QUALITATIVE AND QUANTITATIVE LAND EVALUATIONS

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Keywords: agro-ecological system, artificial intelligence techniques, biophysical requirements, data and knowledge engineering, environmental impact, land productivity and vulnerability, land resources planning and management, soil survey, soil survey interpretation

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Publication on line: D. de la Rosa and C.A. van Diepen. 2002. **Qualitative and Quantitative Land Evaluation**, in 1.5. Land Use and Land Cover, in *Encyclopedia of Life Support System (EOLSS-UNESCO)*, Eolss Publishers. Oxford, UK. [http://www.eolss.net]

Summary

Land evaluation operated in a traditional or modern system can focus on qualitative or quantitative aspects. Traditional systems are most often qualitative assessments depending largely on experience and intuitive judgement; they are real empirical systems. Parametric systems allocate a numerical value on the most significant land characteristics, and the account for interactions between such significant factors are expressed through a simple multiplication or an addition of single-factor indexes. In statistical systems, correlation and multiple-regression analyses are used to investigate the relative contributions of the selected land characteristics on land suitability. The single-factor systems try to quantify the influence of individual land characteristics on the performance of the land-use system.

Within modern technologies, expert-system models express inferential knowledge by using qualitative decision trees giving a clear expression of the matching process comparing land-use requirements with land qualities. In 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 nonlinear multivariate systems as those analyzed in semiquantitative land evaluation.

It is pointed out that there is a current “cross fertilization” between quantitative simulation modeling and qualitative land evaluation techniques, leading to excellent scientific and practical results and gradually improving the accuracy and the applicability of the models. In hybrid systems, the linkages between two types of models simulate both the qualitative reasoning functions and the quantitative modeling part. Finally, the practical automated application of land evaluation systems is described as a land-use decision support tool, which makes use of information technologies allowing for linkages of integrated databases and various kind of models. Land-attribute databases, computer programs, optimization tools, and spatial analysis are reviewed as essential parts of land-use planning.

1. Introduction

In biophysical land evaluation analysis and land performance assessment, there are two major trends: qualitative and quantitative. In general terms, a land evaluation system is considered qualitative when in its development the values of diagnostic properties define categories. The system is considered quantitative when these values are combined mathematically to give an index on a sliding scale.

Qualitative land evaluations may be as simple as narrative statements of land suitability for particular uses, or they may group the land in a subjective way into a small number of categories or suitability classes. This assumes a thorough knowledge of the optimum land conditions and of the consequences of the deviations from this optimum. These relatively simple systems of land evaluation depend largely on experience and intuitive judgement and are, therefore, real empirical systems. No quantitative expressions of either inputs or outputs are normally given.

Arithmetical or parametric methods are considered as a transitional phase between qualitative methods, which are entirely based on empirical expert judgements, and standard mathematical models that would be the real quantitative systems. The statistical models can be also considered as semiquantitative methods.

Current progress in information technology has given opportunities for the application of many different modeling techniques to the most complex systems. These newly emerging methodologies facilitate the enhancement of the quantification and integration trends of land evaluation analysis. Empirical expert modeling has moved from simple statistical models to other more sophisticated ones, based on artificial intelligence techniques. Also, the process-oriented modeling which simulates crop growth following a deterministic path (through mathematical equations) and based on the understanding of the actual mechanisms of plant growth, has been integrated in land evaluation.

This contribution reviews the qualitative and quantitative trends in land evaluation as follows. Section 2 discusses the traditional systems in land evaluation, from the real qualitative systems until the single-factor models. Section 3 reviews the newly emerging modern methodologies, following also a quantification line from the qualitative expert systems until the quantitative simulation models. Finally, in Section 4, the computer processing of data for land evaluation as a decision support tool is analyzed.

2. Traditional Systems

2.1. Maximum-Limitations Systems

The USDA Land Capability Classification is an example of the most traditional land evaluation system that 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 qualitative system and its adaptations, such as the British Land Use Capability Classification, the Canadian Land Capability Scheme, and the Dutch system (for more details see Chapters *The FAO Guidelines for Land Evaluation* and *Other Land Evaluation Systems*) have been widely used around the world; and they remain today as important tools for natural resources evaluation.

Also, in many approaches to express land suitability classes for a given particular land use qualitatively, the principle of the maximum limitation factor is followed. In these cases, simple matching tables such as the following are used (Table 1). 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.

Table 1. Example of maximum limitation factors for defining land suitability classes.

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

2.2. Parametric Methods

Semiquantitative land evaluation methods such as parametric assessments are positioned halfway between qualitative and quantitative methods. These are derived from the numerical inferred effects of various land characteristics on the potential behavior of a land-use system. Arithmetical systems consider the most significant factors and account for interactions between such significant factors, either by simple multiplication or by addition of single-factor indexes.

Multiplying systems assign separate ratings to each one of several land characteristics or factors, and 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 cannot be a negative number. A limitation of the system is that the overall final 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, multiplying criteria for rating soil productivity through an inductive assessment was developed by R. Storie in 1933. The original Storie Index Rating (SIR) was calculated by multiplying separate ratings for profile morphology (*A*), surface soil texture (*B*), slope angle (*C*), and modifying conditions such as soil depth, drainage, or alkalinity (*X*).

$$SIR = A \cdot B \cdot C \cdot X \quad (1)$$

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

Three other well-known systems—the Universal Soil Loss Equation (USLE), the Modified Universal Soil Loss Equation (MUSLE), and the Revised Universal Soil Loss Equation (RUSLE)—take a very similar form to the Storie Index, and operate by multiplying the most critical factor values. The USLE has, in many cases, superseded the USDA Land Capability System for on-farm planning function in the 1980s.

Additive systems also allocate a numerical value to the most important land factors, but instead of being multiplied these parameters are added. 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 do multiplying systems. Experience has shown that four or five factors appear to be a good average to use in multiplying systems; otherwise most final ratings become so low that the approach can no more distinguish small differences in response. Additive systems allow the consideration of many more criteria, both single and in combination with the effects of other factors. Other advantages of this approach are that no single factor can have enough weight to unduly influence the final rating, and that it is generally easier to specify the criteria and their factor ratings for an unambiguous land performance determination.

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 land units or soils are all realistic. Another problem might occur in cases where negative ratings have to be taken into consideration.

Combined methods for rating soil productivity levels utilize both additive and multiplying procedures. Most combined methods use additive processes to derive single-factor ratings, and subsequently multiply these single-factor ratings together to derive final rating indexes. It is obvious that each of the factors taken into consideration has to be judged and validated through individual response curves before these can be integrated in the formula. The major advantage of these combined systems is that they allow us to integrate information from several selected factors without creating an unrealistically low or even negative final result. The complexity of the approach is obviously higher than that of simple multiplying systems. Most of the combined methods have been derived from Storie's original concept.

2.3. Statistical Systems

The statistical land evaluation systems are powerful semiquantitative 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:

$$Y = \phi\ (X_1, X_2, \ldots, X_n) + \varepsilon \tag{2}$$

where Xn 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 ε measures the residual factors. As the mathematical form of the ϕ 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 value for the percentage of the observed variation.

In the development of these systems, 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.

This methodology has been used to predict soil productivity for major crops, and is based on an integrated knowledge of a wide variety of disciplines. Hence, competent statisticians, agronomists, and soil scientists must work together to develop polynomial regressions for a maximal 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.

2.4. Single-Factor Systems

As a real step of the quantification trend in land evaluation, the single-factor systems try to mathematically 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 express the sufficiency of the individual factor soil depth on crop production could be as shown in Figure 1.

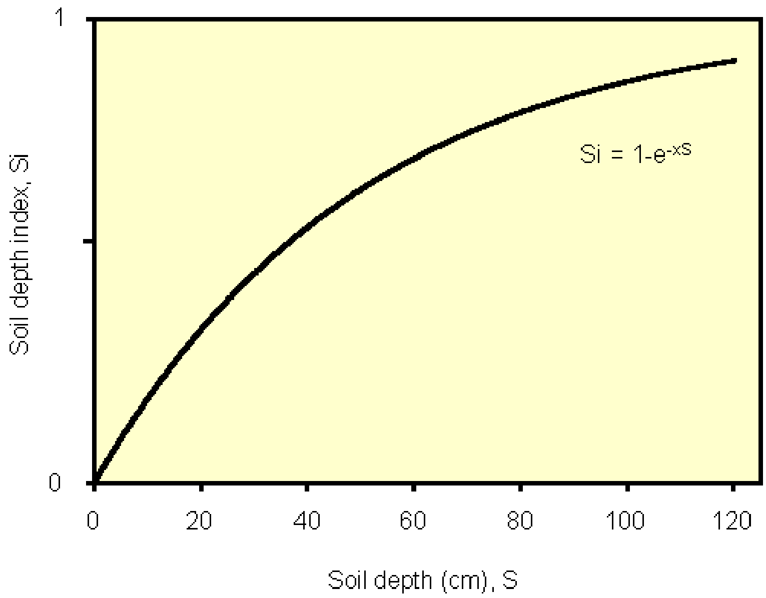

Figure 1. Typical response curve of the single-factor systems

In this case,

$$Si = 1 - e^{-xS} \qquad (3a)$$

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, equation 3a can be modified to:

$$Si = 1 - e^{-x(S - 20)} \qquad (3b)$$

valid for $S > 20$ cm and $Si = 0$ for $S < 20$ cm

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.

3. Modern Methodologies

3.1. Expert-System Models

The expert systems, as a subfield 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 qualitative systems express inferential knowledge by using decision trees. In land evaluation, decision trees give a clear expression of the qualitative matching process, comparing land-use requirements and land qualities. The better the knowledge of the collaborating experts is, the better will be the performance of the expert system. Expert decision trees are intrinsically based on the scientific background (theoretical description) and experience of the individuals, and on the quality of the discussions between them.

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 Figure 2, the decision trees visualize the qualitative sequence of decisions being made in a clearer fashion than traditional matching tables.

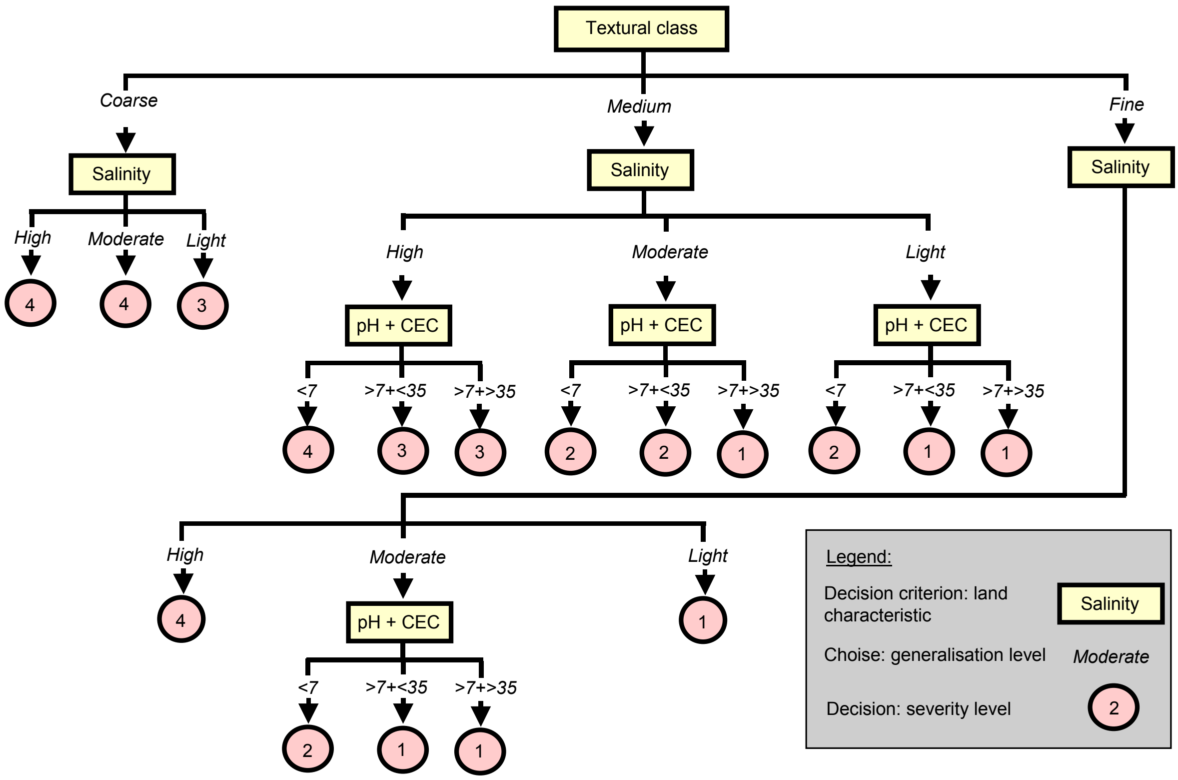

Figure 2. Decision tree formulated for rating land characteristics associated with land suitability class

Where suitable practical experience data are available, statistical decision-trees analysis can be used to generate land evaluation models with good prediction rates; this is particularly useful in cases when the assumptions for other statistical models are not met. These classification and regression trees are designed to be used under situations where the ratio between the number of observations and the number of variables (which is typical of soil and land resource surveys) is low. 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 2) or as a rule-based system in a computer program.

Both expert-system procedures, theoretical decision trees and statistical decision trees, are often used in order to optimize results. The Automated Land Evaluation System (ALES) is a computer program that allows land evaluators to build expert systems for evaluating land units according to the methods 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 choice of land qualities and associated land characteristics for a given land utilization type, which is a crucial activity in land evaluation, is, however, not facilitated by this shell.

3.2. Fuzzy-Set Methodologies

In general terms, the traditional land evaluation systems follow a Boolean or rule-based approach adapted to 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, and it can be considered as a new phase in the quantification trend.

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 that 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 ($0.0 < \mathrm{MF} < 1.0$) 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).

$$\mathrm{JMF}_x = a_A\mathrm{MF}_A + a_B\mathrm{MF}_B + \ldots + a_Z\mathrm{MF}_Z \tag{4}$$

and

$$a_A + a_B + \ldots + a_Z = 1 \tag{5}$$

The choice of the weights (a_A, a_B ... 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 a 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.

3.3. 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 nonlinear 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 and agricultural and environmental sciences. In land evaluation, this technique allows us to develop sophisticated semiquantitative models.

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 statistical regression models, neural networks do not require a knowledge of the functional relationships between the input and the output variables. Moreover, neural networks are nonlinear, 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 3 shows an example of the correlation-cascade neural network developed to relate land qualities (LQ*r* = runoff erosivity, LQ*t* = relief hazard, LQ*k* = soil erodibility) and management qualities (MQ*c* = crop protection, MQ*z* = tillage translocation and MQ*y* = productivity influence) to a vulnerability index (Vi) of soil erosion.

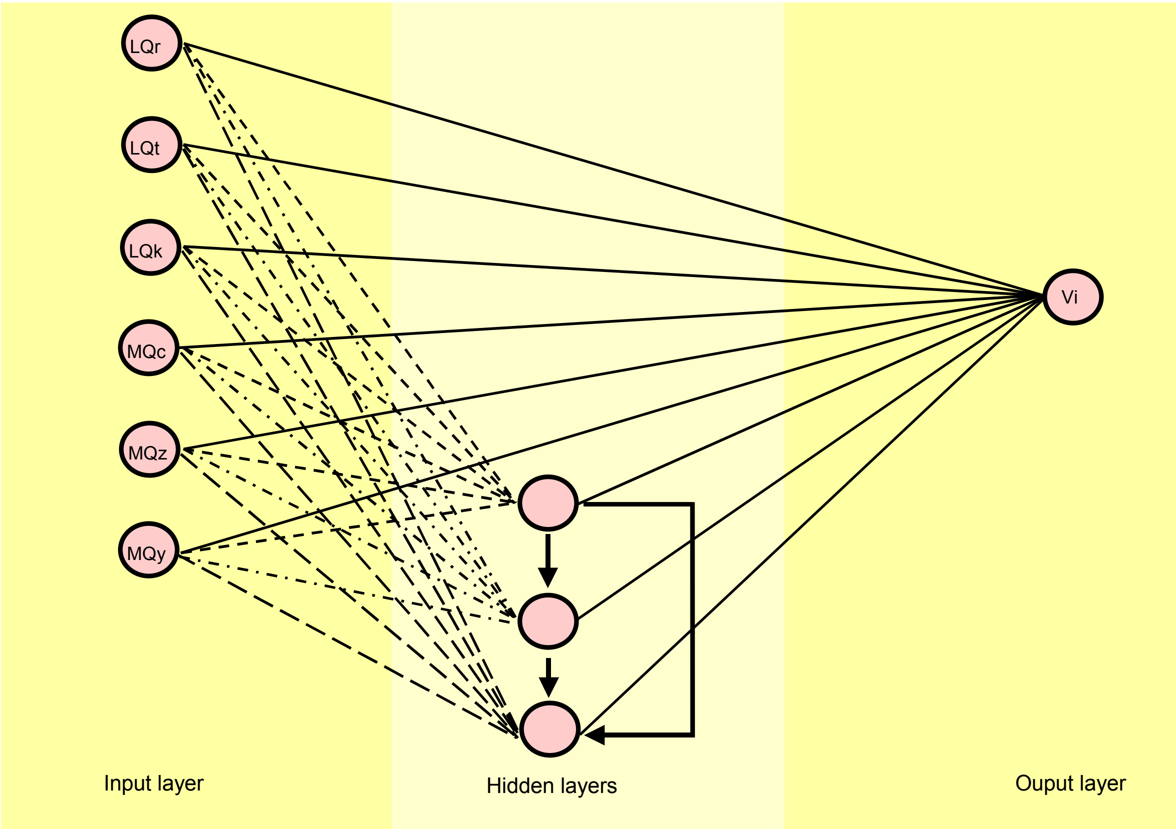

Figure 3. Structure of a neural network showing the interrelationships between land and management qualities to reproduce the vulnerability index of soil erosion

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.

3.4. Dynamic-Simulation Models

The dynamic-simulation models can 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. These process-based models are applied in land evaluation to really 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 land use systems in a next step of data processing.

The greatest limitation to applying the simulation 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.

The process-based simulation modeling and the rest of the empirically based land evaluation techniques are currently producing a "cross fertilization" of excellent scientific and practical results, improving the accuracy and the applicability of the evaluation 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 especially on the soil water regime and how it effects crop performance. Dynamic-simulation analysis adds an extra dimension to land evaluation: the temporal variability of land use requirements and land qualities.

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

3.5. Hybrid Systems

In the land evaluation hybrid systems, through the linkages of 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 mixed model could be obtained in a decision tree of branches based on qualitative data combined with branches using quantitative data obtained by simulation. Dynamic 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, though not all land qualities can be necessarily characterized by simulation modeling.

Other hybrid systems have been developed using qualitative expert decision trees and semiquantitative artificial neural networks for assessing soil erosion risk. The example of the expert/network approach presented in Figure 4 offers an excellent performance in modeling the complex soil erosion problem, and provides a very good quantification and generalization capability for prediction. According to the sensitivity and validation analysis, this mixed model recognized the main interrelationships of the input parameters, and could reproduce the soil erosion vulnerability accurately.

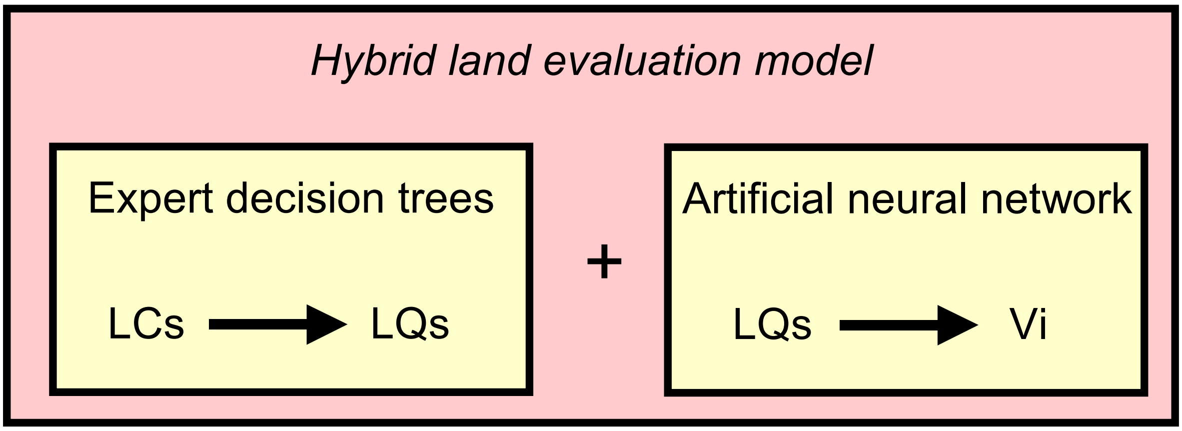

Figure 4. Hybrid land evaluation model using decision trees to relate land characteristics and land qualities, and neural network to relate land qualities and land vulnerability index

4. Automated Application

The application phase of land evaluation systems is often implemented in unknown scenarios. It is a scaling-up process going from the representative areas of the development phase to these unknown application scenarios. The application phase previously done manually can now be executed by computer-assisted procedures. Modern technologies in data and knowledge engineering provide excellent possibilities for application in land evaluation. This basically involves the development and linkage of integrated databases, computer programs and GIS-related tools which, along with the land evaluation models previously described, constitute decision support tools for land use planning (e.g., MicroLEIS, Figure 5).

The Mediterranean Land Evaluation Information System, currently on Internet (MicroLEIS.com), is an integrated system for land data transfer and agro-ecological land evaluation. It is an interactive software with comprehensive documentation for anyone who is involved in the planning, research, or teaching of the sustainable use and management of rural resources, particularly in Mediterranean regions. This system provides a computer-based set of tools for an orderly arrangement and practical interpretation of land resources data. The major thematic modules of MicroLEIS are: (a) three attributes databases referred to soil, climate, and agricultural management, respectively; (b) a set of land evaluation models for soil quality and land degradation assessment; and (c) an optimization tool to formulate strategies of agricultural management to reduce soil degradation.

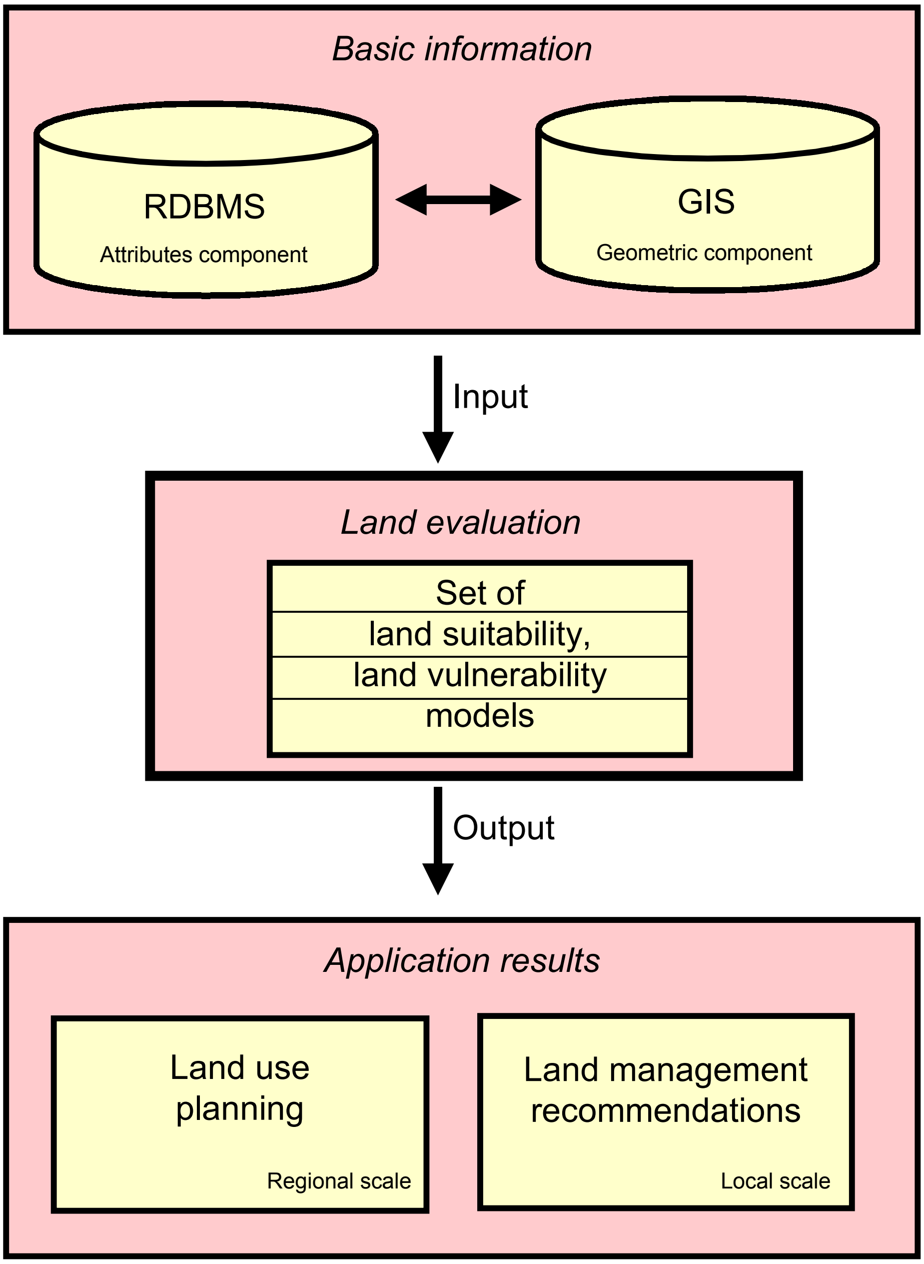

Figure 5. General scheme of a decision support tool for land use planning and management

4.1. 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 FAO-CSIC multilingual soil database (SDBm Plus), as an essential part of MicroLEIS, is a good example of a 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. Among 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.

4.2. 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 also developed which allows the model to be easily applied. These user interfaces basically have the following major characteristics: (a) a connection with the basic attributes and geometric databases; (b) "pop up" screens showing codes, types, and classes of input variables; (c) individual and batch processing modes; (d) hypothetical scenario predictions; and (e) 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 the Internet through a web server, so that the user can apply these systems via a web browser. These web applications are open to the public and offer several advantages, such as their use by many people, thus allowing for their usability check and system improvement. The upgrades are made directly on the web server and are immediately ready for the users.

4.3. Optimization Tools

Land evaluation decision support tools 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. In other words, the best soil conditions for plant growth may not be the best for erosion or pollution concerns.

Response surfaces based on statistical models and backtracking procedures of expert systems, such as used in the MicroLEIS system, are good examples of optimization tools to characterize the best suitable soils for selected crops or to formulate the optimum agricultural management strategies.

4.4. Spatial Analysis

In a more detailed stage of the scaling up process of the land evaluation application phase, spatial 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 a rapid generation of thematic maps and area estimates, and enables many of the analytical operations to be carried out in a spatial format, for example, 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.

5. Future 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, salinization, acidification, eutrophication, nutrient loss, soil and water contamination, bio-diversification loss;
- manage land-based greenhouse emissions and establish carbon sinks;
- provide an explicit basis for quantifying greenhouse gases emission from agricultural production, and establish the size of potential carbon sinks under various policy scenarios.

In order to be actually fitting to the potentialities and limitations of each land unit, these changing land uses and management practices 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 what, why, and how of moving towards sustainable rural development.

Although the new development and application needs in land evaluation must be considered location specific, some general trends can be indicated. In this sense, it is clear that the rapid development of information and communication technologies will be a powerful tool 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 quantification 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;
- accuracy and applicability of the models, which 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 georeferenced inventories and monitoring of soil and soil-related attributes and land use/management systems. As land use is dynamic and land evaluation is interested in the changes, a future challenge will be to improve the efficiency of the maintenance and updating of the land use data sets. Moreover, this will allow the identification of representative areas, whether high-potential or critical problem areas, for more detailed inventories on medium- or large-scale maps. The procedures will also repsond with integration of georeferenced databases, evaluation models, and results presentation, generating maps of land use options or alternatives, through land use and management decision support systems.

Another recent trend is the conversion of land evaluation results into legislative instruments, e.g., for good agricultural practices or environmental legislation.

Acknowledgments

The authors are grateful to Prof. W. Verheye for the opportunity to contribute to the EOLSS and for the helpful suggestions in the preparation of the manuscript. Helpful comments and manuscript revision from E. Diaz-Pereira and V. Castillo are also much appreciated.

Glossary

Database: An organized, integrated collection of data stored for rapid search and retrieval.

Decision support system (DSS): System used on choosing optimal use and management decisions.

Decision tree: A hierarchical multiway key, leading via a series of questions at the nodes of the tree to a decision at its leaves.

Expert system (ES): A qualitative empirical modeling tool that uses high-quality, in-depth knowledge to solve complex and advanced problems typically requiring experts.

Geographical information systems (GIS): Databases that store information in a geometric format.

Integrated package (IP): Set of databases, models, computer programs and/or GIS used in an integrated framework.

Land capability: The fitness of a given type of land for a nonspecific kind of land use.

Land characteristic (LC): A single attribute of land that can be measured or estimated.

Land quality (LQ): A land attribute that refers to the basic requirements of land use and that influences land suitability.

Land suitability: The fitness of a given type of land for a specified kind of land use. Land suitability and land potentiality are used as synonymous terms.

Land unit (LU): An area of land that possesses specific land characteristics and land qualities and can be mapped. It is considered to be spatially homogeneous in terms of all elements of physical environment: climate, site, soil, and use.

Land use: A series of operations on land, carried out by humans, with the intention to obtain products and/or benefits using land resources.

Land-use planning: Evaluation of land resource condition, formulating options and selecting the best ones. Land use planning and land resources planning are used as synonymous terms.

Land-use requirement (LUR): Specific requirements set to the land by each land use type.

Land-use system (LUS): A specific land use, practiced during a known period on a known and contiguous piece of land with reasonably uniform land characteristics. It is a combination of one land unit and one land use type.

Land-use type (LUT): A kind of land use described or defined in terms of management, economics, and technical inputs.

Land vulnerability: The susceptibility of a given type of land for a specified kind of degradation problem. Land vulnerability and land limitation are used as synonymous terms.

Major land improvement: Activity that causes changes of a permanent nature and can only be accomplished by big investors or government agencies.

Minor land improvement: Nonpermanent improvement that can be made by individual land users.

Model: A simplified representation of a limited part of reality with related elements. Most of the land evaluation models are empirically based models, which have been developed and distributed in the form of computer programs that readily run on desktop computers. Therefore, model and program are used as synonymous terms.

Neural network: A quantitative empirical modeling tool characterized by a network of highly interconnected nodes that pass numerical values to each other and calculate an output based on the sum of inputs from other nodes.

Relational database management system (RDBMS): System used to manipulate attribute databases.

Sustainable land use: Use of the land that does not progressively degrade its productive capacity for a defined purpose.

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Biographical Sketches

Diego de la Rosa is a Scientific Professor of land evaluation at the Spanish Research Council (CSIC), Sevilla, Spain. His research is focused on the application of information technology for developing agro-ecological land use decision support systems. Since 1990, all these investigation results are being included into the MicroLEIS system (http://www.microleis.com). He has conducted numerous studies in the area of soil survey and land evaluation funded by regional and national governments, EU, and FAO; which have been reported in numerous publications.

Professor De la Rosa has worked as a visiting professor at the University of Florida, USA. He was head of the Natural Resources Evaluation Service, Junta de Andalucia, Spain, and director of the Institute for Natural Resources and Agrobiology, CSIC. He was also leader of the European Topic Center on Soil, European Environment Agency. Professor de la Rosa operates and manages his family's farm in western Sevilla.

Kees van Diepen is senior scientist land evaluation at Alterra, Wageningen University and Research Centre, Wageningen, The Netherlands. He has conducted many studies combining qualitative and quantitative methods for estimating the productive potential of lands for various purposes and at different scales. These usually involved the combination of judgment-based land suitability ratings with numerical deterministic crop models, and their application in a GIS environment.

He was coordinator for the development of the WOFOST (World Food Studies) crop model, and was leader of the team that built the Crop Growth Monitoring System for the MARS (Monitoring Agriculture with Remote Sensing) project of the European Union, an agrometeorological information system for crop yield prediction across Europe. Related systems dealt with the quantification of effects of climate change on crop yield and water use, and comparative analysis of regional crop production potential. He participated in eco-regional studies in support of regional land use planning. He has written a number of review articles on approaches in physical land evaluation.