Requirements
for the decision support systems for land management[1]

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SUMMARY

Land management must go on as a decision process, respectively as an iterative sequence of well-defined steps. Its general objective is the sustainable use of land as defined by FAO (simultaneous achievement of productivity, production security, land/environment protection, economic viability and social acceptability). The concept of "land - use" system helps the system analysis of the problems and process of land management. Important characteristics of land management (data uncertainty, knowledge uncertainty, uncertainty related to the management process, multi-criteria decisions, multiple complexity of problems and solving methods) make it a "poor-structured problem" and, consequently, it must be helped by using an appropriate class of computer applications - the decision support systems (DSS). A DSS for sustainable land management must put into practice some important requirements: (a) functional requirements (the decision-maker must be included in the system as the main and final actor in the decision-making process and, consequently, the DSS must be strongly interactive; the DSS must support the decision-maker for structuring the problem in all steps of the decision process, including information acquisition, identification/definition of the problem, establishing the variants/options, establishing the appropriate evaluation and multi-criteria decision models, monitoring and revising the decisions, etc.; complex data bases and "models bases" - containing different data and models for land evaluation, multi-criteria decision-making and for the decision process - are necessary, etc.), (b) operating requirements (flexibility, reliability/security, ease in use, adaptability, etc.) and (c) implementation requirements (integration of different information technology methods/techniques; the DSS must be an "open system" and the prototyping method must be used for development; besides the traditional disciplines, many other "auxiliary" disciplines must participate in the DSS design). The concepts developed are applied in the design of the decision support system for the agricultural land management in the Romanian conditions. The general structure of this system (named "DexTer") is given: communication (user interface) subsystem, knowledge (models base and data bases) subsystem and problem solving (decision process model) subsystem.

Key words: *land management, decision support systems, decision support systems for land management, decision process, land-use system, uncertainty, poor-structured problems, functional requirements, operating requirements, implementation requirements, Romania.*

1. INTRODUCTION

Lately, both in developed and developing countries, the land management has become more important, as people must cope with more stressing land problems, (Davidson, 1992; Smyth et.al.,1993; FAO,1993; Fresco et. al.,1994; Vlad,1997a,2001).

In the developed countries some important problems must be solved:

- land use change of the “marginal” lands (requested by the agricultural overproduction);
- land use change requested by changes of agricultural products demands (e.g.: industrial crops, new diet preferences of people, etc.);

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- increasing importance to the quality of agricultural products (Verheye,1992), which leads to land re-evaluation, specific land management for biological agriculture, etc.;
- land request for urbanisation, industrialisation, transport development, recreation necessities, etc., which leads to a continuing need to define and protect the prime agricultural lands;
- growth of pollution and degradation of environment due to industrial, urban and agricultural activities, which requests the establishment of land protection and rehabilitation measures (such as erosion control, etc.) and accurate farming practices (controlled use of pesticides, fertilisers, mechanisation, irrigation systems, etc.);
- use of land released from different activities (industrial, urban, etc.).

In the developing countries, prime emphasis is laid on identifying agricultural potential for expanding the arable area and on increasing the output from existing area. Another problem in these countries is the decrease of the soil productivity. The increase of present land use efficiency and sustainable use of land are stressing problems both in developed and developing countries.

This paper firstly defines the land management (decision process, general objectives and object of management) and then analyses the land management process/characteristics, concludes the necessity of using the decision support systems technology and presents the main requirements for a decision support system for land management. Finally, the general structure of such system designed for Romanian agricultural conditions is outlined.

2. LAND MANAGEMENT ACTIVITY

Land management comprises three general types of actions: (a) land use planning (select the best land use option for a land) at different levels (national, districtual, regional, local and of the farm), (b) technological management of land (establishing the detailed technological recommendations at tactical or operational levels, for different land uses, according to existing land characteristics - e.g.: agrotechnic/tillage works, soil amelioration/reclamation works, environmental impacts) and (c) arbitration and application of legislation concerning the land (taxation, exchange/compensation value of land, land leasing, bank loans, etc.).

2.1. General Objective of Land Management

Land management means, at present, *sustainable land management*. This is a decision process that combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously (Smyth et.al.,1993): (1) maintain or enhance production/services (Productivity); (2) reduce the level of production risk (Security); (3) protect the potential of natural resources and prevent degradation of soil and water quality (Protection); (4) be economically viable (Viability) and (5) socially acceptable (Acceptability).

2.2. Land Management: a Decision Process

As a decision process, the land management must go on as an iterative succession of steps (FAO,1993; Fresco et. al.,1994; Vlad,1999,2001):

1. Gathering the information;
2. Establishing the problem - the specific goals and terms of reference;
3. Analysing the problem;
4. Identifying opportunities of land uses (variants/options) including technological options;
5. Evaluation of land suitability for land uses and/or technological options;
6. Choosing the best variant/option (making decision);

7. Implementing the decision/plan;
8. Monitoring and revising the decision/plan.

2.3. The Object of Land Management: the "Land-Use" System

In the land management process, each combination of each homogenous land unit with each relevant and well-defined land use - "land utilisation type" (FAO,1976) - must be taken into consideration. So that, the working unit - object of land management activities (respectively, of land evaluation) - is the binom "Land Unit - Land Utilisation Type", shortly: the "Land - Use" System. It is the elementary (basic) driven system in the decision process and can be schematically presented as in the *Fig. 1* (Vlad,1997a,2001).

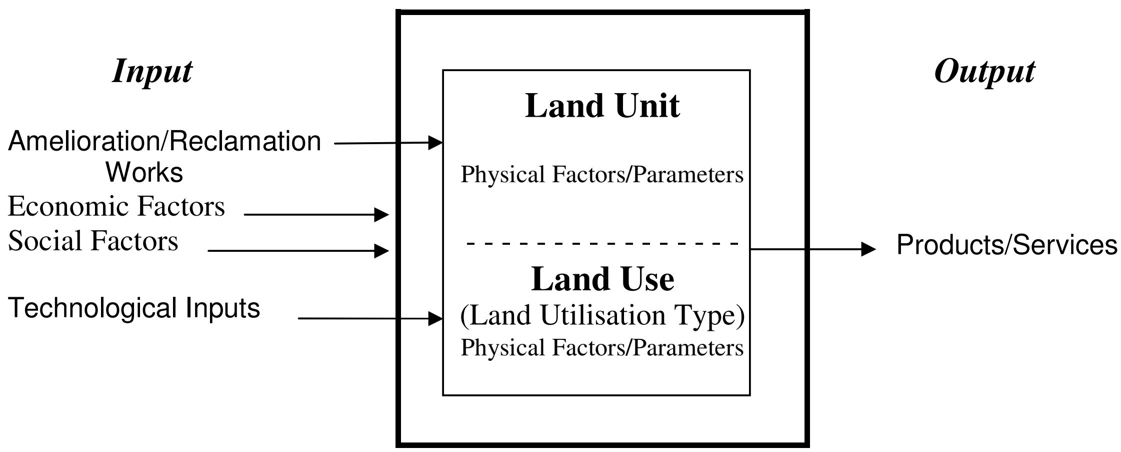

Fig. 1. Schema of "Land - Use" System
[Modified after FAO (1983)]

3. LAND MANAGEMENT: A POOR-STRUCTURED PROBLEM; NECESSITY OF DECISION SUPPORT SYSTEMS

There is a set of essential characteristics of land management process/content, which lead it to be considered a "poor-structured problem":

a) Data uncertainty: Errors in measurements (field measurement, physical and chemical analyses, etc.) and observations concerning land units and land-uses; errors in sampling (samples are not right representatives for land units); fuzzy nature of land unit delineation; errors in representing the land units on maps; qualitative, descriptive or statistical nature of some characteristics /parameters of land units and land uses; spatial variability of data in a land unit (considered homogenous by definition); temporal variability of data (data may become obsolete); human errors in manipulating and storing the data; errors in primary processing of data; tolerance in the behaviour of natural processes (e.g. soil, climate) and biological processes (e.g. plant); occurring risky/unknown phenomena (e.g. physical, chemical, weather, economic, social); incomplete/unavailable data; etc.

b) Knowledge uncertainty: Incomplete knowledge about the processes of the "land-use" systems (e.g.: soil processes, plant processes, land - land use relations, etc.); uncertainty in establishing the right representative indicators for factors; qualitative knowledge; approximate methods/models for evaluation and decision (qualitative, statistical, heuristic, or deterministic with uncertain parameters and approximate submodels), etc.

c) Uncertainty related to the management process: Uncertainty in establishing the objectives/goals of management and the evaluation criteria; errors in choosing/applying the models; delays in data availability; decision-maker's subjectivism; errors/delays in applying the decisions, etc.

d) Multi-criteria decision: In practice, almost always, the best land use means to simultaneously accomplish more criteria, most often conflicting. Multi-criteria decisions (Rădulescu & Gheorghiu, 1992; Rossiter,1994) may be multi-attributes or/and multi-objectives. In land management, many attribute criteria - others then productivity and capability limitations (as usually) - must be taken into consideration (FAO,1983; Vlad,1997a,b,2001), e.g.: physical criteria (quality and variability of land use results, flexibility of land use, recreation value, etc.), economic criteria (Rossiter,1994,1995), social and sustainability criteria (Smyth et.al.,1993; FAO,1993). Also, almost always, there are several objectives at the same time (e.g.: maximum productivity, quality and efficiency, minimum risks/degradations, etc.). Most often between these objectives there are conflicts and trade-offs, e.g. there may be conflicts between different groups of land users on the distribution of the benefits and the costs (government - private; national - districtual - local; land owners - tenant farmers; commercial - subsistence, etc.).

e) Overall complexity: There are a great number and variety of land unit and land use factors/parameters (Teaci,1980; FAO,1983; Vlad,1997a,2001); There are a great number and complexity of processes, state variables and inter-relations implied in a "land-use" system; There are complex and dynamic interactions of a "land-use" system with other systems, existing a three-dimensions hierarchy of these interactions (Vlad,1997a,2001): socio-economic systems hierarchy (e.g.: cropping system, farm system, local system, county system, national system, multi-national system, World system), multi-sector dimension/hierarchy (agriculture, forestry, urban, industry, transport, recreation, natural reservations, etc.) and multi-territorial dimension/hierarchy (e.g.: regional, land reclamation systems, ecosystems, etc.). Some dynamic characteristics of the "land-use" systems change slowly (in a long time) and these changes are more difficultly perceived by man. This leads to their neglect, omission or ignoring by decision-makers.

As a result, there are a great number and variety of complex methods/models - qualitative, semi-quantitative and quantitative - for land evaluation (assessment of land qualities, evaluation criteria and land suitability) and for decision-making (FAO,1983; ICPA,1987; van Diepen,1991; Vlad,1997a,b,2001). The solving procedures are based on multi- and inter-disciplinarity (soil science, agronomy/farming, climatology, economics, sociology, operations research, probability theory, fuzzy set/logic, decision theory, system analysis/engineering, artificial intelligence, information technology, etc.); often, they cannot be clearly defined in the beginning stage and, consequently, the decision process must be interactive and iterative (successive refinements). Large volumes of complex data, sometimes of different quality and structures (as a result of their long life/history), are necessary. The decisions are based on general knowledge and, also, on site-specific knowledge. To solve the problems, often the experience, intuition, judgements and preferences of decision-makers are essential (sometimes, the expert decisions cannot even be completely explained).

All the above issues make the land management a poor-structured problem and, consequently, it must be solved using decision support systems (Vlad et.al.,1986; Vlad, 1997b,1998,1999, 2001). In fact, at present, the land evaluation itself evolves towards decision support systems (Vlad,1997b,1998,2001).

4. REQUIREMENTS FOR THE DECISION SUPPORT SYSTEMS FOR LAND MANAGEMENT

A *decision support system (DSS)* is a computer application system used in supporting a decision-making activity provided that it is not possible and not even wanted (advisable) to be a completely automatic system that accomplishes the entire decision-making process (Bonczek et.al., 1984; Hollnagel et.al., 1986; Filip,1989; Rădulescu & Gheorghiu, 1992; Filip & Bărbat, 1999; Vlad,1999,2001).

a) Functional requirements:
For the time being, it is accepted that "automation, artificial intelligence and neural nets cannot replace human operations" (Terano,1991). A DSS does not automatically reach solutions. It helps (collaborates with) the decision-maker for yielding the solution. The man is supported not replaced by computer. He is the main and final actor in the decision-making process. For this, the decision-maker is organically included in the computer-implemented procedure for decision-making, by a *strong interactivity* with the DSS.

The interactive decision models represent a promising solution for the poor-structured problems. They must allow the decision-maker himself to insert his own estimates for the key-parameters, to modify the models and to obtain and judge the results in different conditions/constraints and under different criteria/objectives.

In principle, a decision solution transforms the initial state of the driven system into a target state. In the poor-structured problems, all these three elements (initial state, decision solution and target state) have poor structure (uncertainty). Consequently, the basic objective of a DSS is to support the decision-maker (to offer aggregated information and knowledge) for structuring (clarifying) all the three elements. This clarifying activity needs iterative passing through all the steps of decision process (§.2) and the DSS must support all of them, by providing the appropriate functions to help:

- Acquisition of information concerning the problem;
- Problem identification/definition (objectives, constraints, etc.);
- Establishing the model for solving the problem;
- Establishing the variants/options (land units, land utilisation types, technological options, etc.); Management of data bases (both attributive and spatial - GIS) containing different data sets (we must use the historical data because of data acquisition costs), at appropriate scales, concerning the land units and land utilisation types, including socio-economic data, sustainability data and specific data to use the probabilistic and fuzzy methods for coping with the uncertainty;
- Establishing the appropriate models for land evaluation (LE); Management of a "models base", containing different LE models for different types of LE methods and criteria (FAO, 1976, 1983; van Diepen et.al., 1991; Davidson, 1992; Smyth et.al., 1993; Rossiter,1994,1995; Vlad,1997a,b,2001): limitation methods, parametric methods, heuristic combinations; deterministic (dynamic simulation) models, financial/economic/social evaluations, risk analysis, sensitivity analysis, knowledge-based, fuzzy, geostatistics, etc.; Management of a "models base" containing different technological recommendation models: fertilisers, tillage, irrigation, drainage, erosion control, pollution control, etc.; Management of a "models base" of general algorithms: pedotransfer functions, indirect estimation of unavailable data, spatial data interpolation, climatic/weather scenarios generators, data converters between different formats, statistical data processing, etc.;
- Establishing the appropriate models for multi-criteria decision-making to help choosing the best solution variant; Management of a "models base" of multi-criteria methods:

multi-objectives (mathematical programming - linear /non-linear /stochastic /fuzzy /interactive), multi-attributes (maximum weighting average, Wald, Laplace, Hurwitz, Savage, ELECTRE, etc.), models of decision processes (normative, "limited reasoning", "default favourite") and others (sub-optimal, post-optimal, "try and error", "controlled search", knowledge-based, fuzzy, predictions, admissibility/optimisation tests, etc.);

- Monitoring and revising the decisions;
- Friendly interfacing decision-maker with the DSS: access to the DSS functions; parameter exchange; entering/modifying/retrieving the data and models, including knowledge-based; report/graphics generators; explanations and help facilities; etc.

b) Operating requirements:

- Flexibility, reliability and ease in use;
- System integrity and security;
- Adaptability to different user requests.

c) Implementation requirements:

- Integration of different information technology methods - conventional (including GIS) and knowledge-based;
- Ease in developing different improvements and including new functions (open system).
- Using the prototyping method (evolutive development, adaptive design) for DSS development. 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 personalised;
- Using different methods for integrating different system components (weak-coupled and close-coupled; file and message program communications). Proposals for close-coupled implementations are given by Vlad (1994,1996,1998,2001) and methods for weak-coupled implementations are outlined by Vlad (1999,2001).

5. DexTer - A DECISION SUPPORT SYSTEM FOR AGRICULTURAL LAND MANAGEMENT IN ROMANIA

The above requirements and, also, the Romanian conditions (particularities) have been taken into account to design the "***DexTer***" system ("***De***cisions & ***ex***pertise on ***Ter***rain") - a decision support system for the agricultural land management in Romania. The system is structured in three conceptual subsystems: communication (user interface) subsystem, knowledge (models base and data bases) subsystem and problem solving (decision process model) subsystem. The system must provide the information and knowledge necessary for the main public and private land ownership requirements in Romania, so that for system conception the focus was directed to the models base and the main models that answer these requirements were identified. A set of land uses taken into consideration (26 crops and 5 technology types for each of them) was established and the main requested land evaluation models were chosen (and some of them improved or new-developed): land productivity (parametric multiplicative, additive and hybrid methods and crop yield simulation models); land capability; land improving/amelioration capability/requirements; soil tillage recommendations; soil fertilisation and liming recommendations; site assessment; economic, social and sustainability evaluation criteria estimation; evaluation of the land having perennial vegetation; evaluation of the compound land units and compound land uses; evaluation of the variability of the land use outputs and cadastral evaluation. Two types of land use planning models (merging of the parcels of an owner and crop planning at farm level) have been elaborated. The main data base of the decision support system is the data base of the agricultural qualitative cadastre, which provide the main data necessary for the main models taken into consideration. Fourteen tables of data and their relations were completely defined and 81 (pedo-)transfer functions for calculation or estimation of 63 land parameters were identified to implement the data base.

6. CONCLUDING REMARKS

1. At present, important land-related problems must be solved. This requires an advanced land management using appropriate computer-based support tools.
2. The concepts of decision process and "land-use" system help the system analysis of the problems and activity of land management process - in order to develop a computer-based support tool. This analysis has demonstrated that the land management is a "poor-structured" problem and to solve it an appropriate class of computer applications must be used - the decision support systems (DSS).
3. A DSS for land management must put into practice some important general and specific requirements:
   - the decision-maker must be included in the system; he is supported not replaced by computer; he is the main and final element in the decision-making process; the DSS must be strongly interactive;
   - the basic objective of the DSS is to support the decision-maker for structuring the problem in all the steps of the decision process, including information acquisition, identification/definition of the problem, establishing the variants/options, establishing the appropriate evaluation and multi-criteria decision models, monitoring and revising the decisions, etc.;
   - complex data bases and "models bases" - containing different data and models for land evaluation, multi-criteria decision-making and for decision process - are necessary;
   - different operating requirements (flexibility, reliability and ease in use, system integrity and security, adaptability to different user requests), as well as an advanced user-interface are also very important;
   - besides the traditional disciplines (soil science, agronomy, climatology), different "auxiliary" disciplines must participate in the DSS design, including economics, sociology, mathematics (operations research, probability theory, fuzzy set/logic, etc.), decision theory, system analysis/engineering, artificial intelligence, etc.;
   - computer implementation of such DSS must use the prototyping method and must integrate different information technology methods - conventional (including GIS) and knowledge-based; the built DSS must be an "open system" (easily and "on going" modified and developed by adding new functions).

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