DOI: 10.1007/s002679910011

# Land Evaluation in a Salt-Affected Irrigated District Using an Index of Productive Potential

**J. NOGUÉS**
**J. HERRERO***
Soils and Irrigation Department
Laboratorio Asociado de Agronomía y Medioambiente, DGA-CSIC
PO Box 727, 50080 Zaragoza, Spain

**R. RODRÍGUEZ-OCHOA**
Department of Environment and Soil Science
University of Lleida
Rovira Roure 177, 25198 Lleida, Spain

**J. BOIXADERA**
Soils Section, Generalitat de Catalunya
Rovira Roure 177, 25198 Lleida, Spain

ABSTRACT / The indiscriminate allocation of funds supporting agricultural policies can lead to land misuse, with undesirable effects either on the shorter to mid-term productivity or on the environment. This article proposes a methodology, based on land rating, that can be useful to land-use planning or to decide about environmental protection measures. The methodology is applied to the land evaluation of a 260-km$^2$ semiarid irrigated area with salt-affected soils. The available soil map is at 1:100,000 scale and its mapping units are used for the land evaluation with the FAO framework. These data are then elaborated using the index value method. This procedure gives a map of land evaluation units and a table that rates the productive potential of these units for six crops: alfalfa, barley, maize, rice, sunflower, and wheat.

Irrigation has been a basic need for sedentary societies settled in arid or semiarid lands. However, in recent times the modernization or the enlargement of irrigation schemes has been called into question by nonagricultural water users in many developed countries where irrigation schemes were intended to alleviate situations of poverty.

The European Union countries are a good example of where both the active farming population and the agricultural area will probably continue to decrease, with the expected result of increasing farms competitiveness due to their larger sizes and the lower labor inputs required to reach an acceptable production level. The allocation of subsidies or other public funds to farms throughout the European Union, without taking into account the characteristics of the land, will become less and less accepted. Therefore, a better insight into the environment, together with new methodologies for evaluating lands and foreseeing their behavior after the application of agricultural policy measures, will be required. These environmental and methodological requirements are results of the global economy and the changing agricultural policies in the example presented herein, where investments are needed for irrigation system modernization but, on the other hand, the future of the irrigation district is questioned because of the competition for water and the environmental impacts of salinity and crop intensification.

Most of the changes in the common agricultural policy (CAP) of the European Union were limited to the instruments used, as pointed out by the Netherlands Scientific Council for Government Policy (WRR 1992), and probably the same is true for agricultural policies in other developed countries. The program presented by WRR (1992) for 12 countries of the European Union allows land allocation to forestry or to agricultural use, depending on policy options. These options are considered in four contrasting scenarios (free market and trade, regional development, nature and landscape conservation, and environmental protection), and maps are presented considering as units the 58 rural regions of 12 countries of the European Union. Both the scenarios and the map units presented are acceptable with the intention of assessing the strategic policy options. However, a procedure of rating lands at a map scale close to the subsidy recipients is needed to implement changes in the CAP budget. This is the case for irrigation in northeastern Spain, quoted by WRR (1992) as a matter of water and land allocation conflict, and is a good example of aridity-related problems around the world (Herrero and Snyder 1997). As the generators of subsidy rights are the individual plots, a scale of 1:25,000 will be needed for purposes of executing plans due to the sizes of plots, but a scale of 1:100,000 is allowable for planning purposes, as will be used here.

The aim of this article is to set up a land evaluation

KEY WORDS: Land evaluation; Soil salinity; Irrigation

---

*Author to whom the correspondence should be addressed.

methodology useful to refocus the application of agricultural policies, mainly in subsidies to crops or to the land set-aside of agriculture, avoiding unwanted effects either on the production or sustainability of the agricultural system.

This work uses a previous soil survey by Rodríguez-Ochoa (1998, personal communication) at a 1:100,000 scale, which seems appropriate for the objectives as a main source of data for the land evaluation exercise. A key aspect of the exercise is to deal with salt-affected soils, from both agriculture productivity and environmental points of view. Although soil salinity occurs in many irrigated districts of the Ebro Valley (Herrero and Aragüés 1988), as in other semiarid lands in Spain and around the world, their evaluation from the above-mentioned perspectives is still far from being accomplished.

The study is based largely on the application of the method proposed by Boixadera and Porta (1991) developed from the concepts of the FAO framework (FAO 1976). It evaluates the land for a set of climatically suited crops taken as a land use type (LUT), by defining a set of requirements and management practices; the selection of the LUTs is critical but in the preliminary applications of such a method this has proved to be a powerful tool in allowing discrimination of land regions. The method aims to be a measure of the productive potential of an area considering its versatility, i.e., the land suited for more crops is rated best. The method also explicitly takes in to account the environmental risks important in the area, such as salinity. Although the method starts as a suitability type method (McRae and Burnham 1981), the combination of the different suitabilities gives a ratio broadens the scope. The use of either the found ratings or the estimated yields may provide the technical coefficients (Rossiter 1996) needed for the land allocation in general land-use problems or for agricultural policies.

This approach is a first step in the evaluation of those lands because too many gaps in our knowledge remain. In the foreseeable near future, dynamic models to estimate specific land qualities may become available but expert knowledge still will be needed to assess the interactions among land qualities. The use of geographical information system (GIS) support for land evaluation will allow continuous updating of the information and new modeling according to market parameters or to policy conditions.

## Study Area

The study area (Figure 1) is located in the Ebro basin (Aragón, Spain) bounded by the Alcanadre and Flumen rivers and by the Flumen Canal. The area is 263 km$^2$, including nonagricultural surfaces. The new irrigated lands (90% of the area) are those where irrigation started 40 years ago by means of the Flumen Canal, but some older irrigated areas (7% of the area) have also been taking water directly from the Alcanadre and Flumen rivers for several centuries. Basin and border irrigation was the available technology when the irrigation system was designed and it still largely prevails in the study area, with most land parcels smaller than 1 ha. Intensive earth works for land leveling brought in the surface saline or saline–sodic materials to a significant part of the newly irrigated lands. The salt content of the water of the Flumen Canal is low, with electrical conductivity (EC) of around 0.4 dS/m at 25°C.

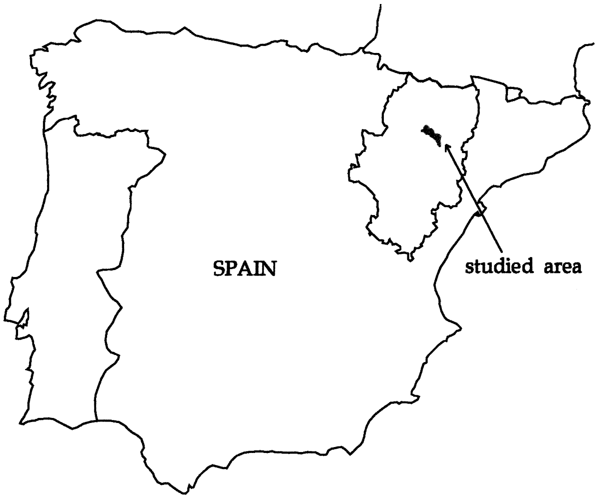

**Figure 1.** Location of the studied area in Aragon, Spain.

The climate is semiarid, with mean annual precipitation of 525 mm, air temperature of 14.3°C, and $ET_0$ of 1304 mm, according to weather records from the Montesodeto station (Faci and Martínez-Cob 1991). Following the model of Jarauta (1989), the soil moisture regime is xeric or aridic depending on the available water-holding capacity of the various soil units.

The information about biophysical factors and soils comes from Rodríguez-Ochoa (1998, personal communication) and is based on the study of 110 pedons (profile descriptions and analytical data) and 47 auger holes, averaging 0.6 observations per square kilometer. After having been checked by aerial photography and fieldwork, the cartographic units were transferred to the National Topographic Map of Spain at a scale of 1:25,000. The map was digitized and incorporated into a GIS using ARC/INFO and ArcView on a SUN workstation. Table 1 displays the dominant soils with their percent area.

The main crops planted in the study area are listed in

Table 1. Soil map units with their percent distribution over the entire study area (sectors IV–XI of Flumen, Spain) excluding miscellaneous areas

| Symbol | Land evaluation units (LEU) | % |
|---|---|---|
| A.1.1 | Soils of the irrigated structural platforms of sandstone and lutite. Association of Typic Xerorthents and Xeric Torriorthents, with inclusions of Lithic Torriorthents. | 4 |
| A.1.2 | Same that A.1.1, but nonirrigated. | <1 |
| A.2.1 | Soils of the irrigated residual platforms with coarse detrital sediments. Consociation of Calcixerollic Xerochrepts with inclusions of Petrocalcic Xerochrepts, Xeric Haplocalcids, and Xeric Petrocalcids. | 20 |
| A.2.2 | Soils of the nonirrigated residual platforms with coarse detrital sediments. Consociation of Calcixerollic Xerochrepts with inclusions of Petrocalcic Xerochrepts, Xeric Haplocalcids, Xeric Petrocalcids, and Calcic Haploxeralfs. | 1 |
| B.1 | Soils of the glacis slopes on fine detrital sediments. Association of Typic Xerofluvents and slightly saline Typic Xerorthents, with inclusions of Typic Natrixeralfs and Fluventic Xerochrepts. | 11 |
| B.2.1 | Soils of the other irrigated slopes on fine detrital sediments. Association of moderately saline Typic Xerofluvent, and slightly saline Typic Xerorthent, with inclusions of Typic Natrixeralfs; Calcixerollic Xerochrepts and slightly saline Xeric Torriorthents. | 41 |
| C.1 | Soils of the Flumen and Alcanadre river terraces on fine detrital sediments. Association of Typic Xerofluvents and Typic Xerorthents. | 3 |
| C.2 | Soils of the Flumen terrace on fine detrital sediments. Association of Typic Xerofluvents and slightly saline Typic Xerorthents. | 2 |
| C.3 | Soils of the Flumen terrace on fine detrital sediments. Strongly saline, sodic Xeric Torriorthents. | <1 |
| C.4 | Soils of the Flumen terrace. Moderately saline, sodic Typic Xerofluvents. | 1 |
| D.1 | Soils of the irrigated bottoms on fine detrital sediments. Association of strongly saline, sodic Typic Xerofluvents; strongly saline, sodic Oxyaquic Xerofluvents and strongly saline, sodic Typic Xerorthents; with inclusions of strongly saline, sodic Typic Natrixeralfs; slightly saline, sodic Xeric Torriorthents and moderately saline, sodic Aquic Xerochrepts. | 14 |

Table 2. Extent of main crops and their percent in sectors IV–XI of irrigation district of Flumen, Spain in three past years

| | 1991 | | 1993 | | 1994 | |
|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % |
| Alfalfa and forage | 4,358 | 17 | 5,785 | 23 | 5,479 | 21 |
| Barley | 4,775 | 18 | 3,944 | 15 | 2,639 | 10 |
| Maize | 2,232 | 8 | 477 | 2 | 2,001 | 8 |
| Rice | 2,453 | 9 | 2,260 | 9 | 2,779 | 11 |
| Sunflower | 1,277 | 5 | 3,324 | 13 | 1,879 | 7 |
| Wheat | 3,089 | 12 | 1,488 | 6 | 2,521 | 10 |
| Sum | 18,094 | 69 | 17,139 | 67 | 17,379 | 68 |

Table 2. The area (in hectares) was deduced by a regression estimator between ground surveys and remote sensing for the studied area from the data of Barbosa and others (1996) and Herrero and Casterad (1999). The six crops of Table 2 plus fallow and natural vegetation occupied between 89% and 95% of the study area, depending on the year. The differences up to 100% are due to miscellaneous areas and minor crops.

## Methods

Lands are evaluated according to the FAO (1976) framework for the six leading crops in the study area listed in Table 2. These crops are also the most suitable for the region under the present climatic, technical, and economic conditions. The results of the evaluation are elaborated following Boixadera and Porta (1991) to obtain an index of the productive potential of the different land units. One possible application of this index is to prioritize subsidies for the set-aside, or other CAP measures, to those lands with lower potential.

We start from the 1:100,000 soil survey whose map units (Table 1) are associations and consociations of soils (Soil Survey Division Staff 1993) named as phases of the subgroups established according to the Soil Survey Staff (1994). From these map units, we characterize land evaluation units (LEU) that are composed of evaluation units (EU) corresponding to all subgroup phases that are the dominant soils within the associations and consociations.

The evaluation method is applied to the evaluation units by considering 19 land qualities adapted from Boixadera and Porta (1991): adequacy of the irrigation water delivery system, chemical fertility, ease of crop establishment, flood risk, growth period, hailstorms and winds, location, mechanization potential, oxygen availability, pests and diseases, pre- and postharvest management, rooting depth, salinity, salinization/sodication risk, sodicity, soil adequacy for trafficability and plowing, solar radiation, temperature regime, and water availability. A data matrix relates each of these land qualities with each evaluation unit defined in the study area; this matrix is named a general land matrix (GLM). The land use types (LUTs) studied are the six crops listed in Table

Table 3. Variation in crop yields by four suitability levels[a]

| LUT | S1 | S2 | S3 | N |
|---|---|---|---|---|
| Alfalfa | >15 | 12–15 | 8–12 | <8 |
| Barley | >4 | 3–4 | 2–3 | <2 |
| Maize | >10 | 8–10 | 7–8 | <7 |
| Rice | >5 | 4–5 | 2–4 | <2 |
| Sunflower | >3 | 2–3 | 1–2 | <1 |
| Wheat | >6.5 | 4.5–6.5 | 3.0–4.5 | <3 |

[a] Yield is in Mg/ha at the allowable relative moisture for each crop yield.

Table 4. Relationship between soil salinity ($EC_e$ dS/m at 25°C), and suitability level for six crops[a]

| LUT | S1 | S2 | S3 | N |
|---|---|---|---|---|
| Alfalfa | <8 | <8 | 8–16 | >16 |
| Barley | <8 | 8–16 | 8–16 | >16 |
| Maize | <4 | 4–8 | 4–8 | >8 |
| Rice | <16 | >16 | >16 | >16 |
| Sunflower | <4 | 4–8 | 4–8 | 8–16 |
| Wheat | <4 | 4–8 | 8–16 | >16 |

[a] Yields for the four suitability levels are shown in Table 3.

Table 5. Final production of the six considered crops related to SAR $(meq/l)^{0.5}$ and ECe (dS/m at 25°C)[a]

| | S1 | | S2 | | S3 | | N | |
|---|---|---|---|---|---|---|---|---|
| LUT | SAR | ECe | SAR | ECe | SAR | ECe | SAR | ECe |
| Alfalfa | <10 | <4 | <10 | >4 | 10–15 | >4 | >20 | any |
| | | | 10–15 | <4 | 15–20 | any | | |
| Barley | <10 | <4 | <10 | >4 | 10–15 | >4 | >20 | any |
| | | | 10–15 | <4 | 15–20 | any | | |
| Maize | <10 | <4 | <10 | <4 | <10 | >4 | 10–15 | >4 |
| | | | | | 10–15 | <4 | >15 | any |
| Rice | <10 | any | 10–15 | >4 | >20 | any | >20 | any |
| | 10–15 | <4 | 15–20 | any | | | | |
| Sunflower | <10 | <4 | <10 | <4 | <10 | >4 | 10–15 | >4 |
| | | | | | 10–15 | <4 | >15 | any |
| Wheat | <10 | <4 | <10 | >4 | 10–15 | >4 | >20 | any |
| | | | 10–15 | <4 | 15–20 | any | | |

[a] The suitability levels of the LUTs are S1, S2, S3, and N, as described in Table 3.

2, considered under a well-defined set of management practices. Every LUT is characterized by a particular use matrix (PUM) of land-use requirements that reflects how each of the above land qualities affects the LUT.

Each PUM is combined with the GLM. The resulting figures, named numerical values (NV), are apportioned by conducting an aggregation process for every LEU according to the proportion of each subgroup (EU) in that LEU, and a numerical value of evaluation (NVE) is obtained. The average of the NVE ranges from 0 to 100, and there is an index (Boixadera and Porta 1991) of the productive potential of each LEU for the considered set of LUTs in the studied area.

A survey of farmers and local agricultural experts was conducted to establish the relative importance of the different land qualities considered, as well as their impact on the final production of each of the six LUTs. Some of the 19 considered land qualities are homogeneous in all the study area, notwithstanding that all land qualities are maintained in the GLM to allow the future comparisons with other irrigation districts as well as the evaluation of the possible introduction of improvements, such as sprinkling, on-farm reservoir construction, or emerging technologies. Salinity, sodicity, and water availability exert the main influence on production in the present context. The following paragraphs describe the treatment of these qualities.

Table 3 displays the average yield levels that have been established in the study area for each suitability level of the system FAO (1976), from the most suitable (S1) to nonsuitable (N).

The standard values of relative yield decrease under saline conditions (Rhoades and others 1992, Francois 1996) do not agree exactly to local field experience; the most outstanding case is rice grown in the Flumen area under a continuous flood of fresh water (Herrero and Snyder 1997). Table 4 shows the relationship between the electrical conductivity of the saturation extract of the soil ($EC_e$) and the suitability levels for six crops (LUT). The data in this table were established from surveying farmers about yields and by subsequent comparison with the available ECe data.

The relationship between soil sodicity and the production of the different crops was established by comparing the soil analytical data of the evaluation units with their production recorded in the field survey. Soil sodicity and soil salinity showed an interaction on the production of different crops. The theoretical study of these interactions is beyond the scope of this study, although a quantitative assessment (Table 5) was possible based on field survey. The interaction is expressed by the sodium adsorption ratio (SAR) of the saturated paste extract combined with $EC_e$, and the production of the different evaluation units.

The lack of water supersedes the other land qualities in the nonirrigated LEUs, where sunflower, barley, and wheat are the only physically feasible crops. These lands are now cropped with barley and some wheat that, under present market conditions, are profitable in rainy years.

The drainage of platforms, i.e., the A units (Table 1) is excessive for rice, thus water availability is considered favorable for rice only in the irrigated LEU, excepted the platforms. The other crops in the irrigated LEUs are evaluated based on the total potential of the soil water extracted by plants and a threshold of the total potential for yield decrease caused by water stress (adapted from Taylor and Ashcroft 1972). Disregarding the gravitational potential, the total potential ($\Phi_t$) of the water that the plants extract from soil is:

$$\Phi_t = \Phi_p^m + \Phi_o$$

where $\Phi_t$ is total potential (kPa); $\Phi_p^m$ is matric potential (kPa); and $\Phi_o$ is osmotic potential (kPa).

For calculations in nonsaline soils ($EC_e < 4$ dS/m at 25°C) we consider:

$$\Phi_t = \Phi_p^m$$

The available water-holding capacity of the land evaluation units was estimated from soil texture, depth, and coarse fragments, without taking into account soil salinity. For modeling purposes, the matric potential is added to the osmotic potential when dealing with saline soils.

As an example, we give the calculation of the water-holding curve for loam soils within the control section (adapted from Goldberg and others 1976) as:

$$\Phi_p^m = -\left[\left(\frac{AWHC_r}{13.3356128}\right)^{1/-0.78112}\right]$$

where $AWHC_r$ is the soil moisture content available to the plant, i.e., the remaining fraction of the available water holding capacity (AWHC) at the moment when the irrigation water is applied; $AWHC_r$ is expressed as a fraction of the AWHC.

For the osmotic potential we use the expression given by the US Salinity Laboratory Staff (1954) adapted by Jurinak and Suarez (1990) and by Rhoades and others (1992) to the standard temperature of 25°C:

$$\Phi_o = -39 * EC_r = -39 * \frac{\theta_c * EC_e}{\theta_r}$$

where $ECr$ is the EC in the soil solution at the moment when the irrigation water is applied (dS/m at 25°C); $EC_e$ is the EC in the saturated paste extract (dS/m at 25°C); $\theta_e$ is the saturation content, or the water content of the saturated paste expressed as a fraction of the dry soil mass; and $\theta_r$ is the soil water content at the moment when the irrigation is applied, expressed as a fraction of the field water capacity.

Table 6. Critical month for different LUTs, and $ET_0$ values in study area[a]

| LUT | Critical month | $ET_0$ (mm/day) | $K_c$ |
|---|---|---|---|
| Alfalfa | July | 7.6 | 1.15 |
| Barley | May | 4.8 | 1.03 |
| Maize | July | 7.6 | 1.15 |
| Sunflower | July | 7.6 | 1.10 |
| Wheat | May | 4.8 | 1.05 |

[a] From Faci and Martínez-Cob (1991). The values of the crop coefficients ($K_c$) are adapted from Doorenbos and Pruitt (1977).

For modeling purposes, we consider that when irrigation is applied $\theta_r$ is close to the value of $AWHCr$, and we write:

$$\Phi_o = -39 * EC_r = -39 * \frac{\theta_e * EC_e}{AWHC_r}$$

Thus, the total potential is:

$$\begin{aligned}\Phi_t &= \Phi_p^m + \Phi_o \\ &= -\left[\left(\frac{AWHC_r}{13.3356128}\right)^{1/-0.78112} + 39 * \left(EC_e * \frac{\theta_e}{AWHC_r}\right)\right]\end{aligned}$$

from this expression we obtain:

$$AWHC_r = \left(\frac{39 * \theta_e * EC_e}{-\Phi_t - \left(\frac{AWHC_r}{13.33561287}\right)^{-1/\ -0.7811221}}\right)$$

where $\Phi_t$ is the total critical potential, an individual value for each LUT.

As $AWHC_r$ is both a dependent and an independent variable, it has to be calculated by iteration.

The practical irrigation dose ($D_p$) is the water that soil can hold when irrigation is applied:

$$D_p = AWHC * (1 \ - AWHC_r)$$

where $D_p$ is the practical irrigation dose (mm); $AWHC$ is the available water holding capacity (mm); and $AWHC_r$ is the fraction of AWHC when irrigation is applied.

The critical month in terms of crop water requirements is July for summer crops and May for winter crops. The actual irrigation dose ($D_a$) is the amount of water that must be applied in the critical month to replenish the soil water extracted by the crop in that month in order to avoid plant water stress. $D_a$ is calculated for each crop using the reference evapotranspiration ($ET_0$) and the crop coefficients ($K_c$) of the critical month for the crop, and the precipitation in this month (Table 6),

$$D_a = (ET_0 * K_c) - P = ET_c - P$$

where $D_a$ is the actual irrigation dose (mm); $ET_c$ is the crop evapotranspiration in the most critical month

Table 7. Gradation from more favorable to less favorable of the land quality "water availability"

| Grade | Rotational turn of irrigation (days between two irrigations) |
|---|---|
| 1 | >10 |
| 2 | 7–10 |
| 3 | <7 |

Table 8. Relationships between suitability levels and gradation of land quality "water availability"

| | Grade | | | |
|---|---|---|---|---|
| LUT | S1 | S2 | S3 | N |
| Alfalfa | 1 | 2 | 3 | 3 |
| Barley | 2 | 2 | 3 | 3 |
| Maize | 1 | 2 | 2 | 3 |
| Sunflower | 2 | 2 | 3 | 3 |
| Wheat | 2 | 2 | 3 | 3 |

(mm); and $P$ is the precipitation in the most critical month (mm).

$D_a$ is divided by $D_p$ to obtain the number of irrigations needed during the critical month, and thus the period between two water applications that avoids water stress. After that, the rotational turns of irrigation in the study area are taken into account to establish grades in the land quality "water availability." These grades are listed in Table 7.

Table 8 establishes the relationships between the suitability levels and the water availability, a land quality. The LUT rice does not appear in this table because the treatment of this land quality is different for this crop, as has been previously explained.

A list of the suitability levels corresponding to each combination between every LUT and the land qualities that define all the evaluation units is established. This list allows the production of the numerical values (NV) by classifying the land qualities of every evaluation unit according to their significance for each LUT after the criteria inspired by the 'minimum law' that are described in detail by Boixadera and Porta (1991).

## Results and Discussion

Three groups of land qualities can be established in this article, according to their low, intermediate, or high relevance to the study area. In the first group, with slight effects on the productive potential, are those land qualities directly related to climate: hailstorms and winds, solar radiation, and temperature regime. The flood risk affects only the lower terraces of the Flumen river, but the return period is long. The land qualities related to ease of crop establishment, pests and disease treatments, preharvesting management, soil adequacy for trafficability and plowing are not important in the evaluation under the present management. The same applies to postharvesting management and commercialization.

In the second group, the qualities considered of intermediate importance, are the potential risk of soil salinization/sodication, determined by factors that cannot be economically changed, like the low EC of the irrigation water. Other land qualities in this group would be the chemical fertility and the mechanization potential. This last factor is very constraining in some old irrigated lands having a high productive potential but where the small size of plots hinders full mechanization.

In the third group, land qualities with high importance, soil salinity is the most significant. Soil salinity displays its differential effects on the studied uses, provided that $EC_e$ ranges from negligible to >16 dS/m. Soil sodicity also occurs, sometimes with SAR (sodium adsorption ratio) >25 $(\text{meq/liter})^{0.5}$, affecting the crops both by sodium toxicity and by soil structure degradation. Water ponding is often related to structural degradation, reduces the oxygen available for roots, and can also induce plant scalding in the summer. Moreover, irrigation operations become difficult because of the talus instability or piping and the clogging of drainage pipes and trenches.

Table 9 displays the area and the evaluation of every LEU that are mapped in Figure 2. The NVEs in Table 9 allow the comparison of the potential of each LEU for the crop considered. Three kinds of crop behaviors on the LUTs can be distinguished from the NVEs: (1) alfalfa and maize; (2) barley, sunflower, and wheat; and (3) rice. Alfalfa and maize show good yields on LUTs C.1, C.2, and A.2.1, and alfalfa also does well on A1.1; alfalfa yields reach 15–18 Mg/ha, and maize reaches 10–12 Mg/ha. The nonirrigated LUTs A.1.2 and A.2.2 do not allow alfalfa or maize cropping. The soils of other LEUs show different degrees of being affected by salt, and the feasibility of these crops is low. In the second group (barley, sunflower, and wheat) the map units with higher NVE are the same as in the first group, but barley shows good results both on nonirrigated LEUs (A.1.1, and A.2.1) and on saline and saline–sodic soils (D.1, C.4, and C.3). Rice is included in a third group because of its very distinct behavior, with the higher NVE on the irrigated LEU occupying the bottoms and the foot slopes, with poor drainage and with salinity–sodicity.

The index of productive potential (IPP; Table 9)

Table 9. Index of productive potential (IPP) assigned to the land evaluation units (LEU) and numerical value of evaluation (NVE) for the combination of each LEU with six land use types (LUT) determined by the main crops present in Flumen (Aragón, Spain)

| LEU | | Numerical values of evaluation (NVE) of each considered land use type (LUT) | | | | | | IPP[a] | |
|---|---|---|---|---|---|---|---|---|---|
| Map symbol | Extent (km$^2$) | Alfalfa | Barley | Maize | Rice | Sunflower | Wheat | 1 | 2 |
| C.1 | 8 | 75 | 75 | 75 | 50 | 75 | 75 | 70.8 | 75.0 |
| C.2 | 6 | 62 | 75 | 62 | 75 | 75 | 75 | 70.8 | 69.8 |
| A.2.1 | 51 | 75 | 75 | 75 | 25 | 75 | 75 | 66.7 | 75.0 |
| A.1.1 | 12 | 75 | 75 | 37 | 25 | 37 | 75 | 54.2 | 59.8 |
| B.1 | 30 | 50 | 50 | 44 | 62 | 50 | 50 | 51.0 | 48.8 |
| B.2.1 | 107 | 37 | 56 | 37 | 69 | 37 | 56 | 49.0 | 44.6 |
| D.1 | 37 | 44 | 50 | 25 | 81 | 31 | 50 | 46.9 | 40.0 |
| C.4 | 3 | 25 | 50 | 25 | 75 | 25 | 50 | 41.7 | 35.0 |
| C.3 | <1 | 25 | 50 | 25 | 25 | 25 | 25 | 29.2 | 30.0 |
| A.2.2 | 2 | 0 | 50 | 0 | 0 | 50 | 25 | 20.8 | 25.0 |
| A.1.2 | 2 | 0 | 50 | 0 | 0 | 37 | 25 | 18.7 | 22.4 |

[a] 1, IPP obtained considering all LUTs; 2, IPP obtained excluding the LUT rice.

quantifies the potential of each LEU in a scenario determined by the six more extended crops at the present time. If several irrigated areas are evaluated with the same criteria, the GIS allows comparison of the potential and constraints of the irrigated districts or other demarcations. The limitations inherent in the detail of the soil survey must be considered when dealing with small areas, with farms, or with plots. The indices of productive potential presented in this article, or the estimated yields for each combination of LEU and LUT, could be used to regulate the subsides or other policy measures for the considered crops and the LEU delineated on the map.

The making of economic evaluations from these indices requires the incorporation of profitability, prices of outputs and inputs, etc., which is beyond the scope of this study, but the data presented are the technical coefficients needed. Thus, the way is open to use GIS as a tool to simulate the behavior of the irrigated lands under other scenarios of crops, commercial or climatic conditions. For example, Table 9 gives the effect on the evaluation produced by a technology allowing the rice crop on soils unable to maintain other crops: the IPPs rise in those irrigated LEUs that are the worst with the other crops only, except the LEU C.3 that has sodicity problems, but the IPPs decrease in most of the best LEUs. However, the exclusion of the LUT rice in the calculation of the IPP (Table 9) has a negligible effect on the LEUs rank by IPP.

An area of 152 km$^2$, 59% of the whole study area (Figure 3), would be out of agricultural production if land set-asides were applied to the LEUs having an index of productive potential (IPP) less than 50% for the six studied LUTs. Under these conditions, the LEUs to set aside are the nonirrigated enclaves (LEU A.1.2 or structural platforms, and LEU A.2.2 or residual platforms with coarse detrital sediments), LEU C.3 (a salt-affected enclave in the Flumen terrace), LEU C.4 (moderately saline soils in the Flumen terrace), LEU D.1 (bottoms), and LEU B.2.1 (slopes), even if the size of the last LEU would require a more detailed survey allowing the subdivision of this big LEU. The IPP can help to determine the amount of the incentives, and the available information about these soils allows identification of alternative land uses that are environmentally friendly.

## Conclusions

The application of FAO (1976) methodology and the calculation of an index of productive potential (Boixadera and Porta 1991) provide a framework for the ranking of land evaluation units of the study area that were previously drawn from a reconnaissance soil survey. In 59% of the study area the indices of productive potential are under 50%. The lower indices occur in the nonirrigated enclaves, followed by some salt-affected soils.

One land evaluation unit occupies 41.4% of the study area, and its index of productive potential is medium. This fact requires a more detailed soil survey in order to draw smaller units with more distinct indices that may be more suitable for making decisions of land set-asides. Such a survey would make easier the application of the evaluation method, which was formulated for more detailed soil surveys.

The incorporation of rice in the evaluation scenario smoothes the differences in the indices of productive

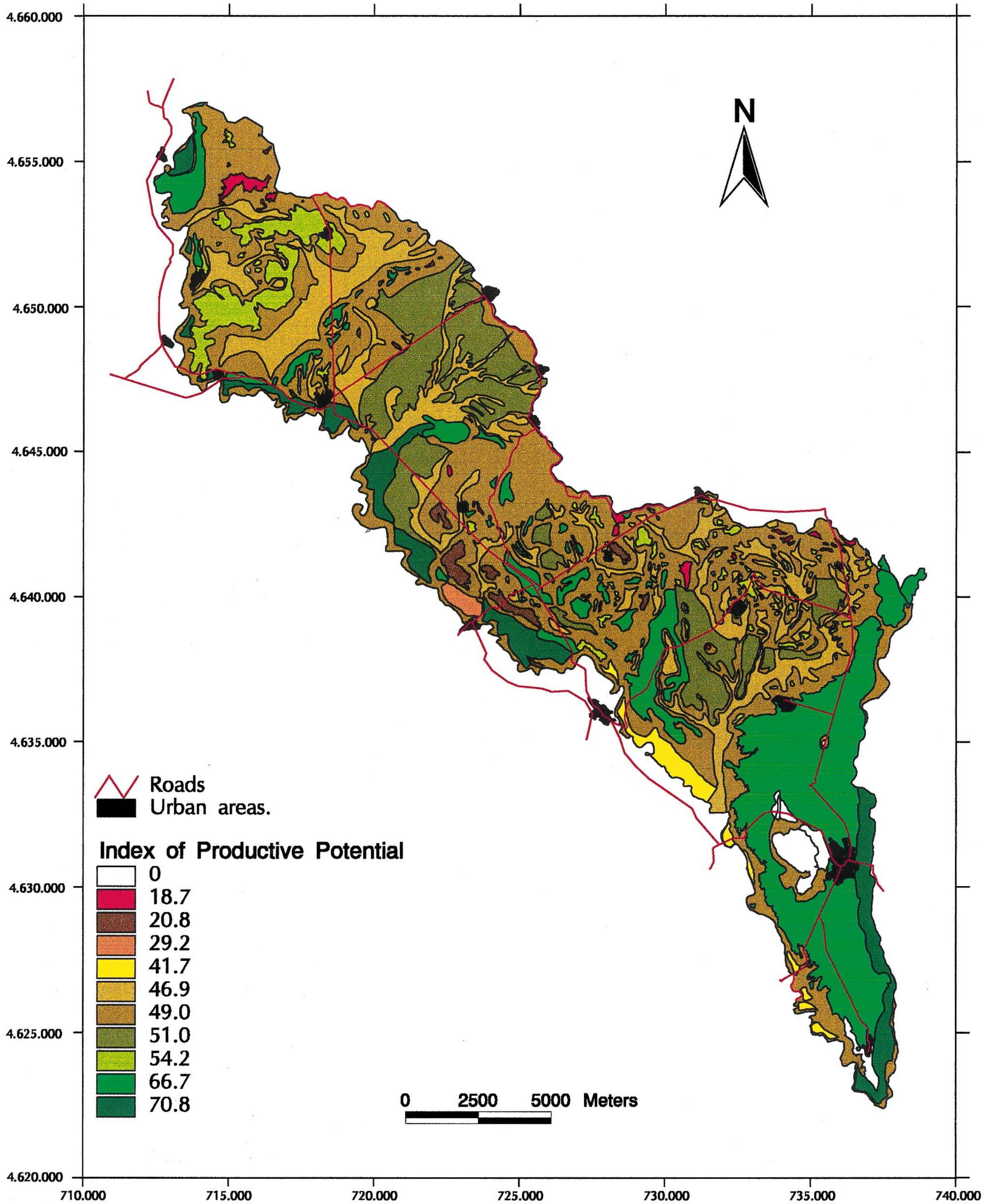

**Figure 2.** Land evaluation units in the Flumen irrigation district (sectors IV–XI) mapped by their index of productive potential (IPP) for six land use types: alfalfa, barley, maize, rice, sunflower, and wheat.

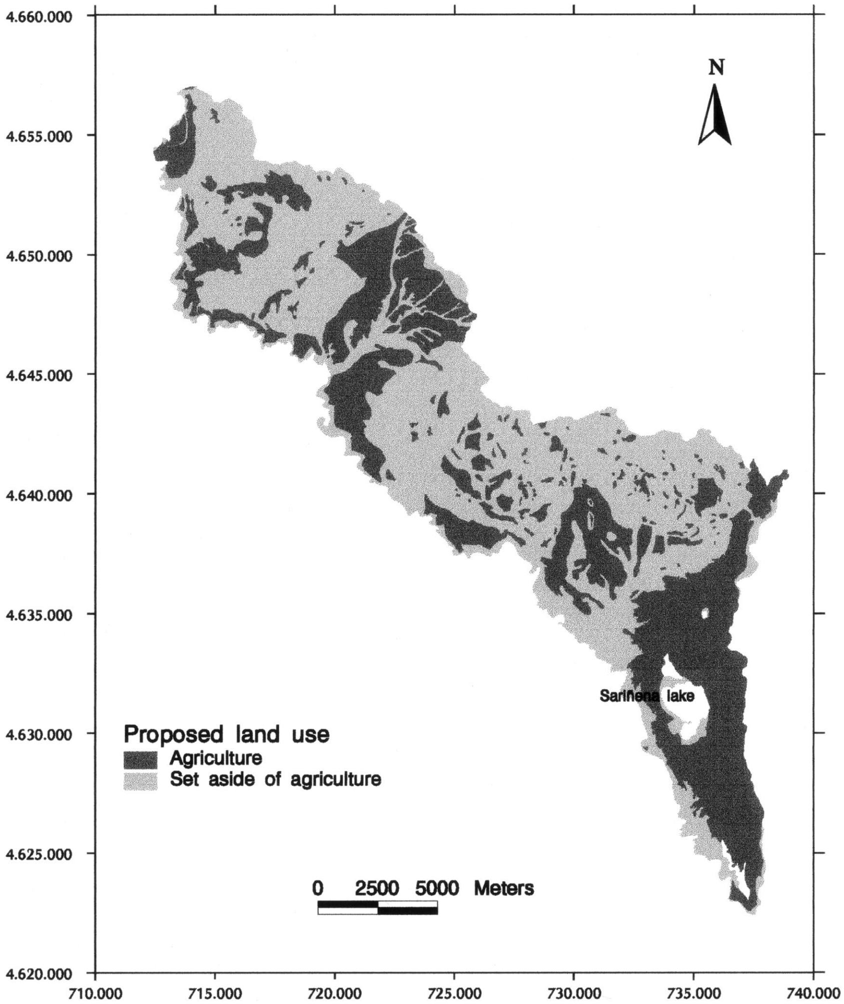

**Figure 3.** Resulting land use if set-aside was applied to the lands having IPP <50% for the six considered land use types.

potentials between the land evaluation units, but the effects on the ranking by productive potential are negligible.

The proposed land evaluation and its incorporation into a geographical information system allows for a rapid quantification of the productive potential of land. The limitations imposed by the intensity of soil surveying and the mapping scale of this work must be remembered in order to avoid the misuse of cartographic information, for example, trying to compare individual farms or plots that are below the maps' resolution.

## Acknowledgments

This work was funded by the Spanish Ministry of Agriculture under project INIA-SC97025. The first author received a fellowship from CONSID (Government of Aragon).

## Literature Cited

Barbosa, P. M., A. Casterad, and J. Herrero. 1996. Performance of several Landsat TM image classification methods for crop extent estimates in an irrigation district. *International Journal of Remote Sensing* 17:3665–3674.

Boixadera, J., and J. Porta (eds.). 1991. Información de suelos y evaluación catastral: Método del valor índice. Centro de Gestión Catastral y Cooperación Tributaria. Ministerio de Economía y Hacienda, Madrid, 151 pp.

Doorenbos, J., and W. O. Pruitt. 1977. Crop water requirements, 2nd ed. Irrigation and Drainage Paper 24. FAO, Rome, 144 pp.

Faci, J. M., and A. Martínez-Cob. 1991. Cálculo de la evapotranspiración de referencia en Aragón. Diputación General de Aragón, Zaragoza, 115 pp.

FAO. 1976. A framework for land evaluation. FAO Soils Bulletin 32. Rome, 66 pp.

Francois, L. E. 1996. Salinity effects on four sunflower hybrids. *Agronomy Journal* 88:215–219.

Goldberg, D., B. Gornat, and D. Rimon. 1976. Drip irrigation, principles, design and agricultural practices. Drip Irrigation Scientific Publications, Kfar Shmaryahu, Israel, 296 pp.

Herrero, J., and R. Aragüés. 1988. Suelos afectados por salinidad en Aragón. *Surcos de Aragón* 9:5–8.

Herrero, J., and A. Casterad. 1999. Using satellite and other data to estimate the annual water demand of an irrigation district. *Environmental Monitoring and Assessment* 55:305–317.

Herrero, J., and R. L. Snyder. 1997. Aridity and irrigation in Aragon, Spain. *Journal of Arid Environments* 35:535–547.

Jarauta, E. 1989. Modelos matemáticos de régimen de humedad del suelo. Aplicación a la determinación de la humedad del los suelos del área meridional de Lleida. Doctoral thesis. ETSII Universidad de Barcelona, 181 pp. + appendices.

Jurinak, J. J., and D. L. Suarez. 1990. The chemistry of salt-affected soils and waters. Pages 42–63, *in* K. K. Tanji (ed.), Agricultural salinity assessment and management, ASCE Manuals and Reports on Engineering Practice No. 71. American Society of Civil Engineers. New York, 619 pp.

McRae, S. G., and C. P. Burnham. 1981. Land evaluation. Clarendon Press, Oxford, 239 pp.

Rhoades, J. D., A. Kandiath, and A. M. Mashali. 1992. The use of saline waters for crop production. FAO Irrigation and Drainage Paper 48. FAO, Rome, 133 pp.

Rossiter, D. G. 1996. A theoretical framework for land evaluation. *Geoderma* 72:165–202.

Soil Survey Division Staff. 1993. Soil survey manual. United States Department of Agriculture Handbook No. 18. Washington, DC, 437 pp.

Soil Survey Staff. 1994. Keys to soil taxonomy, 6th ed. Soil Conservation Service, USDA, Washington, DC, 306 pp.

Taylor, S. A., and G. L. Ashcroft. 1972. Physical edaphology. Freeman. San Francisco, 533 pp.

US Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. L. A. Richards (ed.), USDA handbook No. 60. US Government Printing Office, Washington DC, 160 pp.

WRR (Netherlands Scientific Council for Government Policy). 1992. Ground for choices. Four perspectives for the rural areas in the European Community. Sdu Uitgeverij, The Hague, The Netherlands, 144 pp.