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DESCRIBING AGRICULTURAL LAND USE.

(A proposal for procedures, a data base and a users' manual to be incorporated in a FAO Soils Bulletin)

A draft

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contents

Preamble

The following report presents the results of a study carried out at the request of Food and Agriculture Organization of the United Nations. The title of the contract is: Draft Soils Bulletin: Components, nomenclature, and classification of land use types. The terms of reference for the contract involve:

- a prototype database for the storage of aspects of agricltural land use provided on disk with necessary instructions for use.
- a report on concepts for the description of those aspects of agricultural land use that influence the bio-physical functioning of both produced plant and animal species and the natural environment. This report should form the basis for a FAO Soils Bulletin .

The report discusses the development of an appropriate concept for the quantified analysis of land use and the classification of agricultural land use. It intends to initiate and stimulate the discussion on the subject in order to elaborate the proposed approach and concepts.

The intended audience includes:

- Professional land evaluators in developing and developed countries,
- Program officers and scientists working in agencies providing inputs to land evaluation such as Ministries of Agriculture, Forestry, Fisheries, Natural Resources, Planning, etc., and Agricultural and Economic research institutes.
- Professionals, interested in related issues such as sustainable land use, land use database design and development and Geographical Information Systems.

The work was executed under supervision of a group of experts from the following institutes:

- International Institute for Aerospace survey and Earth Sciences (ITC), Enschede, The Netherlands

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Detailed feedback was provided by Messrs J. Antoine, R. Brinkman, M. Purnell, D. Sanders, and Sims from FAO head quarters in Rome, and by Mr. A. Remmelswaal. Mrs. H.J. Scholten-Koerselman from the department of informatization and data communication of the Wageningen Agricultural University and ir. C. de Bie form the ITC, Enschede provided much support with the development of the datamodel for the database and with the programming of the user interface.

Readers are invited to comment upon the concepts and database presented in this report. Reactions can be directed to the authors at the following address:

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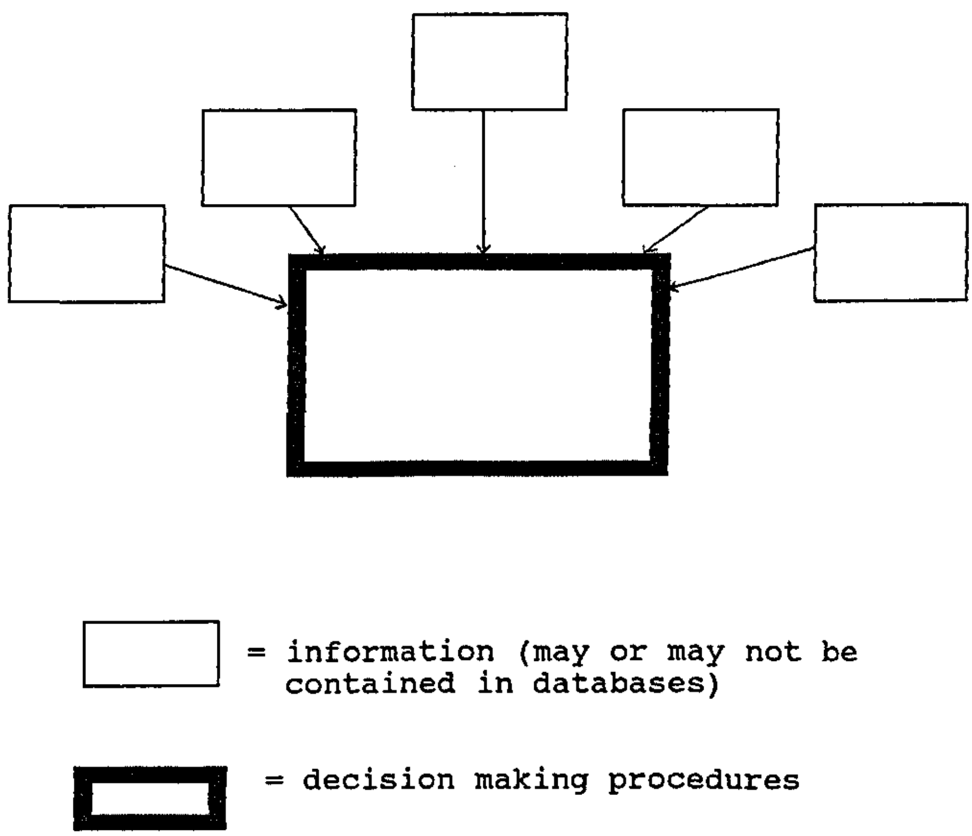
I. Decision-making on wise use of land resources

It needs no argueing that more than ever before in the course of human history, the way people use the land has become a source of widespread concern for the future of the world. Land use in developing and developed countries is increasingly subject to population pressure, environmental degradation and pollution and perhaps even climatic changes. The inability of many developing countries to meet the growing and changing demands for agricultural products, as well as the difficulties of nearly all countries in balancing environmental and production needs, present 'mega-scale' issues. More than ever, therefore, the need for rational planning to make optimal use of the land resources at our disposal is evident. FAO has been involved in the establishment and the linking of data bases to promote land use planning on global as well as national scales.

A general structure of decision making processes is presented in figure 1. This structure is also applicable to land use planning. Simply put, the following information (sometimes contained in data bases) is needed as a starting point of the planning and during the course of the planning process:

1. information on land resources: climate, soils, physiographic and hydrological characteristics of land units. This type of information is the most developed: there is an internationally agreed system of describing, interpreting and aggregating point data on soils. There is also a digital world soils map, as well as many sources of data at national and regional levels.

Figure 1. General structure of the decision making process.



sources of data at national and regional levels.

2. information on crop, animal and vegetation species characteristics: phenological and physiological characterisation. This information is available on most major crops (although not yet in a universal data base form), and on some animals, even though it has not been tested for all production circumstances and crop cultivars and animal breeds. Information on natural flora and fauna is usually much less detailed.

3. information on production techniques used to produce different commodities: this involves the sequence of operations executed during the production of the commodities and the implements and inputs used.

4. point data on specific combinations of crops, trees or animals, production techniques and land resources: outputs like yield, erosion etc. and e.g. the time needed for ploughing.

5. information on the socio-economic and political factors influencing the land use environment.

6. detailed objectives on what is to be attained through land use planning.

The processing of information from these sources during land use planning falls into two complementary categories:

a. an assessment of the bio-physical feasibility and sustainability of the technical options: the combination of (data base) information with expert judgements and simulation modelling will yield a series of physically attainable combinations that are then translated into estimated actual input requirements and outputs. The (statistical) information on point data as mentioned under point 4 above will often be great help in checking reliability of estimated inputs requirements and outputs.

b. an assessment of the socio-economic feasibility and acceptability of the options selected under (a): in confrontation with socio-economic boundary conditions and societal objectives a procedure of multiple goal decision making in which the costs (inputs) and benefits (outputs (both positive, like yield and negative like erosion)) are compared to the objectives. The final outcome is a preferred scenario of 'best' (preferred) land use.

This division between biophysical and socio-economic procedures does not indicate a time sequence. The process of decision making on land use is clearly iterative, moving from technical to socio-economic assessment with increasing precision on the options. It is also possible that additional information is collected as the need arises.
A more detailed prototype of the structure of a partly computerized decision support system is given in appendix 1.

II. The need for detailed and quantified descriptions of land use

Decision-makers require not only descriptions of land, but also of land use at all relevant scales, from the individual farmer's field to the level of broad agro-ecological regions. Furthermore, land use planning involves not only the analysis of existing and alternative land uses, but also the matching of alternative options with land resources to analyse their bio-physical and ecological feasibility and sustainability, and their socio-economic acceptability and impact. This implies that we dispose of ways to describe and analyse current and future land use alternatives. This is not as easy as it seems.

Unfortunately, there is a great discrepancy between the degree of detail in the description of the land, and the broad terms in which land use is generally defined. While tremendous progress has been made in the standardization and quantification of climate, soil and vegetation descriptions and classifications, similar descriptions of land use are still in their infancy. This is particularly worrying since it limits to a great extent the accuracy with which we can match land and its uses. Quantified analysis of the processes in soils and crops and interactions between these are increasingly used. However, this refers nearly always to well-controlled experimental or simulated conditions in which the timing of the operations and control of weeds, pests and diseases are optimal. The introduction of the real time sequence of operations, as performed for the production of commodities, into these quantified analyses is still hardly developed.

So on the one hand we are faced with a great and increasing discrepancy between land resource data and land use data. At the same time, in the course of the numerous agricultural and regional development projects of the last decades many forms of data on land use has been collected. This information is often hardly accessible, because it is hidden away in survey reports, and is difficult to utilise or to update because no unified descriptors of land use are agreed upon. Moreover, there is currently no basis to compare land use in different regions or to extrapolate from one region to another. For example, how are we to know that upland rice grown in Mindanao is comparable, in what way, with upland rice in Sierra Leone? How are we to use the existing wealth of information on farming practices?

We would like to argue here that any effort to describe land use must involve quantification. At any level of detail (or scale) quantified outputs of combinations of land use and land requires that both the attributes of land and the inputs of land use are given in quantified terms. Quantification of inputs into land use scenarios and of outputs of combinations of land and its use are not only essential for the sake of bio-physical impact studies but also for socio-economic impact studies. For example, if an input like fertilizer is only known in vague, non-quantitative terms (like 'medium level' fertilizer application), the corresponding yields can only be defined in terms of 'medium level yields'. This means that little can be said about the socio-economic relevance of such input (fertilizer use) and output (yield) specifications, apart from the fact that they are likely to relate to those farming systems which use medium level technology and are partly market oriented. If, however, inputs are defined as: between 25 and 60 kg/ha of NPK (15-20-15) fertilizer, applied 10 to 20 days after sowing during weeding, the effect on yield can be assessed much more accurately in terms of kg/ha of harvested biomass. As a result, the effect of fertilizer treatment on crop performance can then include an assessment of required changes in labour requirements. The quantified terms in which inputs (fertilizer and labour) are thus described also allow an assessment of socio-economic impact (costs of inputs, need for labour inputs at different times of the year, benefits of outputs) and feasibility (labour availability, benefit of the inputs compared to alternative uses of capital, etc.). In other words, no realistic assessment of land use is possible without a quantified integration.

Whenever combinations of land use and land are analyzed, the potential of selected land areas for the production of selected commodities (crops, livestock, forest, etc.) is assessed. Next, production levels of the promising commodities (outputs) are assessed with the production management defined in the alternative land use options. Production management includes inputs of agro-chemicals and labour, timing of operations, traction source and implements used for operations, etc.

Both inputs and outputs of land use can only be specified in relation to land. We cannot decide on optimal land use on the basis of average yield figures alone. Outputs of any agricultural activity are linked to both the inputs applied and operations executed by the land user and to the land resources in their widest sense, including weather, soil, hydrology, pest, weed and disease pressure, etc.

General statements like :

-- Maize requires X kg of fertilizer and Y hours of labour to produce Z kg of grain per hectare, or

-- On land A Maize can produce N kg/ha

make no sense.

The only possible statement type is:

* **Maize on land A produces Z kg/ha when X kg of fertilizer is applied, Y hours of labour is spent on weeding, tillage, etc. and operations are timed in a given way.**

Therefore the unit of analysis of land use is the combination of land, commodity and production management and never either of these in isolation. In Land use Planning terms this means that the Land Use System has to be the unit of analysis.

III. What type of land use data are required? Components of land use data.

Land use comprises physical, ecological as well as socio-economic relations. Examples of physical and ecological aspects are the relationship between the amount of nitrogen applied at sowing and yield on a given type of land or the hydrological balance of the land when cropped with a well fertilized dense stand of maize. Examples of socio-economic aspects are the fact that at farm level a number of activities, including production of several commodities and off-farm employment, are often combined, or the fact that farmers have a number of goals which may include profitability but also self sufficiency in food, risk avoidance, etc. A full insight in the socio-economic feasibility and acceptability should include an analysis of combinations of land uses at farm level and of goal functions of the farm household. These examples demonstrate that there is a fundamental difference between the bio-physical and the socio-economic aspects of land use systems. The first aspects determine the yield, the changes in the environment, etc., in other words, they define the relations between land users and their bio-physical environment. The second aspects deals with the land user as part of human society.

Whatever the socio-economic conditions, however, bio-physical input-output relations will always need to be defined. Whether maize is grown as an unfertilized intercrop by a female farmer or at high input levels on a commercial farm, the response curve of maize to nitrogen application under similar ecological conditions will be the same. That is why describing and analysing bio-physical land use is a first priority. Outputs of bio-physical land use include erosion losses, salinisation, amount of the produced commodity, crop residue, changes in pest populations etc. Only quantification of all inputs and outputs allows an assessment of (ecological) sustainability and comparison of land use across regions. Finally, a quantification of the inputs and outputs then allows an economic analysis which will provide insight into the profitability of the different land use options.

We distinguish, therefore, between bio-physical relations in land use analysis and the socio-economic boundary conditions that govern land use. These boundary conditions and goal functions influence the socio-economic applicability of land use options and should be analysed using methods from the economic and social sciences. So there are two groups of attributes (properties) of land use:

1) the data on commodities and operations
2) the socio-economic boundary conditions and goal functions of land users. [1]

[1] This distinction is not made in the description of land use attributes as mentioned in the framework for land evaluation (FAO, 1976), and is also not made in many of the agricultural survey reports.

IV. The bio-physical attributes of land use

A number of bio-physical attributes of land use has already been mentioned implicitly or explicitly above. The full list is given in table 1. A set of data obtained at plot level on the management of one stand of plants or herd will be called the operation sequence.

Table 1. List of attributes of land use which influence the bio-physical functioning of land use systems.

- *the choice of species*
- *the operations*
  - *their timing*
  - *the traction used for their execution*
  - *the implements, other than traction source, used during their execution*
  - *the inputs applied*

The choice of species should be seen as the decision taken by the land user to sow or plant a certain crop or crop mixture, or the decision to breed a certain animal or mixture of animals.
Operations are those actions undertaken by a land user prior to, during or after the production of a commodity which influence the production of the grown or bred species and/or the bio-physical environment.
Of each operation four types of information have to be provided. The timing relative to the production

cycle of the grown or bred species, the source used for locomotion, the implements used to execute the operation and the inputs applied during the operation.

The timing of each operation has to be defined for two reasons:

i timing of an operation relative to the production cycle of a species provides information on the possible effect of the operation on the bio-physical functioning of the species, and on the bio-physical impact of the operation on the environment.

ii timing also defines the need for availability of labour, implements and inputs at every moment during the year.

The source of locomotion has to be defined because:

i this indicates the draught power with which the operation is executed, especially important for soil tillage operations

ii this indicates the requirements for the availability of draught power, or human labour.

The implements have to be defined for the same reasons as mentioned for source of locomotion:

i it indicates the type of impact on the grown/bred species and its environment (e.g. weeding efficiency of a hand tool versus an animal drawn weeding equipment)

ii it rpovides requirements for availability of equipment

The material inputs have to be defined because:

i they change availability of yield determining factors (water, nutrients, light, temperature) and the population dynamics of yield reducing factors (weeds, pests and diseases)

ii this information indicates requirements of availability of inputs and costs of the production of the harvested commodities.

This set of attributes of land use is further elaborated in the attached software for a prototype data base and the corresponding users' manual introducing the reader into the data entry and data query system. This data base needs further development before it is fully ready for testing at the field project level. Please note that the data base may still contain errors typical of an untested first version.

V. Aggregation of land use data at different scales

Three levels of analysis are generally distinguished in LUP which are related to different scales of mapping in land evaluation. The most global planning takes place at national or regional level (mapping scales 1:1-2,000,000). The most detailed planning takes place at local or village level (mapping scales between 1:10,000 and 1:50,000). Regional or district planning occurs at intermediate mapping scales (between 1:100,000 and 1:500,000).

In analysing land use, as in analysing land, we need scale neutral units. The LUS is such a unit (although in the minds of many people mainly limited to most detailed, i.e. field level).

For national level planning the bio-physical aspects of land use should be given in broad terms: crop and animal species in groups as cereals, annual cash crops, dairy farming, forest trees, operations and inputs in general terms. These general terms should be adapted to issues which are of importance at national level. For instance, total amounts of fertilizer or chemicals for crop protection, capital goods to be imported for storage or traction, etc. The choice of grouping of (crop) species, operations and inputs will depend on the situation and the goals defined for the land use planning.

National plans may give directions for the definition of regional goals, and often limit the land use options that should be considered in a land use planning, e.g. by determining how much land should be used for a nature reserve, or reforestation. The description of land use is more detailed at regional level than at national level. The commodities for instance, may be grouped into sweet potato, other root crops, cotton, grain legumes, other annual cash crops, etc. The labour film is likely to be expressed in monthly labour requirements. Also the combinations of land use options at farm level and their (in)compatibilities should be analysed.

At local level the entire set of operations, capital goods, consumable inputs,and labour films are needed to provide full insight in the feasibility of alternative land use options for individual land users, given individual and communal goals and capabilities.

It follows from the above that not the same amount of detail is relevant or appropriate at each of the levels. Moreover, at higher level not all details will be available, and it would be very inefficient and virtually impossible to generate all information at e.g. national level in the amount of detail important at farm level. Even if less detail is available or required, the need for a quantitative analysis remains, so the data must be formulated in terms of quantitative attributes.

One of the aims of a detailed description of land use is that it enables us to compare and classify land use across regions. This is very important, because it allows us to extrapolate results from one LUS to another, and would minimize the need for experimentation. Especially when we are concerned with long term processes (as is the case in all assessments of sustainability), such comparability is essential. One great drawback in classifying land use in contrast to soils or vegetation is the dynamic nature of the variables concerned, and the differences in rates of change between the variables, say between seasonal variations in land cover and multi-annual patterns. Moreover, there may be considerable idiosyncratic differences between individual land users, due to, e.g. household composition, access to credit, levels of inputs etc..

Classification of land use is a matter of considerable difficulty and complexity as can be derived from the literature on land use and agricultural typology and classification. There is no agreement whatsoever on an acceptable universal system of classification. In fact, nearly all existing attempts to classify land use suffer from a number of drawbacks:

- the lack of a sound definition of the units of analysis: these may range from field (plot) to farm and region, and often include mapping units;
- the utilization of overlapping or unclear criteria for classification (e.g. land use intensity as well as water control or 'productivity');
- the nearly ubiquitous absence of quantitative class boundaries (critical or threshold values of the criteria) making an assignment of land use to a specific class rather subjective;
- the combination of land use with other features such as land cover and land or climate characteristics that may influence land use but are not inherent features of land use;
- the multitude of objectives of land use classification, often closely tied to a regional or

disciplinary focus.

It appears of great importance to distinguish between two different ways of clustering land use data that are often mixed in the literature: aggregation and classification.

- Aggregation is a pragmatic exercise leading to a typology. Soils can be aggregated into land units on the basis of e.g. their drainage capacity, if this is of major importance in relation to a land use planning problem. Land use can be aggregated into say 'land use units' on the basis of e.g. the presence or absence of perennial crops among the crop species. In other words, the focus and goals of land use planning are of major importance for the rules that should be applied while aggregating. Rules for aggregation of entities tells something about their functioning in relation to human activities.
- Classification is a conceptual exercise. Soils are classified on the basis of attributes that are supposed to determine their genesis and their physical functioning.

The conceptual framework and the data base that are discussed here are a far cry from any attempt at classification. However, the field testing of the data base as well as the continued development of the conceptual framework will hopefully provide a basis for further work on land use classification. We would like to suggest that the following considerations be taken into account when dealing with the aggregation and classification of land use:

- the classification must be comprehensive and universally applicable, i.e. dealing with all possible land uses. The classification should also be strictly hierarchical and contain mutually exclusive classes.

- the classification should be based on a limited number of measurable, quantitative criteria that deal with inherent features of land use, i.e. those that are directly related to the production operation sequence and exclude criteria that deal with factors indirectly affecting land use such as climate.

- classification of aggregated entities like land units or 'land use units' makes no sense (although constructing a typology may be helpful for some limited purposes). A classification of operation sequences might be possible and relevant if we can define a set of criteria related to their bio-physical functioning.

- aggregated units must be mappable. Similar to land units, land use units must be defined in such a way that they can be delineated on a map at an appropriate scale.

- it follows from our analysis that it will be very difficult to design a classification covering the field, farm and higher units in the same universal classification. It seems most appropriate to deal with the 'watershed' or landscape unit and some farm characteristics in macro-level classifications, while classification of individual farms and plots can only be the subject of more detailed classifications (at the national and provincial scales).

7. conclusion

A universally acceptable data base on land use is not an easy undertaking, both in conceptual and in computer programming terms. Such a data base can only function if it forms part of a wider context of related data bases on land resources and crop requirements and is used in the framework of Land Use Planning with clearly defined societal goals and constraints. We have emphasized the need for a quantitative analysis of biophysical aspects of land use, by taking the **operation sequence** as a starting point.

(We also feel that it is not possible to strive for a unified taxonomy of land use independent of the socio-economic context; but it seems possible to classify land use on the basis of biophysical or ecological characteristics).

The data base presented in the users' manual still meets with a great number of limitations and needs extensive testing before it can be adapted and applied on a wider scale. There is no doubt in our minds, however, that the effort is very worthwhile and has considerable off-spin in making us rethink some of the concepts and units used in Land Use Planning and Land Evaluation.

Glossary

- Commodity: Any population of plants or animals, or parts thereof, grown, reared and/or harvested by man.

- Commodity management unit: A sole crop, intercrop, single animal species or mix of animal species, grown or reared as one unit. The commodity management unit is a part of a husbandry system (q.v.).

- Crop Sequence: A number of consecutive crops grown within one year.

- Farming system: A class of similarly structured farm systems (q.v.).

- Farm system: A decision making unit, comprising the farm household and one or more Land use Input and Operation types, that produces crop and animal products for consumption and sale.

- Husbandry system: The actual sequence of operations, including their timing, applied inputs of labour and capital in physical terms and used implements and traction sources, carried out to produce one or a number of specified commodities as executed by any individual land user. Husbandry systems encompass crop rotations, crop sequences and/or intercrops. They can be combined into physical LUTs (q.v.) during land use planning.

- Land evaluation: The process of assessment of the performance of land when used for specified purposes, involving the execution and interpretation of surveys and studies of land use, vegetation, land forms, soils, climate and other aspects of land in order to identify and make a comparison of promising land use systems in terms applicable to the objectives of the evaluation (FAO, 1976).

- Land use planning (LUP): LUP is a form of (regional) agricultural planning. It is directed at the 'best' use of land, in view of accepted objectives, and of environmental and societal opportunities and constraints. *It is meant to indicate what is possible in the future* with regard to land use ('potentials') and what should be done to go from the present situation to the future one, in other words, how to change land use.

- Land use system (LUS): A specified land utilization type (q.v.) practised on a given land unit (q.v) (FAO, 1976). See also physical LUS.

- Land use type: equivalent to land utilization type (q.v.) (e.g. FAO, 1983 and 1985).

- Land unit (LU): An area of land demarcated on a map and possessing specified land characteristics and/or qualities (identical to land mapping unit, FAO, 1976).

- Land utilization type (LUT): A kind of land use described or defined in a degree of detail greater than that of a major kind of land use (q.v.). The detail and precision depends on the purpose. Refers to any defined use below the level of the major kind of land use. (FAO, 1976). **(In this study only referred to in connection with the FAO framework and related publications** (FAO, 1976, 1983, 1984, and 1985)

- Ley-system: A rotation of arable crops requiring annual cultivation and artificial pastures occupying the field for at least 2 years (Ruthenberg, 1980)

- Major kind of land use: A major subdivision of rural land use, such as rainfed agriculture, irrigated agriculture, grassland, forestry, recreation (FAO, 1976). **(In this study only referred to in connection with the FAO framework** (FAO, 1976).

- Physical Land Use System (physical LUS): The purely physical part of the land use system (q.v.) defined by the combination of a land unit (q.v.) and a specified physical land use type (q.v.).

- Physical Land Use Type (physical LUT): The sequence of operations, including their timing, applied inputs of labour and capital in physical terms and used implements and traction sources, carried out to produce one or a number of specified commodities.

- Rotation: Fixed sequence of crops and/or fallow grown on the same area of land over a number of consecutive years, minimally 2, including situations where more than one crop is grown annually (e.g. intercrops, relay crops and sequential crops).

- R-ratio:Percentage of crop land actually cropped in a year. Frequency of cropping in a fallow cycles (Ruthenberg, 1980)

- Sustainable land use: Land use, guaranteeing continuous productivity of land without deterioration of the land resources.

- System: An arrangement of components (or subsystems) that process inputs into outputs. Each system consists of boundaries, components, interactions between components, inputs and outputs.

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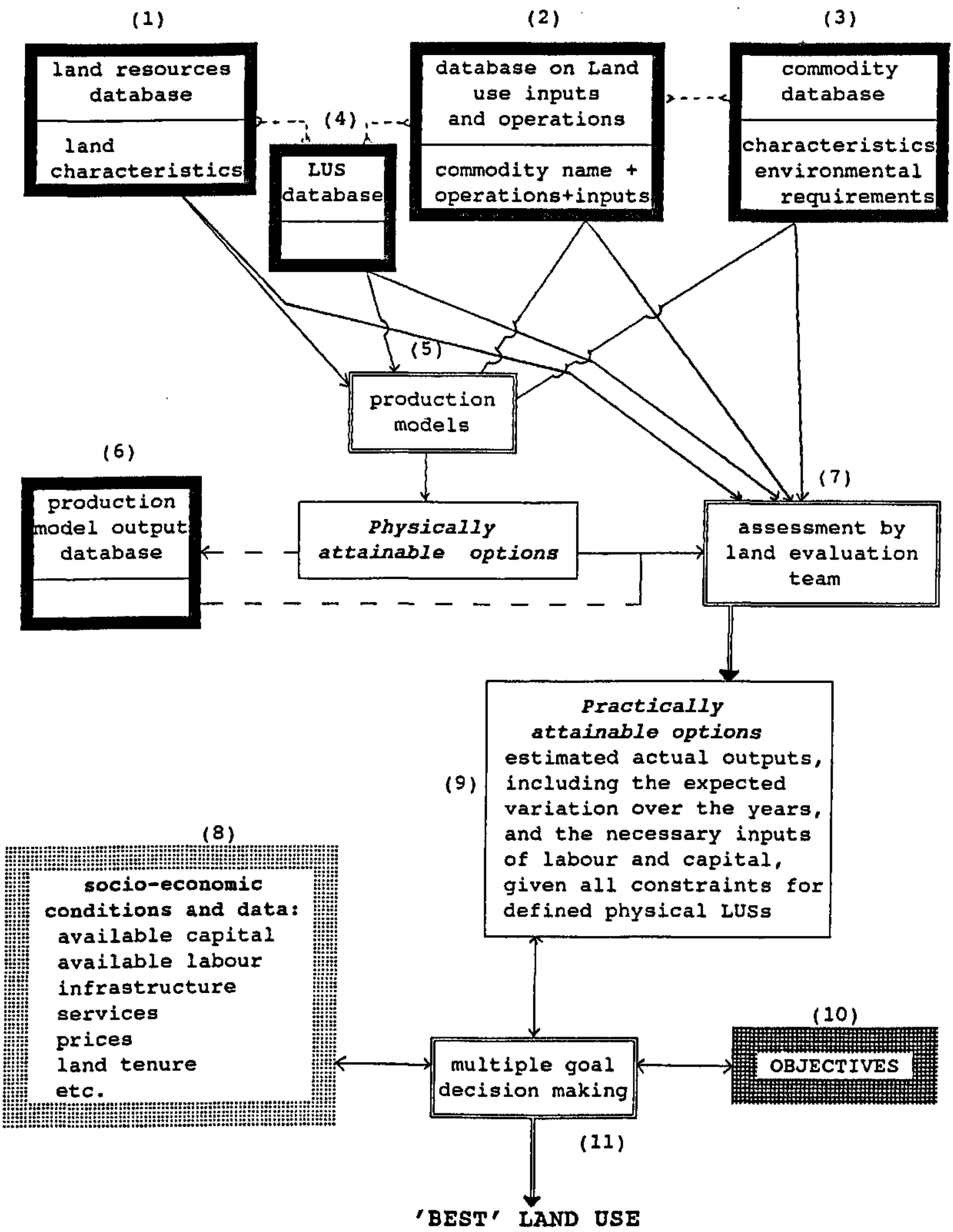
APPENDIX

Appendix 1. A possible structure of a decision support system for Land Use Planning.

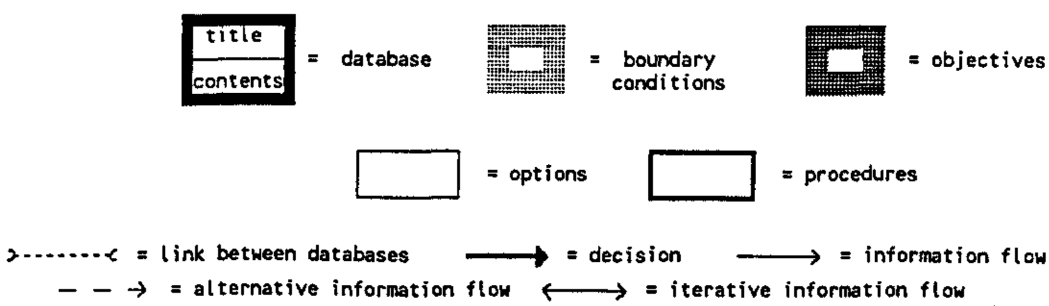


For legend and explanation of numbers see next page.

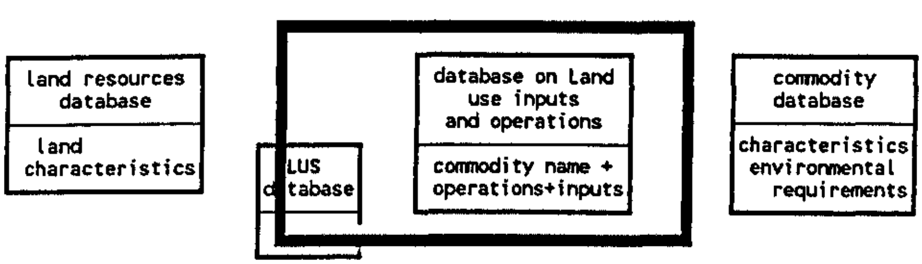
Explanation of apendix 1:

The decision support system includes a modular database containing information on: (3) phenological and physiological characteristics of commodities (crops, animals, natural flora and fauna) and their reactions to environmental conditions; (1) climate, soil, physiographical and hydrological characteristics of distinguished land units; (2) the commodities and sequences of operations and inputs (this study); (4) characteristics of land use systems (LUS) that can not be disaggregated into land unit or operation sequence information. If production models are used to estimate outputs of land use systems, this information could be stored in separate data sets in what can be called a production-model-output part of the database (5). The information in database parts 1 to 3 is used to 'construct' land use systems. Information on LUS-outputs (4), information on the socio-economic boundary conditions (8) and expertise in the land evaluation team (7) will be used to avoid 'construction' of nonsense LUSs. The outputs* of the land use systems are assessed by the land evaluation team (7), using production models (6) and/or available LUS-data (4).
The land evaluation team finally decides on the practically attainable land use options and provides estimates of their outputs (9). In the next step in land use planning this information and information on objectives (10) and socio-economic boundary conditions and individual farm systems decision functions (8) is used in a multiple goal decision making procedure (11), resulting in scenarios for the best land use under given conditions.

Legend to figure 2.



The parts of the database within the rectangle below are addressed in the present study. This includes the links between the operation sequence part and the Land use system and crop/animal parts and the link between the Land Unit and Land use system parts. Not all of the Land use system part of the database is covered here.



* outputs defined here include all plant parts (harvested and residues) as well as other outputs like soil losses through erosion, nutrient losses through leaching, salinization, etc.