Proceedings of the 16-th World Congress of Soil Science
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A decision support system for sustainable land management: structure and functions

Un système d'aide a la décision pour la gestion durable des terres: structure et fonctions

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SUMMARY

The paper analyses the domain of land evaluation taking into consideration evaluation purposes, evaluation support disciplines, evaluation factors, land uses, evaluation types, evaluation criteria and evaluation methods. User requirements are more complex, quantitative and specific. The land evaluation has evolved from qualitative to quantitative methods based on complex models and from single-criterion to multi-criteria methods. More evaluation factors and more land uses are taken into account. The analysis points out the evolution of land evaluation towards using decision support systems, which can integrate different land evaluation methods/elements and different land data sets and cope better with the complexity of user requirements. For this they integrate land evaluation into decision-making process using a tight interactivity with the user (decision-maker).

The structure and functions of such system (DEXTER) to be used for sustainable land management are presented. It is structured in four subsystems: database, models base (a collection of different models/submodels implementing different land evaluation methods/elements using algorithmic or knowledge based techniques), control subsystem (which builds interactively the appropriate evaluation model and decision process by choosing from models base the best available submodels/procedures, suggests criteria and evaluates the alternatives on a multi-objective and multi-criteria basis) and user-interface subsystem. The database and models base are hierarchical multi-level organized, having well-defined standardized interfaces. The prototype method is used for the system development/implementation.

Key words: land evaluation, decision support systems, management support systems, land use planning, soil information infrastructure.
Mots clés: évaluation des terres, systèmes support aux décisions, systèmes support à la gestion, aménagement du territoire, systèmes d’informations sur les sols.

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1. Introduction

The interest for land evaluation in the last years, far to be reduced, has become more important (Smyth et.al., 1993; Fresco et.al., 1994; Davidson, 1992; Vlad, 1997a; etc.). In the industrialized countries some important problems must be solved: land use change of the marginal land because of agricultural super-productions, change of agricultural land use because of new requirements (industrial crops, new diet preferences of people, biological agriculture, etc.), land request for urban, industrial, transport and recreation necessities, pollution control and environment protection, etc. Of course, the increasing of present land use efficiency and sustainable use of land are a stressing problem both in developed countries and other countries. The appropriate answers to all such problems cannot be done without using the advanced methods for land evaluation/management.

This paper analyses the domain of land evaluation (evaluation purposes, evaluation support disciplines, evaluation factors, land uses, evaluation types, evaluation criteria and evaluation methods) pointing out its evolution towards using the decision support systems. Then, the structure and functions of such system to be used for sustainable land management are presented.

2. Land evaluation is evolving towards decision support systems

. *Evolution of evaluation purposes*

The purposes of land evaluation have evolved from simple uses (taxation, land use choice) towards a multitude of uses, more complex, more quantitative and more specific (Vlad, 1997a):

- land use planning (increasing number of land uses taken into consideration; increasing number of evaluation/planning criteria - sometimes contradictory; planning may be strategical or tactical - at national, district, regional, local or farm level);

- technological management of land (establishment of detailed technological recommendations at tactical or operational levels: agrotechnical works, soil amelioration/reclamation works, environmental impacts, etc.);
- arbitration and legislation application concerning the land (taxation, exchange/compensation value of land, land leasing, bank loans, etc.).

. *Evolution of evaluation support disciplines*

If land evaluation was only based on soil science and agronomy, at present it uses also many other disciplines: climatology/meteorology, hydrology, geomorphology, farming systems, environment science, economics, sociology, systems theory (analysis), operational research, information technology, etc. All of these have made remarkable progresses: soil science and agronomy have become more quantitative and have developed deterministic/mechanistic models; information technology have developed advanced techniques for software engineering, artificial intelligence, distributed processing, geographical information systems, networking, etc. They are good opportunities to improve further the support for land evaluation/management.

. *Evolution of land evaluation*

As a result of increasing of variety and complexity of user requirements, the land evaluation domain has evolved itself (Dumanski & Onofrei, 1989; Bouma, 1989; van Diepen et.al., 1991; van Lanen, 1991; Sys et.al.,1991; Driessen & Konijn, 1992; Davidson, 1992; Smyth et.al., 1993; Fresco et.al., 1994; Rossiter,1994; Vlad, 1994,1996,1997a,1997b; Vlad et.al., 1997):

The number and variety of *factors* to be taken into account have increased, as well as their measuring/estimating accuracy (land characteristics and qualities, site assessment factors, economic factors, social factors, sustainability factors, etc.). More (pedo-) transfer functions/rules are being developed.

The number and variety of *land uses* taken into consideration have increased: The land utilization types (FAO, 1983) are defined at different detail degrees and from different point of view (physical, technological, economic and social). Different cropping and farming systems are taken into account. There are complex interdependencies between evaluation factors that define land uses at different levels.

From qualitative physical evaluation it has come to many different *types of land evaluation* (Vlad, 1997a): physical, economic, social, sustainable; natural, actual, conditional, potential; qualitative, semi-quantitative, quantitative (precise); reconnaissance, semi-detailed, detailed, very detailed; general, specific (summary, intermediate, detailed); current, special.

From few *evaluation criteria* (productivity, capability/limitations) it has come to many others: physical criteria (qualities and variability of land use results, flexibility of land use, recreational/environment values, etc.), economic criteria, social criteria, sustainability criteria (Smyth et.al., 1994). Different measures of land performance/suitability may be defined: global, partial (physical, economic, social, sustainability), natural, actual, conditional/potential, etc. They may be measured/estimated by absolute or relative values, using continuous or discrete scales.

From few qualitative methods it has come to many different *evaluation methods*:

- frameworks, general methods, concrete (detailed) methods;
- qualitative, semi-quantitative, quantitative (using deterministic/mechanistic models);
- statistics of observations, interpretation of soil/agroclimatic surveys, limitation methods (maximum limitation, multiple limitations), heuristic combinations (decision trees, etc.), parametric methods (additive, multiplicative, other algebraic combinations), deterministic models (mechanistic, simulation; a large variety of models, each of them appropriate to some purposes, requesting some specific data and valid in some assumptions), multi-criteria and multi-objective decision methods and other special methods/techniques (fuzzy sets/logic, geostatistics, risk analysis, artificial intelligence, etc.); usually, an appropriate combination of some of these methods must be applied (hybrid method).

. *Decision support systems – a solution for the complexity of the land management*

The present complexity, multitude and variety of user requirements for land evaluation/management and the complexity, multitude and variety of land evaluation types, elements and methods to respond to these requirements impose use of an appropriate type of computer application systems – the decision support systems (Filip, 1989; Radulescu & Gheorghiu, 1992; Vlad et.al., 1986; Vlad, 1994,1996). These systems have come out to solve poor-structured problems, that is those characterized by complexity, incompleteness, uncertainty and fuzzy values. Generally, the procedures (algorithms) for solving such problems cannot clearly and a priori be defined. The solutions are based on complex data and processing models, the solving procedures depend on intermediate results and there are many and conflicting decision criteria. To solve such problems, the experience, intuition, judgements and preferences of decision-maker are essential. A decision support system does not automatically reach solutions. It helps (collaborates with) the decision-maker for yielding the solution. For this it is necessary an advanced interactivity between the decision support system and decision-maker.

A decision support system for sustainable land management must provide:

- Integration of different land evaluation methods (models) and elements in order to assuring answers and adaptability to multiple and complex user requirements;
- Integration of different land data sets requested by land evaluation models and by decision-making: internal and external parameters of land-use systems (FAO,1983; Vlad,1997a); The costs and duration of data collection lead to reusing as more as possible the available data, which have different structures (defined during their long life-period);
- Integration of land evaluation into the decision-making processes that use its results (land use planning, land technology design, etc.).
- Integration of different techniques for computer implementation.

3. DEXTER - A decision support system for sustainable land management

The decision support system DEXTER, dedicated to sustainable land management, has been structured in four main subsystems having the following functions:

. *Data Base Subsystem*

This subsystem manages different land data sets characterizing a well-defined territory. The different data sets are spatial referenced and hierarchical multi-level organized. They are accessed by a well-defined standard interface. (The efforts carried on, at FAO and EU levels, for databases standardization are very important in this context.) The Database is connected and exchanges data with a geographical information system. A meta-database helps to retrieve the data requested.

. *Models Base Subsystem*

This subsystem, as a balance to the database, contains a collection of different models/submodels, which implement different methods for land evaluation and other algorithms and expert-type rules. Two types of models are managed: numerical and heuristic (expert-type).

The numerical models refer to algorithmic methods: qualitative evaluation methods (limitations, parametric), physical and economic evaluation methods, site assessment methods, soil and crop simulation models/submodels, (pedo-)transfer functions/rules, indirect estimation algorithms for not-available data, uncertainty and risk analysis, spatial variability analysis, data converters, data generators (e.g. weather data), etc. The models (e.g. soil/crop simulation models) are hierarchical multi-level structured with well-defined standard interfaces. Also, a well-defined data structure is associated with each model/submodel and intervals of admissibility/optimization (which may be defined by experts or decision-makers) are defined for different state variables.

The heuristic models used for implementing different qualitative evaluation methods are based on expert knowledge representation (knowledge bases) by production rules - simple and variable, using predicate logic (Carstoiu, 1994; Zaharie & Nastase, 1993). Uncertainty can be represented using coefficients of certainty associated with some rules, based on fuzzy techniques (fuzzy sets/logic).

The models contained in the Models Base are calibrated and tested for the territory to which the decision support system is dedicated (implemented). A meta-database helps to use the Models Base.

. *Control Subsystem*

This subsystem implements general procedures for land evaluation and decision-making processes. For a user problem, the Control Subsystem can manage one or more "decision processes". Each decision process is run in iterative steps:

- definition of the problem,
- building the solving method (strategy),
- building the evaluation model and selection of the appropriate data set,
- analysis (evaluation) of the alternatives and finding out the solution.

A decision process is established and run progressively and interactively with the collaboration of user (decision-maker). A specific evaluation model is built by "choosing" from Models Base, in different steps of decision (evaluation) process, the best available (sub-)models for the specific situation (user problem/requirements, kinds of land uses, type of evaluation, relevant evaluation factors, available data sets, etc.). The subsystem can manage one or more simulation scenarios. A model editor provides functions for the specification of new (sub-)models and modification of existing ones. An inference engine provides the solutions of the heuristic (expert-type) models.

A Decision Module suggests criteria for comparison of alternatives and evaluates the alternatives on a multi-objective and multi-criteria basis. A hybrid method is used for this: classical operational research, expert rules and interactivity with decision-maker. Sensitivity and stability tests, evolution prediction and overflow of admissibility/optimization intervals of state variables are included. The decision model of "limited reasoning" (heuristic rules used to identify promising/satisfying alternatives) and of "default favorite" (the decision-maker specifies at the beginning a "favorite" and the system checks his choice) are also used (Radulescu & Gheorghiu, 1992).

. *User-Interface Subsystem*

This subsystem provides functions for the user dialogue and the presentation of the results and recommendations:

- user specification of input data and of options in different steps of decision (evaluation) processes;
- data enter and retrieval to/from the Database;
- knowledge (expert rules) acquisition/modification for heuristic models;
- providing system suggestions, intermediate results and other useful information in different steps (contexts) of decision processes;
- presentation of results (solutions) of decision processes using a base (library) of reports, tables and graphs;
- providing system explanation (justification) on the way (methods, processing, simulations, judgements, etc.) used to obtain the solutions;
- help facilities.

The user communication is friendly by using different types of interface methods: menu type, question-answer type and "windows" type (multiple windows, icons, buttons, lists, etc.). The access to the system is controlled, both for getting data and for entering/modifying data, using three levels of access (system, group, user).

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The development of the system is carried on using the *prototype method*, also known as evolutive development or adaptive design (Radulescu & Gheorghiu, 1992). The prototype is a first variant of the requested system, which has its essential characteristics in an incipient way. It is more rapidly and economically built, but in such a way to be easily modified (open system). The method is useful because of initial uncertainty on system requirements. During its development, the system is adapted and personalized.

For the beginning, few elements are taken into account for implementation:

- 24 crops and land uses;
- the Romanian parametric multiplicative evaluation method (semi-quantitative);
- the deterministic (mechanistic) models SIBIL, SIBQUICK, WOFOST, EPIC and DSSAT3;
- some qualitative technological recommendation models;
- some existing data bases.

4. Conclusions

- The requirements for land evaluation have become more complex, more quantitative and more specific.
- To follow the requirement dynamics, land evaluation (evaluation factors, land uses, evaluation types, evaluation criteria, and evaluation methods) has also become more complex, more quantitative and more specific.
- The advances in the support disciplines offer good opportunities for land evaluation development.
- To cope with this complexity of land evaluation and user requirements, decision support systems must be used.
- A decision support system for sustainable land management must integrate different land evaluation methods/elements, different land data sets and different computer implementation techniques (numerical/algorithmic, simulation, knowledge-based, etc.); it also must integrate land evaluation into decision-making processes.
- A models base, as a balance to the database, must be used. It permits dynamically building the evaluation/decision models.
- It is useful that the database and models base to be hierarchical multi-level organized, having well-defined standardized interfaces; the efforts carried on, at EU and FAO levels, for databases standardization are very useful; the same efforts are necessary for standardization of model interfaces.
- Meta-databases are useful for accessing the databases and models bases.
- As complex systems, decision support systems for sustainable land management are more advantageously developed using the prototype method.

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