MicroLEIS 2000: Conceptual Framework

Agro-ecological Land Evaluation*

D. de la Rosa

Instituto de Recursos Naturales y Agrobiologia, CSIC, Avda. Reina Mercedes 10, 41010 Sevilla, Spain

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(*) This chapter is an adaptation of the following on-line publication: D. de la Rosa and C.A. van Diepen. 2002. Qualitative and Quantitative Land Evaluations, in 1.5. Land Use and Land Cover, in Encyclopedia of Life Support System (EOLSS-UNESCO). It shows a general view of the present knowledge in the field of biophysical land evaluation. As an introduction to the MicroLEIS system (Appendix A), frequent links are made through the text of this chapter to the correspondent module of MicroLEIS. Sevilla, 2002.
Summary

This paper presents various approaches to analyze the enormous complexity of land resource and its use and management from an agro-ecological perspective. It discusses the effectiveness of land evaluation for assessing land use changes in rural areas. Land evaluation analysis determines whether the requirements of land use and management are adequately met by the properties of the land. Within this framework, land evaluation is considered as the only way to detect the environmental limits of land use sustainability. From the simple or qualitative procedures until the more complex or quantitative methods, the land evaluation analysis is carried out in this paper considering two major phases: development and application.

Regarding methodological development of land evaluation, each stage has had its own focus. Within the development of traditional systems, qualitative assessments depend largely on experience and intuitive judgement, and are real empirical systems. The single-factor systems try to express the influence of individual land characteristics on the performance of the land use system. Arithmetical systems consider the most significant land characteristics and account for interactions between such significant factors by simple multiplication or addition of single-factor indexes. In the statistical systems, correlation and multiple regression analyses are used to investigate the relative contributions of the selected land characteristics on land suitability. As emerging technologies, expert system models express inferential knowledge by using decision trees which give a clear expression of the matching process comparing land use requirements with land qualities. In the fuzzy set methodologies, the rigid boolean logic of land suitability as determined by limiting land characteristics is replaced by fuzzy membership functions. Neural network models have shown good capability in dealing with non-linear multivariate systems as those analyzed in land evaluation. It is pointed out that between dynamic simulation modeling and empirical land evaluation techniques is currently producing a ‘cross fertilization’ of excellent scientific and practical results, improving the accuracy and the applicability of the models. In the hybrid systems, through the linkages of normally two types of models, one simulates the qualitative reasoning functions, while other simulates the quantitative modeling part.

As for the practical automated application of land evaluation systems, this is described as a land use decision support system which makes use of information technologies allowing for linkages of integrated databases and various kind of models. By using land attribute database, data analysis can be greatly facilitated if the basic data are systematically arranged and stored in an ordered format for ready sorting and retrieval. Through computer programs, the land evaluation algorithms are expressed in notation forms that can be understood by a calculating device. The spatialization analysis includes the utilization of spatial techniques to expand land evaluation results from point to geographic areas using soil survey and other related maps. Optimization tools based on land evaluation models are considered very important to formulate decision alternatives, for example, agricultural management practices to minimize threats to the sustainability of farming systems.
1. Introduction

All lands can be used for almost all purposes if sufficient inputs are supplied. The application of inputs can be such that it dominates the conditions in which crops are grown, such as it can be the case in greenhouse cultivation. However, each land unit has its own potentialities and limitations, and each land use its own biophysical requirements. Such external inputs or improvements are expressed in terms of capital, energy or environment costs. In order to minimize these socioeconomic and environmental costs, the main objective of land evaluation is to predict the inherent capacity of a land unit to support a specific land use for a long period of time without deterioration.

Land evaluation, as the assessment of land performance when used for specified purposes, provides a rational basis for land use planning. From an agricultural point of view, the biggest challenge for land use planning is to sustain biophysical land potentiality and, at the same time, to diversify agricultural land use. To avoid a deterioration of the environment, sustainable land use systems must be defined. All the possible options to increase agricultural production: i) expansion of the agricultural land’s surface; ii) introduction of irrigation techniques; iii) use of fertilizers and pesticides; iv) improvement of management practices; and v) use of improved crop varieties; must be based on the results of land evaluation.

Land evaluation creates an ‘interface’ between soil survey and land use planning. It is directly related to soil survey interpretation. Since land is a broader concept than soil, soil survey interpretation and land evaluation are not synonymous, although they are frequently used interchangeably. Soil survey is the initial and obligatory phase of this interpretative process which considers interpretation of the biophysical land attributes and their relation to different socioeconomic aspects. It does not involve economic evaluations, and it specially refers to agro-ecological evaluations. However, land evaluation can have non-agricultural purposes.

Basic information: Land evaluation requires information from different domains: soil, climate, crop and management. Soil surveys are the basic building blocks for developing the comprehensive data set needed to drive land evaluation. Land evaluation is normally based on data derived from soil survey, such as useful depth, soil texture, water capacity, drainage class, soil reaction or landscape (soil and site attributes). Other biophysical factors, mainly referred to monthly or daily climate parameters, are also considered as basic information (climate attributes) (see SDBm: Soil database and CDB: Climate database).

Traditionally, one of the most disappointing aspects of land evaluation has been the scarce relations with other areas in soil and crop sciences. Agricultural management aspects have been only considered as a prerequisite. Now, management factors are being incorporated in land evaluation in response to a growing need for integrating farming information. Although the interactions between biophysical factors: site, soil and climate, and management factors are very complex, new land evaluation procedures are being able not only to predict optimum land use types, but also to define optimum agricultural management practices such as crop rotation, tillage operations, fertilization management and conservation practices. In this last sense, the crop and management data derived from field observation, monitoring or simulation modeling, such as growing season length, rooting depth, tillage operations and residues treatment, are also considered as basic information (see MDBm: Agricultural management database).
Land capability and land suitability: The early land evaluation approaches basically developed the process of estimating the potential of land for general kinds of use. The main application of these land capability approaches has been as a means of identifying good or prime agricultural lands. However, the evaluation of particular kinds of use is an essential development of current land evaluation methodology. These land suitability approaches refer to specific land uses. A conceptual framework on land suitability was developed by FAO (1976), which has been internationally accepted in land evaluation analysis (see Annex 1: Glossary of major terms).

Land suitability and land vulnerability: During the past decade, the land evaluation domain has been broadened from land suitability to land vulnerability. Land suitability (for example referred to crop productivity, natural fertility, land irrigation, soil workability) provides support to production-oriented applications. However, land vulnerability (for example referred to soil erosion, soil salinity, soil contamination, subsoil compaction) focuses on environmental degradation assessment.

Users of land evaluation: It is clear that land evaluation results represent an information framework for establishing decisions that provide the sustainable use and protection of land resources. But who are the people to decide?

Land evaluation based on soil survey data is scale independent, but applications are most often made at regional scales involving a large number of different land units. Thus, evaluations are often focused on regional land use planning rather than on use by farmers as a local decision support system. However, land evaluation can support on regional land use policy making and also on-farm decision making.

At the regional level, traditional land evaluation procedures provide relevant results to the questions of land use planning or regional planners, such as preservation of prime agricultural lands, selection of appropriate engineering and environmental sites for urban development, natural and hazard prediction.

At the farm level, new land evaluation procedures can give responses to farmer questions, such as crop variety to select, date and sowing rate, tillage implement to be used, trafficability conditions. Agricultural extension services must take care of the transfer of soil management information from land evaluation results to the farmers. In advanced agriculture, direct implementation of detailed land evaluation information by farmers is becoming a reality to establish optimum management practices.

Incorporating the sustainability concept: The term ‘sustainability’ is generally used to indicate the limits placed on the use of ecosystems by man. Obviously, land evaluation touches on different aspects of sustainability as it focuses on one important natural resource: the land. New land evaluation procedures estimate land use and management not only in terms of production efficiency but also in terms of its impact on the environment. The simultaneous consideration of both criteria: suitability and vulnerability, can define sustainability in the conceptual sense that a sustainable or an optimum land use system includes maximum land suitability and minimum land vulnerability. In other words, the fundamental purpose of land evaluation is to predict the positive or negative consequences of change (Figure 1).

Within the context of environmental protection efforts made by the European Environment Agency (EEA, 1999) for policy support, and in order to incorporate the sustainability concept in land evaluation analysis, progress can be also made following the general ‘DPSIR framework’ (Figure 2). Where:
D-Driving forces: the human activities causing an environmental problem;

P-Pressures: the level and source of the pressure;

S-State: the extent of the current problem, e.g. amount of soil erosion, soil contamination;

I-Impacts: the effects of the problem on creating further problems, e.g. land productivity loss, biodiversity loss;

R-Responses: strategies accommodation to solve or minimize the problem.

**Figure 1.** General scheme of the land use and management sustainability through the simultaneous prediction of land suitability and land vulnerability as can be considered in the land evaluation process.
In a framework similar to that of DPSIR, many approximations have been made from land evaluation to assess the impacts of continuing land degradation rates for extended periods of time on land productivity. For example, the rate of change of the relative productivity of soils due to soil erosion has been calculated on the basis that favorable rooting characteristics are present in the soil profile. As erosion removes the upper soil profile, productivity will decline if the subsoil is limiting for crop growth. The effect of diminishing soil organic matter and nutrient contents, plant population reduction, etc. on crop productivity has not been considered in this kind of evaluation analysis. However, these additional considerations are important in assessing the over-all effects of soil erosion such as environmental indicators (see *ImpelERO model: Prediction of soil loss, impacts and optimum management*).
2. General Procedure

The inductive analysis of land evaluation includes two main phases: development and application. The development phase is carried out with basic information from representative areas, while the application phase is implemented in basically unknown scenarios (Figure 3). The development of algorithms in the first phase involves the following stages:

- **selection** of land attributes: land qualities and associated land characteristics;

- **definition** of relevant land use requirements: response of the land use or level of the degradation;

- **comparison** of the land attributes to land-use requirements: identifying cause-effect relationships through narrative statements, matching tables, response curves, rating indexes, decision trees, weighting factors or comprehensive models; and

- **formulation** of algorithms of application.

The comparison or matching stage forms the basis for assessing the suitability of the land for a particular use. This interpretation process is often difficult and subjective because of a lack of knowledge on the performance of the land of a combination of non-ideal but possibly satisfactory land qualities and characteristics. In general terms, from qualitative methodologies, developments in land evaluation are increasingly directed at measurement and calculation of aspects of land and land-use, and at mathematical description of processes and interactions.

The land evaluation development phase represents the major part of this article, and the application phase is considered from the possible automatic procedures used. According to the comparison procedure followed, from qualitative narrative statements to quantitative comprehensive models, the land evaluation development is considered in this work.
The development phase is separated from the application phase. Based on the information and knowledge from the representative zone, the development phase includes the following basic steps: i) selection of land characteristics and land qualities to be considered; ii) definition of the most important land use requirements; iii) comparison between land qualities and land use requirements through simple qualitative expressions, evaluation tables, response curves, indexes, decision trees, weight factors, or complex models; and iv) formulation of algorithms which facilitate the application of the developed evaluation system. The application phase is carried out in unknown scenarios, representing an extrapolation of the detailed knowledge from the reference representative zone.
3. Traditional Systems

3.1. Qualitative Assessments

Qualitative land evaluations may be as simple as narrative statements of land suitability for particular uses, or they may group lands subjectively into a small number of classes or grades of suitability. In many qualitative approaches a formal quantification is achieved by the application of the rule that the most limiting land quality determines the degree of land suitability. This assumes knowledge on optimum land conditions and on the consequences of deviations from this optimum. These relatively simple systems of land evaluation depend largely on experience and intuitive judgement, these are real empirical systems. No quantitative expressions of either inputs or outputs are normally given.

Probably the first qualitative classification of soil productivity was developed by Whitney at the beginning of the 20th century in the grouping of the soils of the United States into three agricultural ranks plus a non-agricultural group. He recognized that actual yields depend on management and economic factors as well as soils, and tried specifically to rate soils on their potential, regardless of present use. No specific criteria for determining the rank of a soil were given.

The ‘USDA Land Capability System’ evolved by the Soil Conservation Service of the US Department of Agriculture (1961) provides conceptual definitions of capability classes according to the degree of limitation to land use imposed by land characteristics on the basis of permanent properties. This system and its adaptations, such as the British Land Use Capability Classification (1969), the Canadian Land Capability Scheme (1970) and the Dutch system (1975), have been widely used around the world; and practically all soil survey reports in the USA contain a section on land capability following this methodology, meant for use by advisory and planning agencies.

In the approaches to express qualitatively land suitability classes for a given particular land use, according to the principle of maximum limitation factor, simple matching tables as the following are used:

<table>
<thead>
<tr>
<th>Suitability class</th>
<th>Soil depth, cm</th>
<th>Texture</th>
<th>Salinity, mS/cm</th>
<th>Slope, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1. Very high</td>
<td>More than 120</td>
<td>Medium</td>
<td>0 to 2</td>
<td>0 to 3</td>
</tr>
<tr>
<td>S2. High</td>
<td>60 to 120</td>
<td>Medium to Heavy</td>
<td>2 to 4</td>
<td>3 to 8</td>
</tr>
<tr>
<td>S3. Moderate</td>
<td>30 to 60</td>
<td>Medium to Coarse</td>
<td>4 to 8</td>
<td>8 to 15</td>
</tr>
<tr>
<td>S4. Low</td>
<td>15 to 30</td>
<td>Coarse</td>
<td>8 to 10</td>
<td>15 to 30</td>
</tr>
<tr>
<td>N. Not suitable</td>
<td>Less than 15</td>
<td>Very Heavy</td>
<td>More than 10</td>
<td>More than 30</td>
</tr>
</tbody>
</table>

Refinements are possible by making the suitability class ratings dependent on more than one limiting land characteristic. This leads to more complex rating tables or diagrams.
3.2. Single-factor Systems

As a first step of the quantitative trend in land evaluation, the single-factor systems try to quantitatively express the influence of individual land characteristics on the performance of land use. These schemes are best where a single land characteristic has an extreme positive or negative effect on a proposed land use, such as for example ‘soil depth’ on crop productivity. ‘Soil depth’ is positively correlated to crop production, strongly so when the soil is shallow and tending to an asymptote when the depth approaches the rooting depth of the crop. An interpreting response curve to quantitatively express the sufficiency of the individual factor ‘soil depth’ on crop production could be as shown in Figure 4.

In this case,

\[ Si = 1 - e^{-xS} \]  \hspace{4cm} (1a)

where \( Si \) is the soil depth index, on a scale from 0 to 1; \( x \) is a crop-specific coefficient, in cm\(^{-1}\); and \( S \) is the soil depth, in cm. The value of coefficient \( x \) has been 0.02 cm\(^{-1}\) which could be specific for forest trees. All relations and the values of all coefficients used are to be established or validated by field experiment.

A logical refinement of this response curve could be formulated on the basis of the assumption, that a minimum soil depth is required before production can take place. If a threshold value of 20 cm is considered as minimum soil depth, the equation (1a) can be modified to:

\[ Si = 1 - e^{-x(S-20)} \]  \hspace{4cm} (1b)

valid for \( S>20 \) cm and \( Si=0 \) for \( S<20 \) cm.
Figure 4. Typical response curve of the single-factor systems. In this example, the curve transforms the values of the land characteristic: useful soil depth in soil suitability indexes for a given crop.

Although these systems do not take into account the combined effects of two or more land characteristics, the calculated values for few significant single land characteristics can be combined to generate a suitability index (see Terraza model: Bioclimatic limitation).

3.3. Arithmetical Methods

Halfway between qualitative and quantitative methods semi-quantitative land evaluations may be distinguished, which are derived from the numerical inferred effects of various land characteristics on the potential behavior of a land use system. Arithmetical or parametric methods can be considered as a transitional phase between qualitative methods that are entirely based on expert judgment, and standard mathematical models. Arithmetical systems consider the most significant factors and account for interactions between such significant factors by simple multiplication or addition of single-factor indexes.

Multiplicative systems assign separate ratings to each one of several land characteristics or factors, then take the product of all factor ratings as the final rating index. These systems have the advantage that any
important productivity factor controls the rating. Another advantage is that the overall rating can not be a negative number. One limitation is that the overall rating may be considerably lower than the ratings of each one of the individual factors.

The first and most widely known effort to spell out specific, multiplicative criteria for rating soil productivity inductively was developed by Storie (1933). The original Storie Index Rating ($SIR$) was calculated by multiplying together separate ratings for profile morphology ($A$), surface soil texture ($B$), slope angle ($C$) and modifying conditions such as soil depth, drainage or alkalinity ($X$).

$$SIR = A \cdot B \cdot C \cdot X$$

(2)

Storie made it quite clear that the factor ratings he provided were to be taken as guides rather than absolute values and that the ratings were to be changed as soil scientists gained experience with the index.

The USLE-type systems, basically the Universal Soil Loss Equation (USLE) and its revisions: the Modified Universal Soil Loss Equation (MUSLE) and the Revised Universal Soil Loss Equation (RUSLE), have a very similar form to that of the Storie Index and is also operated by multiplying the factor values.

In the additive systems, several land characteristics are assigned numerical values according to their inferred impact on land-use. These numbers are either summed up or subtracted from a maximum rating of 100 to derive a final rating index. Additive systems have the advantage of being able to incorporate information from more land characteristics than multiplicative systems. Four or five factors appears to be a practical limit for multiplicative systems; otherwise most ratings are so low that the approach can not distinguish small differences in response. Additive systems allow the consideration of many more criteria, both singly and in combination with the effects of other factors. Other advantages are that no single factor can have enough weight to unduly influence the final rating, and it is generally easier to exactly specify the criteria for unambiguous determination or factor values and land performance ratings.

Limitations of additive systems stem from their complexity. As the number of factors evaluated increases, so does the difficulty in juggling factor ratings so that the final ratings derived for a number of lands or soils are all realistic. Other limitation is the possible calculation of negative ratings.

Combined methods specially for rating soil productivity utilize both additive and multiplicative procedures. Most combined methods use additive processes to derive single-factor ratings, then multiply single-factor ratings together to derive final rating indexes. Also, the sufficiency of each selected single factor used to be judged by interpreting response curves, and then utilized multiplicative procedures to get the final index. The major advantage of these systems is the ability to incorporate information from several selected factors without minimizing the impact of one or two major limitations and without generating ratings which are unrealistically low or even negative. The major limitation can be its complexity which is higher than that of simple multiplicative systems. Most of the combined methods were derived from Storie’s original multiplicative concept.

3.4. Statistical Systems

In land evaluation, statistical systems are powerful methods for predicting land suitability on the basis of selected land characteristics. Correlation and multiple regression analyses have been used to
investigate the relative contributions of selected land characteristics. Where suitable basic and response data are available, statistical models can provide the basis for objective ratings of land attributes.

The land suitability or response variable $Y$ is analyzed as a function of the type:

$$ Y = \Phi (X_1, X_2, \ldots, X_n) + \epsilon $$

(3)

where $X_n$ corresponds to the selected land characteristics or independent variables (e.g. soil depth, clay content, organic matter, caption exchange capacity, pH, sodium saturation, etc.), and $\epsilon$ measures the residual. As the mathematical form of the $\Phi$ is not known, this function can be approximated satisfactorily, within the experimental scenario, by a polynomial equation. The calibration of this polynomial model can be treated statistically as a particular case of multiple regression. The regression coefficient ($R^2$) facilitated by this analysis represents an inductive validation index of the model corresponding to the accounted for the percentage of the observed variation.

In the development of these systems, the correlation analysis provides a convenient starting point in the selection of $X$-variables, according to their simple effects on the $Y$-variable; as well as the possible interactions between independent variables (see Albero model: Crop production).

This methodology has been specially used to predict soil productivity for major crops. Competent statisticians, agronomists and soil scientists must work together to develop polynomial regressions to benefit from such statistical analysis. However, in soil survey interpretations for engineering uses statistical relationships are often used to estimate certain geotechnical properties of soils, (e.g. plasticity, compaction and water status), from pedological characteristics (e.g. clay content, organic matter, bulk density). In this last case, it is better to speak of pedo-transfer functions rather than of land evaluation systems.

4. Emerging Methodologies

The current progress in information technology is making possible the application of many different modeling techniques to the most complex systems. These more complicated methods facilitate the enhancement of the quantitative trend of land evaluation analysis. Models are a simplified representation of the real world which can be expressed in a wide variety of forms such as conceptual diagrams, classification systems, statistical or deterministic mathematical models. In land evaluation, the empirical expert modeling has moved from simple statistical models to others which are more sophisticated and based on artificial intelligence techniques. However, process-oriented modeling which specially simulates crop growth follows a different path and is deterministic (through mathematical equations) and based on an understanding of the actual mechanisms of plant growth.

Other kinds of models related with the land evaluation are the spatial interpolation models which deal with the spatial variability in land characteristics; and the integrated models which combine the results of biophysical land evaluation with a range of alternative goals such as maximizing economic return or conserving a landscape or a habitat.
4.1. Expert System Models

The expert systems, as a sub-field of artificial intelligence, are computer programs that simulate the problem-solving skills of one or more human experts in a given field and provide solutions to a problem. These systems express inferential knowledge by using decision trees. In land evaluation, decision trees give a clear expression of the matching process, comparing land use requirements and land qualities. The better the knowledge, the better the performance of the expert system. The expert decision trees are based on the scientific background (theoretical description) and results of experiences and discussions with human experts (practical experience), and thereby reflect available expert knowledge.

Decision trees are hierarchical multiway keys in which the leaves are choices (classes/ranges), such as land characteristic generalization levels, and the interior nodes of the tree are decision criteria, such as land quality severity levels or land suitability classes. As shown in the example of Figure 5, the decision trees visualize the sequence of decisions being made in a clearer fashion than traditional matching tables.
Figure 5. Decision tree formulated for rating the land characteristics: textural class, soil salinity, pH and cation exchange capacity, associated with the land suitability class for a particular crop.
Where suitable practical experience data are available, statistical decision trees analysis can be used to generate land evaluation models with good prediction rates when the assumptions for other statistical models are not met. These classification and regression trees are designed to deal with a low ratio of number of observation to number of variable typical of soil and land resource surveys. This analysis is an iterative process of identifying attributes that are critical for the description of the response variable. The limiting factor model that is developed can be presented graphically as a tree diagram (Figure 5) or as a rule based system in a computer program.

Usually both expert system procedures: theoretical decision trees and statistical decision trees, are used in order to optimize the results (see Raizal model: Soil erosion risk; and Pantanal model: Specific soil contamination risk).

The Automated Land Evaluation System (ALES) is a computer program that allows land evaluators to build expert systems to evaluate land unit according to the method presented in the FAO Land Evaluation Framework. Evaluators can build their own expert system with ALES, taking into account local conditions and objectives. ALES is not an expert system by itself, and does not include any knowledge about land and land use. It is a shell within which evaluators can express their own local knowledge. The choosing of land qualities and associated land characteristics for a given land utilization type, which is a crucial activity in land evaluation, is not facilitated by this shell (see Arenal model: General soil contamination risk).

4.2. Fuzzy Set Methodologies

In general terms, the traditional land evaluation systems follow a boolean or rule-based approach adapted following the principle of maximum limitation factors. There is a growing awareness of this methodology’s failure to incorporate the inexact or fuzzy nature of much of the land resource data. In recent years there has been marked interest in the use of fuzzy set methodology in land evaluation.

The use of this methodology in land evaluation is of particular importance in those cases where the impact of one land characteristic, which has a value just outside a specified range, can be minimized. The rigid boolean logic of land suitability as determined by limiting land characteristics is replaced by fuzzy membership functions. Individuals which exactly match strictly defined classes are assigned a membership value (MF) of 1. Individuals falling outside the defined class range are given a membership value (0.0 < MF < 1.0) depending on their degree of closeness to the defined class. Fuzzy set methodology is a refinement of Boolean logic which has only two possibilities of membership: full (MF value 1) or none (MF value 0). Land characteristics which are given in classes are converted to a grade of membership, depending on the values of the characteristics.

The overall suitability assessment of land units has to be based on a weighting factor of the relevant land characteristics. The Joint Membership Function (JMF) provides a weighted sum of the different land characteristics (A, B, … Z).

\[ JMF = a_A MF_A + a_B MF_B + \ldots + a_Z MF_Z \] (4)
and

\[ a_A + a_B + \ldots + a_Z = 1 \]  

The choice of weights \((a_A, a_B, \ldots, a_Z)\) is of critical importance. This can be obtained on the basis of expert knowledge and local advice, experimental data, previous land evaluation methods, etc.

The use of strict boolean algebra with simple true/false logic in combination with a rigid, exact model is often inappropriate for land evaluation because of the continuous nature of soil variation, the uncertainties associated with describing the phenomenon itself or in the measurements made on it, or because of inexactness in formulating queries. In any case, land evaluation using the fuzzy set methodology is subject to data and knowledge limitations in just the same way as other methodologies.

### 4.3. Neural Network Models

Interest in neural networks has grown rapidly over the last few years. These artificial intelligence-based technologies have shown good capability in dealing with non-linear multivariate systems. Also, they have been shown to discriminate quite well between actual data and noise and to have generalization ability, i.e. they can process input patterns never presented before, in much the same way as the human brain does. Recently, connections have emerged between artificial intelligence and its applications in engineering, agricultural and environmental sciences.

An artificial neural network is a computational mechanism that is able to acquire, represent and compute a weighting or mapping from one multivariate space of information to another, given a set of data representing that mapping. Neural networks can identify subtle patterns in input training data, which may be missed by conventional statistical analysis. In contrast to regression models, neural networks do not require a knowledge of the functional relationships between the input and the output variables. Moreover, neural networks are non-linear, and therefore may handle very complex data patterns which make mathematical modeling unattainable. Another advantage of neural networks is that all kinds of data: continuous, near-continuous and categorical or binary, can be input without violating model assumptions, as well as the ability to model a multi-output phenomena.

**Figure 6** shows an example of the correlation-cascade neural network developed to relate land qualities (LQr=runoff erosivity, LQt=relief hazard, LQk=soil erodibility) and management qualities (MQc=crop protection, MQz=tillage translocation and MQy=productivity influence) to a vulnerability index (Vi) of soil erosion (see *ImpelERO model: Prediction of soil loss, impacts and optimum management*).
Figure 6. Structure of a neural network showing the interrelationships between the land and management qualities: $LQ_r=$Rainfall erosivity, $LQ_t=$Relief factor, $LQ_k=$Soil erodibility, $MQ_c=$Crop protection, $MQ_z=$Tillage effect, and $MQ_y=$Productivity influence, to reproduce the vulnerability index ($Vi$) of soil erosion

Once the training and testing phases of the neural network analysis are found to be successful, the generated algorithm can be easily put to use in practical application.

4.4. Dynamic Simulation Models

Dynamic simulation models describe quantitatively biophysical processes that play a role in agro-ecosystems, such as crop growth, the soil water balance, leaching of nutrients, or soil erosion. The models are applied in land evaluation to quantify crop production, effects of drought, nutrient losses and of soil erosion under various land use and management options. When applied over several land units and over several years, the model output represents a consistent data set with average values and their variation over
areas and years. The model output can be used as land performance index, or as technical coefficients of line use systems in a next step of data processing.

The greatest limitations to apply models is that they are data-hungry, requiring excessive amounts of input data, and that they are difficult to calibrate and validate in new agro-ecological environments. Dynamic simulation modeling and empirical land evaluation techniques are currently producing a ‘cross fertilization’ of excellent scientific and practical results, improving the accuracy and the applicability of the models. The simulation models do not capture all aspects considered in land evaluation, but what they do not consider does not vary greatly with time, such as rockiness, relief or natural fertility. However, simulation models can provide quantitative information specially on the soil water regime and how it effects crop performance. Dynamic analysis adds an extra dimension to land evaluation: the temporal variability of line use requirements and land qualities.

The simulation modeling specially referred to soil/plant-grown/contamination systems is relatively well advanced at the local scale (e.g. process measurement sites, experimental stations, small catchments), but extrapolation to a regional scale is still a major priority. This extrapolation can be made i) by scaling-up techniques, developing a linkage between the input variables included in the models and information contained in soil survey databases through the development of pedo-transfer functions; or ii) by empirically based land evaluation techniques, combining the results of representative applications of the simulation models and soil survey database information, through the development of meta-models.

4.5. Hybrid Systems

In the hybrid systems, through the linkages of normally two types of models, one simulates the qualitative reasoning functions, while the other simulates the quantitative modeling part.

For example, a hybrid approach demonstrates that simulation modeling results can fit well into expert systems for assessing crop production. A mix model was obtained in a decision tree of branches based on qualitative data combined with branches using quantitative data obtained by simulation. Simulation of the soil water regime provided quantitative data for several of the land qualities being distinguished. This simulation modeling/expert system approach should be preferred to simple qualitative estimates, although not all land qualities can be necessarily characterized by simulation modeling.

Other hybrid systems have been developed using expert decision trees and artificial neural networks for assessing soil erosion risk. The example of Figure 7 expert/network approach offers excellent performance in modeling the complex soil erosion problem, and very good quantification and generalization capability for prediction. According to the sensitivity and validation analysis, this mix model recognized the main interrelationships of the input parameters, and could reproduce the soil erosion vulnerability accurately (see ImpelERO model: Prediction of soil loss, impacts and optimum management).
5. Decision Support System

The application phase of land evaluation systems is implemented basically in unknown scenarios. It is a scaling up process going from the representative areas of the development phase to these unknown application scenarios (Figure 3). The application phase previously done manually, can now be executed by computer-assisted procedures. Emerging technology in data and knowledge engineering provides excellent possibilities in the land evaluation application process. This basically involves the development and linkage of integrated databases, computer programs and spatialization tools, which along with the land evaluation models previously described, constitute decision support systems (Figure 8). In general terms, the decision support systems integrate and organize all types of information required for a decision to be taken.

Figure 7. Hybrid land evaluation model using decision trees to relate land characteristics (LCs) and land qualities (LQs), and neural network to relate land qualities and land vulnerability index (Vi).
Figure 8  General scheme of a decision support system for land use planning and management. This system includes: i) a set of attributes databases (RDBMS) and a set of geographic databases (GIS) to facilitate the input data used by the models; ii) a set of computer programs corresponding to the land suitability and vulnerability evaluation models; and iii) a set of tools to show the evaluation results, including the optimisation algorithms and allowing to use the evaluation results for land use planning (regional scale) or for optimum management recommendations (local scale).
5.1. Land Attributes Databases

For applying land evaluation systems, data analysis can be greatly facilitated if the basic data are systematically arranged and stored in an ordered format for ready sorting and retrieval. Computer-based land information systems consist of an attribute part manipulated by Relational Database Management Systems (RDBMS) and a geometric component handled by Geographical Information Systems (GIS).

The major land attributes used in land evaluation correspond to the following factors: soil/site, climate, and crop/management. The development of databases to facilitate the integrated use of these attributes represents a critical point. The multilingual database SDBm Plus is a good example of geo-referenced soil attributes database for storage and retrieval of morphological and analytical soil profile data. This database is equally useful for storage of primary soils information assembled at a national level, or for temporary storage of data accumulated during a particular mapping or soil survey exercise at a local level. It can be utilized regardless of scale, at regional, national or farm level. Between other facilities, SDBm Plus has a soil layer generator option which allows outputs to be used in land evaluation models for practical application, as part of a total land use decision-making support system (see SDBm Plus: Multilingual soil profile database).

5.2. Computer Programs

When the land evaluation algorithms are expressed in notation forms that can be understood by a calculating device, the algorithms become ‘computer programs’. In order to put the land evaluation systems to use in practical applications, i.e. to automate the land evaluation models application, a computer program listing is developed. A user-friendly front-end is developed which allows the model to be easily applied. These user interfaces basically had the following major characteristics: i) connection with the basic attribute and geometric databases; ii) ‘pop up’ screens showing codes, types and classes of input variables; iii) individual and batch processing modes; iv) hypothetical scenario predictions; and v) links to output results with geometric databases. In addition, these computer programs are largely self explanatory.

Recently, the computer programs for automated land evaluation systems are being implemented on Internet through a WWW server, so that the user can apply these systems via a Web browser. These WWW applications open to the public offer several advantages, such as their use by many peoples thus allowing for their usability check in order to improve the systems. The upgrades are made directly on the WWW server and immediately made ready for users.

5.3. Optimization Tools

Land evaluation decision support systems for policy-makers and land users focus on choosing optimal use and management decisions. In this sense, optimization tools based on land evaluation models are very important to formulate decision alternatives, for example, agricultural management practices to minimize threats to the sustainability of farming systems. Agricultural management operations according to spatially varying land characteristics have the added difficulty of trying to satisfy multiple, and often
opposing, objectives: the best soil conditions for plant growth may not be the best for erosion or pollution concerns.

In the example of Figure 9, on the basis of an expert system/neural network model, a computerized procedure was followed to find an adequate combination of management practices to minimize soil erosion. As a first step and for one particular land unit, the user can establish a percentage of vulnerability reduction (R) of the actual vulnerability index (Va) in order to calculate the target vulnerability index (Vt). As a second step, applications of the neural network were made in order to calculate the vulnerability index (Vj) which is closer to the target index. Then, the combination of management qualities (MQs) which corresponds to the Vj was selected. As a third step, the decision trees were backtracked by using the selected combination of MQs to finally formulate the optimum management strategies (see ImpelERO model: Prediction of soil loss, impacts and optimum management).
Figure 9. Structure of an optimization tool to formulate sustainable agricultural management practices based on a hybrid system (expert system and neural network) of land evaluation.
5.4. Spatialization Analysis

In a deeper stage of the scaling up process of the land evaluation application phase, the spatialization analysis includes the utilization of spatial techniques to expand land evaluation results from point to geographic areas using soil survey and other related maps. The use of geostatistical techniques and geographical information systems (GIS) leads to the rapid generation of thematic maps and areas estimates, and enables many of the analytical operations to be carried out in a spatial format, by combining different sets of information in various ways to produce overlays and interpreted maps. Also, digital satellite imagery can be incorporated directly into many GIS packages. This technology is already a prerequisite for managing the massive data required for land evaluation.
6. Perspectives

Now, it is generally accepted that future changes of land use and management will be required if we are to:
- move towards sustainable land use systems;
- reduce the present rates of land degradation; such as soil erosion, salinisation, acidification, eutrophication, nutrient loss, soil and water contamination, bio-diversification loss;
- manage land-based greenhouse emissions and establish carbon sinks;
- provide explicit basis for quantifying greenhouse gases emission from agricultural production, and establish the size of potential carbon sinks under various policy scenarios.

These changing land uses and management practices to be actually fitting to the potentialities and limitations of each land unit, must be based on land evaluation results, in order to estimate its suitability and vulnerability. In the near future, it will be much clearer that agro-ecological land evaluation is the correct way to answer the whats, whys and hows of moving towards sustainable rural development.

Although the new development and application needs in land evaluation must be considered local-specific, some general trends can be indicated. In this sense, it is clear that the developing information and communication technologies will be powerful tools in incorporating new information sources (e.g. satellite images, digital elevation models), extracting maximum value from data (e.g. Internet-accessible databases and sophisticated modeling techniques) and increasing the availability of the end products (e.g. low-cost spatial viewers). The current quantitative trend in land evaluation will be much faster in the near future.

New development procedures in land evaluation will make special emphasis on:
- simultaneous determination of suitability (production oriented aspects) and vulnerability (environmental aspects) as the best way to incorporate the sustainability concept;
- also, the accuracy and applicability of the models will be a major priority, along with mixed qualitative/quantitative approaches. The development of pedo-transfer functions will be necessary to get the maximum applicability of accurate models.
- Integrated methods combining information on the suitability and vulnerability of the land resources with information on socio-economic aspects will also be of frequent use.

New application procedures will respond to more sophisticated approaches with:
- geo-referenced inventories and monitoring of soil and related attributes and land use/management systems. As land use is dynamic and land evaluation is specially interested in the changes, a future challenge will be to improve the efficiency of land use data set maintenance and update. The identification of representative areas, whether high-potential areas or critical problem areas, for more detailed inventories (medium- or large-scale maps);
- integration of geo-referenced databases, evaluation models and results presentation, generating maps of land use options or alternatives, through land use and management decision support systems.

Another trend that appears to continue is the conversion of land evaluation results into legislative instruments, e.g. for good agricultural practices or environmental legislation.
Increasing needs for trained specialists, which requires big efforts in land evaluation education, especially so in land survey, land degradation, use types and management practices, along with information technology-related fields.
Recommended Bibliography


Storie R.E.(1933). An Index for Rating the Agricultural Value of Soils. *California Agricultural Experimental Station Bulletin*, 556. [This report illustrates the first and most widely known effort to spell out specific, multiplicative criteria for evaluating soil productivity]


includes a set of eleven papers, presents the development and application of mixed qualitative/quantitative land evaluation methods for agricultural purposes]


Appendix A. Current Content of MicroLEIS: Integrated system of agro-ecological land evaluation in Mediterranean regions

Introduction
Conceptual framework 33 pp

Inf&Kno. Information and Knowledge Databases

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SDBm Plus: FAO-CSIC Multilingual soil database 156 pp
CDBm: Monthly climate database 38 pp
MDBm: Agricultural management database 106 pp
Datasets: Soil, climate and management data 213 pp

Pro&Eco. Production and Ecosystem Modelling

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Terraza model: Bioclimatic deficiency 10 pp
Cervatana model: General land capability 9 pp
Almagra model: Agricultural soil suitability 11 pp
Albero model: Crop yield prediction 6 pp
Sierra model: Forestry land suitability 9 pp
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Ero&Con. Erosion and Contamination Modelling

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Pantanal model: Specific soil contamination risk 21 pp
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Imp&Res. Impact and Response Simulation

ImpelERO model: 26 pp
Submodel #1: Prediction of soil loss
Submodel #2: Impact on crop productivity
Submodel #3: Accommodation of management practices
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Annexes

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