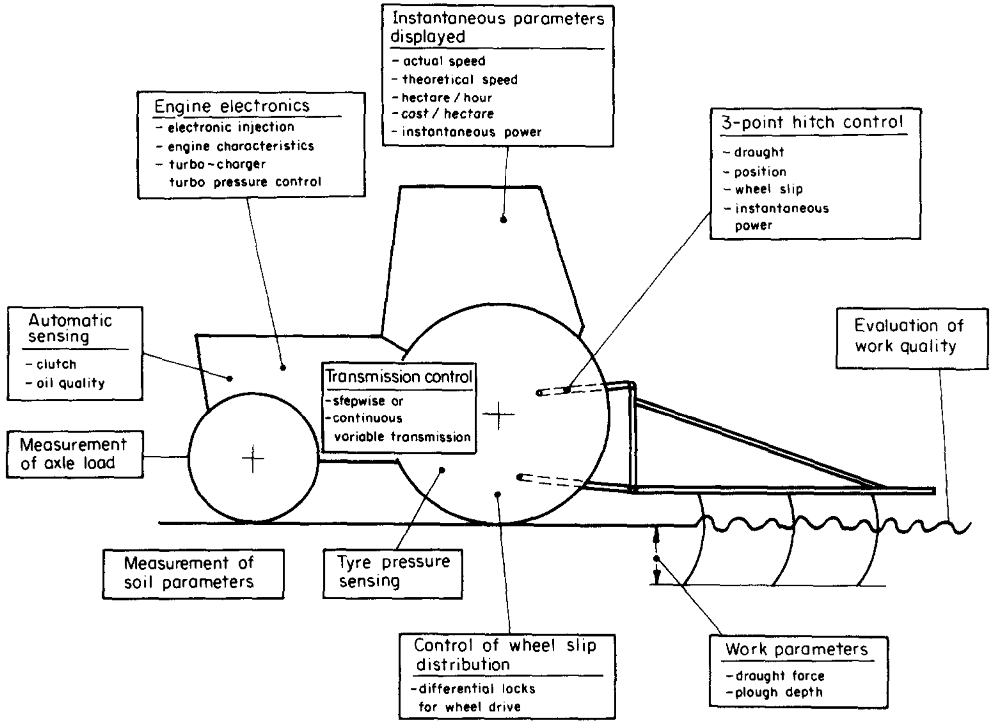

Fig. 9. Possible sources of information for the driver

to the driver, who serves as the human link in a continuous feedback circuit and to introduce new fully-automated control circuits, including automated gear shifting.[8–10] Some of the possible sources of information for the driver are illustrated in *Fig. 9.*

An example of a two-dimensional information system[11] that provides operating information using fuel consumption and hectares covered per hour as inputs may be seen in *Fig. 10.* Such a device enables the driver to select the most economical tractor speed and engine speed according to the power required by the implement. The information in *Fig. 10* is given by the particular location of a flashing light on the screen. The horizontal axis is in ha/h and the vertical axis is me/ha which stands for monetaere einheit representing a unit of cost. Beside the cost of fuel, it may also include the costs of labour and other costs. Through field tests, we have shown that it is possible to increase the area covered per hour by 15% for a 57 kW four-wheel drive tractor, while at the same time we also observed a reduction in operating costs. Similarly, it is possible to apply this information gathering technology to other farm machines such as forage harvesters and field sprayers.

2.3. *Engine performance*

High engine performance has been attained by high pressure turbo-charging and turbo-intercooling. Because of the high maximum power of these engines, they can be operated more often under a medium load, giving lower fuel consumption. New combustion and injection systems will lead to a lower fuel consumption, as well as a lower noise level. For instance, the new "Squish-lip" combustion process leads to a specific fuel consumption of 200 g/kWh due to the special shape of the combustion chamber which activates air turbulence during combustion.[12]

The use of fuels produced from agricultural products will receive more attention in the future, particularly in countries with an insufficient and expensive mineral oil supply. Development of

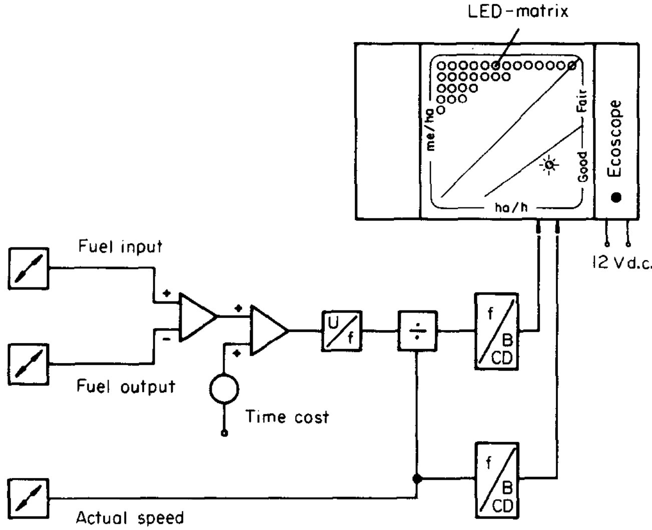

Fig. 10. Driver two-dimensional information system "Ecoscope"

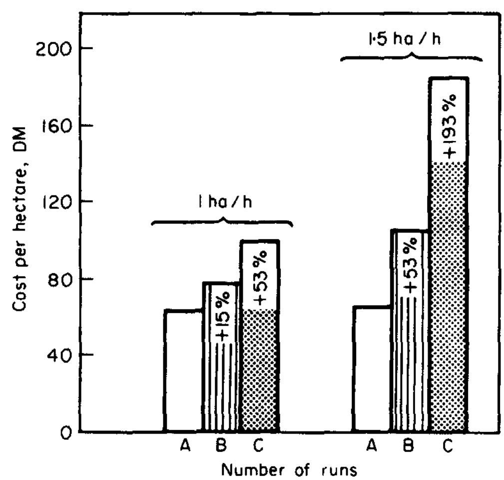

Fig. 11. Comparison of combined and seperate seed bed preparations and sowing. A, Combined sowing drill and rotary harrow; B, (1) seed bed preparation, (2) sowing drill; C, (1), (2) seed bed preparation, (3) sowing drill

the use of alternative fuels, such as biogas and the gas produced from the low oxygen combustion of cellulose products, are well known, but they have not yet found general use because they are more expensive to produce than conventional fuels. Plant oils provide another substitute for diesel fuel, but refined plant oil is very expensive in relation to diesel fuel, and successful application is only possible with engines having a pre-combustion chamber. Ethanol may also be used as a fuel for diesel engines; however, the ignition must be improved through the use of additives. Smoke and other pollutants in the exhaust are very low when using ethanol in diesel engines, and the power output is better than that of a comparable carburettor engine, using the same fuel.

Fig. 12. Tractor and forage harvester operating in the reverse direction

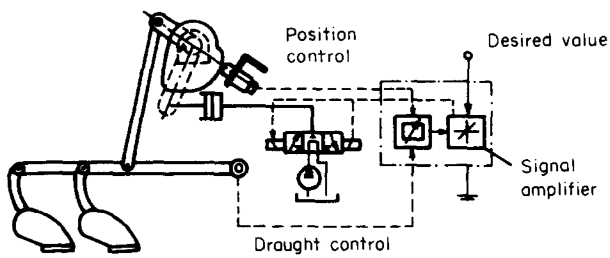

Fig. 13. Schematic of an electro-hydraulic control system

3. Implement mounting and drive requirements

The numerous operations in one year with different agricultural machines and the fact that each of these will be used for only a short period during the year, requires a universally applicable method of transferring power from the tractor to a machine. The difference from the past is the increase in functions on machines and a greater need for implement coupling and power transfer systems.

Up to 1956 most tractors used only two methods of power transfer, that is, rear wheel drive and the p.t.o. Today, the universal tractor frequently has up to seven power transfer functions, that is, rear wheel drive, four-wheel drive, three-point linkage at the rear and at the front, power take-off at the rear and at the front, and hydraulic power transfer.

The combination of different field operations, for example, seedbed preparation with front and rear mounted implements will require an improved and more frequent use of front mounting. Front mounting will lead to a more desirable load distribution, and one example of this is the front and rear mounted ploughing combination. For this reason also, front power take-off may become more common. *Fig. 11* illustrates the economic superiority of a combined process over equivalent separate processes.[13] Another important point in using front and rear mounted implements simultaneously is the fact that additional dead-weights on the front are not necessary.

The conception of new tractors might include an improved selection of reverse gears so that the tractor may be operated in reverse equally as well as in the forward direction. This will take care of the tasks that normally require a self-propelled machine, for example, a forage harvester, by providing for the mounting of implements on the rear of the tractor. This will require a precise

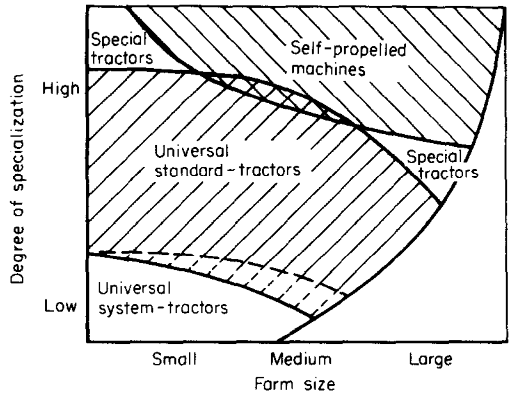

Fig. 14. Tractor and vehicle application trends

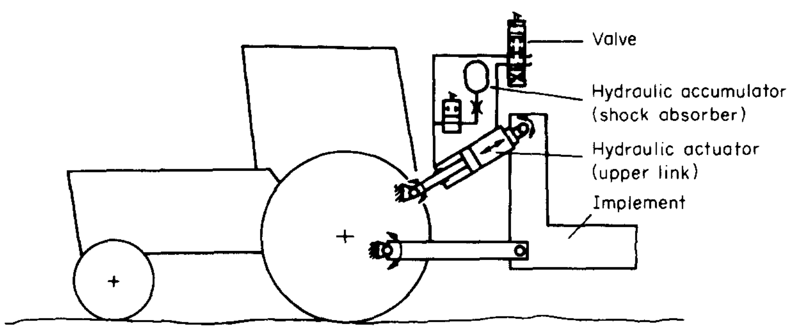

Fig. 15. Damping device to reduce pitch vibration

coupling system, with no compromises, that may be coupled easily and safely by one man. *Fig. 12* shows an example of a tractor that may be operated with a forage harvester in the reverse direction. These combinations provide working conditions similar to a self-propelled machine, but may save considerable cost for the whole operation. Coupling systems have been improved in a variety of ways in recent years, but this does not mean that further improvements are unnecessary.

The force and position control systems will increasingly be operated by electric and hydraulic means, which will provide a higher quality control, particularly in the lower range of forces. However, the full advantages of these systems can be realized by the farmer only when their prices are comparable with mechanical systems. *Fig. 13* shows a schematic of the function of an electro-hydraulic control system.[14] An additional advantage of the electro-hydraulic system is that signals of force could be used to control other parameters, such as draught, working depth and even the speed, where draught is a function of the speed. Different signals may also be combined to achieve the desired control.

New procedures for optimizing the transfer of power through the power take-off will become important. This means that the torque of the p.t.o. must be controllable and the speed should be more variable.[15]

The extent of the hydraulic power transfer from the tractor to the machine will be limited because of several factors. The average installed hydraulic power[16] of small tractors is in the range of 30% and of the larger tractors 15% of the total engine power, and this means between 8 kW and 20 kW with an oil flow of 15–60 l/min. Often the power is used simultaneously for several functions, with the result that the flow becomes limiting. For this reason, many implements are equipped with

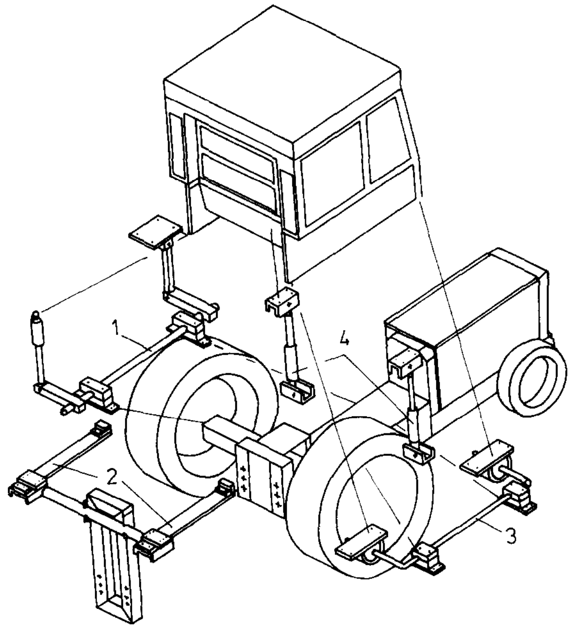

Fig. 16. Prototype of a totally suspended cab. 1, Damping device for pitch mode; 2, leaf springs for bounce and roll mode; 3, suspension for pitch mode; 4, damping units for bounce and roll mode

their own hydraulic power units driven by the p.t.o. The installation of greater hydraulic power should be an option for the farmer requiring a higher fluid flow in order to avoid the use of individual power units on implements which are, in the long run, more expensive.

The different powered agricultural vehicles may be distinguished not only between tractors and self-propelled machines but also between different tractor concepts, as *Fig. 14* shows.[17] The kind of specialization on one hand, and the farm size on the other hand, may well require special tractors alongside the universal tractor. It seems likely, that the so-called "System Tractor" will increase in number in the future because these will be more universally applicable to field and transport tasks than the standard tractor, and will give more flexibility in achieving the correct ballast weight. System tractors are characterized by a design which enables a field operation in forward and backward directions, equipped with mounting systems and p.t.o. drive on the front and the rear of the tractor. Front and rear mounted implements can be used simultaneously. Cab design and visibility permit equally good operation in both directions.

4. Driver comfort and health

The future development and expenditure on driver comfort will depend upon whether the driver's seat in tractors and self-propelled machines remains the farmer's most important workplace. Complete solutions for replacing the driver are not to be expected in the near future; however, some technologies are in the stage of development that may prepare the way for self-operating systems. These include new guidance and navigation systems that sense particular guiding profiles in the field, for example the plants, without installing guiding means in the field, such as wires.[10] One method may be to use the earth's magnetism as guidance. We may not expect this driver system to be realized in the near future, particularly because the percentage of the time used only for transport compared with the working time in the field is quite high. The most likely development we can expect is the further improvement of the driver's comfort and working environment, including his safety. This is particularly important because of the increased speed of the tractor during transport.

To improve the safety of the driver, it will be necessary to increase the efficiency of the brakes and to reduce the dynamic wheel forces, particularly those on the front axle. This could be realized by axle suspension systems with adjustable characteristics or special devices for vibration isolation, as well as correct selection of tyres, which will contribute to greater driver safety especially when operating at higher speeds. *Fig. 15* shows such an isolation device used in conjunction with a rear mounted plough.[18] A hydraulic actuator is substituted for the upper link, which is connected to a hydraulic accumulator and a damping valve. Both the accumulator and the valve have to be chosen such that the vibrating mounted implement moves in opposition to the forcing vibration from the tractor.

With regard to the driver's comfort, the tractor cabs of today have already reached a high standard. Conditioned and dust-free air, a low noise level inside the cab, and sufficient visibility are standard but there is still room for development. For example, air filtering systems have to be improved to eliminate chemical sprays from the cab and the driver needs better isolation from vehicle vibration. Even the best driver's seats can isolate only one vibration component. A further step towards better vibration isolation is a totally suspended cab and research has shown that the driver's comfort could be considerably improved.[19–21] Today, good driver's seats reach an r.m.s.-acceleration value of $1{\cdot}0\,m/s^2$ as weighted according to EEC regulations. Cabs, however, are capable of damping all six degrees of vibration with an average acceleration of only half of those of good seats. *Fig. 16* shows a prototype of a fully suspended cab with leaf springs and actively operating dampers.

The question must be raised as to whether the development of high tractor speeds is justified by the transport needs in agriculture instead of using road vehicles. Recent history has shown that road vehicles, such as trucks, do not satisfy all the requirements for agricultural purposes, for many reasons and this seems unlikely to change. Thus, maximum speeds of around 40 km/h and even higher may have to be taken into consideration for future tractor designs.

5. Conclusions

The universally applicable tractor will certainly remain the key machine for agricultural production in the near future beside a continuous growth in self-propelled machines. More emphasis will be concentrated on reducing the total weight of the tractor–implement system in order to minimize the ground pressure and soil compaction, particularly during seed bed preparation. Front and rear mounted implements will contribute more than in the past to better, more convenient and more economical field operations. Instead of the standard heavy tractors of today, for most of the required field operations a lighter, second tractor power unit with low inflation pressure tyres, which would transfer the majority of its power through the p.t.o. as opposed to through the ground drive, may be a desirable approach on the future farm. The optimization of the power transfer will be facilitated by driver information-displays as well as by control circuits which may eventually take over present manual functions. Components for the driver's comfort and safety will be further improved and this will contribute to ensuring that farming remains a satisfying job for the farm worker.

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