A DECISION-MAKING TOOL FOR LAND EVALUATION IN THE DEVELOPING COUNTRIES

Peder Anker, Margaret Robb, Geir-Harald Strand and Bo Wang,
Norwegian Computing Center,
P.O. Box 335 Blindern,
N-0314 Oslo 3,
Norway.

ABSTRACT

In many areas of the World a rapidly increasing growth in population is putting severe pressure on the Earth's resources. It is, therefore, important that land management practices are carefully regulated. This fact is gradually being recognized by governments in developed and Third World countries alike, and more money is now being channelled into programmes which attempt to offer long-term solutions to this problem. One such programme is the Land Evaluation System which has been developed by the Norwegian Computing Center for the Soil Survey Unit of Zambia. Developed on an IBM/AT personal computer, the system requires two main sources of input data. First, the spatial data is digitized from existing soil and agro-ecological maps. Second, the potential for any given crop to grow in any given area on any given soil is recorded for a number of 'climatological potentials' and 'soil constraints'. Processing of this data allows the user to answer questions such as "How suitable is a certain area for a particular crop?" or "What is the best crop to grow in a certain area?". Output from the system comes in the form of maps either produced on an A3, 6-pen plotter or on a colour screen. Tabulated summaries can be produced on a printer.

INTRODUCTION

In those areas of the World where a rapidly increasing growth in population is putting severe pressure on the Earth's resources, the importance of careful land management practices cannot be under-estimated. This problem has been confounded in recent years by the occurrence of devastating natural disasters in just those areas where the margin between success and failure of a harvest is already very small. Governments in both developed and less developed countries have been aware of this problem for a number of years, and numerous aid schemes have been initiated to help the populations of the most badly affected areas. Within many of these schemes computer technology has played a significant role. However, it is only fairly recently that the costs of computer systems, which could help in offering long-term solutions, have reached a sufficiently low level for the less developed countries to be able to afford them. Considerable effort is now being made to develop systems which provide at least a first step in the process which could alleviate some of the severe human, physical and economic problems afflicting many countries in the World. One such programme is the Land Evaluation System which has been developed by the Norwegian Computing Center for the Soil Survey Unit of Zambia and has been funded by the Norwegian Agency for International Development (NORAD).

OVERALL SYSTEM DESIGN

Design Considerations

Land evaluation involves the integration of a number of factors: including soil properties such as nutrient availability, rooting conditions and salinity; the ways in which soils react to various farming methods; climatic variables such as rainfall, temperature, humidity, wind and amount of sunshine; topography, such as elevation, slope steepness and aspect; geology and geomorphology; and economic and technical considerations. A land evaluation system uses these factors to determine the suitability for growing certain crops in particular areas using a given set of inputs, such as the amount of fertilizer used, the availability of mechanized labour, and the use of irrigation and drainage. However, there may be a number of over-riding human factors which could influence the 'suitability' of a crop. These factors may include traditional farming practices, eating habits, religious beliefs, or societal structure. However, because of the difficulties involved in trying to measure such variables, it is usually necessary to base the design of a land evaluation system on mainly physical characteristics. This approach, of course, yields satisfactory results for determining the physical suitability for crops, but it is important that these results are interpreted in the wider human context.

Information required for a land evaluation system can come from maps, such as soil, geological and topographic maps. Climatic data may be obtained from maps or from tabulated sources. In addition, it is necessary to have a set of rules which define how this derived data should be combined in order to give the suitability for growing any crop on any soil in any location. These rules are usually collated by national agricultural or soil organisations or by international organisations, such as FAO. Clearly, the rules tend to get very complicated and numerous when all the possible combinations of soil, crop, climate, topography, geology and geomorphology are considered for any one country. In order to calculate the suitability for a particular crop to grow in a particular area, all the evaluation rules have to be resolved for the physical characteristics for the area concerned. The final suitability rating for growing a given crop in a particular area is usually defined by the suitability of the physical characteristic which poses the most severe constraint on the growth of the crop. For example, if rainfall was the most severe constraint on the growth of paddy rice in a given area, then the suitability for growing paddy rice in that area would be equal to the suitability rating for rainfall.

Output of the results from an evaluation may be in the form of maps, graphs or tables. By defining suitability as a number of classes ranging from 'very suitable' to 'not suitable', maps can be used to show the suitability of growing a particular crop over a whole country or over a region. Graphs can be used to show which characteristics pose the most severe constraints on the growth of a particular crop. Tables can be used to show summaries or derivations of evaluation results. However, the type of output which is appropriate for any given user may have to be considered carefully. For example, it may be necessary to take into account the fact that farmers may be illiterate or that their map-reading abilities may be very poor or that a numerical suitability rating may mean very little when a farmer measures the success of a crop on the its ability for feeding his family. On the other hand, for agricultural planning purposes, a map showing the suitability for growing a particular crop in a country may be a much easier tool for decision-making than long lists of tabulated results.

System Description

The Land Evaluation System developed at the Norwegian Computing Center (figure 1) incorporates data relating to many of the physical properties of soils, the effects of soil erosion, soil workability, and several climatic variables. A soil map and an agro-ecological map are used as the two major sources of input of spatial data. The former map shows the distribution of soils, and the latter shows agro-ecological zones in which each zone is defined as having homogeneous climatic properties across its area. By overlaying these two maps, one obtains a set of polygons, or geo-units, and to each geo-unit an agro-ecological zone number and a soil type can be assigned in order to identify the climatic and soil characteristics which are to be used in the evaluation process.

The evaluation rules used in this system contain information on the suitability for any crop to grow in any given agro-ecological zone on any given soil for a number of 'climatic potentials' and 'soil constraints'. The 'climatic potentials' are defined as a number of climatic variables relating to: radiation, temperature, humidity, and precipitation. The 'soil constraints' are defined as soil variables relating to: oxygen availability, nutrient availability, the possibility of deficiencies of important minerals, salinity, alkalinity, erosion hazard, soil degradation hazard, and soil workability. Suitability is defined in one of five classes from 1 to 5, and these indicate a range from 'highly suitable' to 'not suitable' for growing a particular crop.

When data from the maps and the evaluation rules are combined, it is possible to produce maps showing the suitability for a given crop to grow in all the areas (geo-units) in a region or to produce maps showing which crop grows best in all the areas in a region. Results can also be produced in tabulated form.

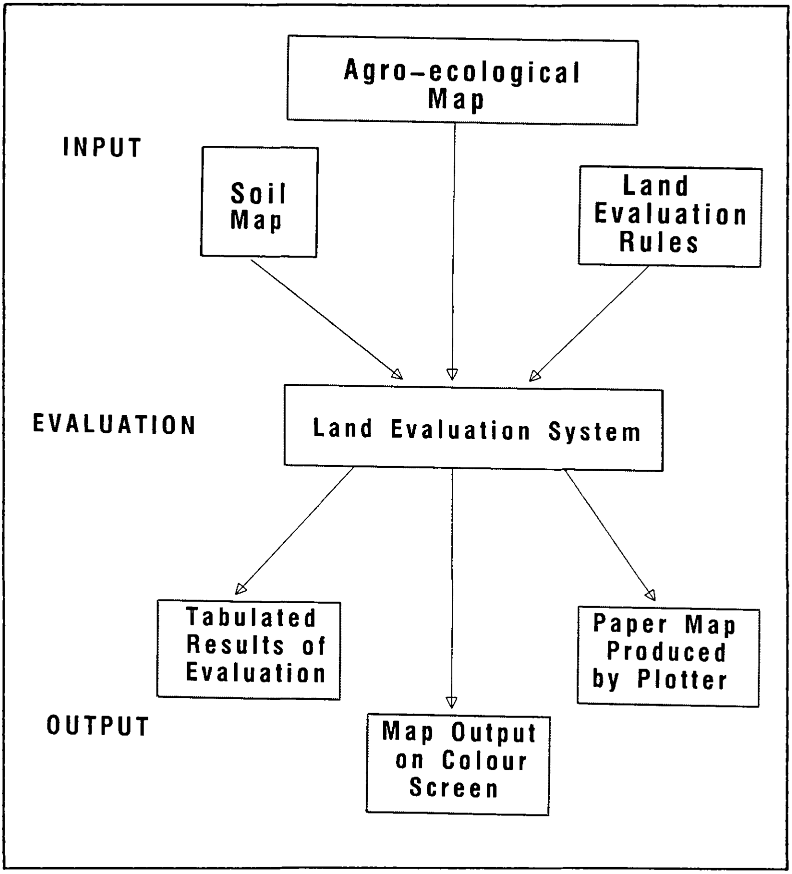

Figure 1. General Structure of the Land Evaluation System

IMPLEMENTATION

Introduction

The system is implemented on an IBM PC/AT with a 20 Megabytes fixed disk and operating under MS-DOS version 3.1. The peripheral devices attached to the PC/AT are as follows: monochrome monitor, colour monitor, printer, Hewlett Packard A3 6-pen plotter and Calcomp 15" digitising tablet. A special variant of PASCAL, Turbo PASCAL, was chosen as the main programming lauguage.

The three parts of the system shown in figure 1 have been programmed in eight major modules :

1. INIT - initialization module
2. READEVAL - data entry module
3. GEODIGIT - digitizing module
4. UPDATE - update module
5. MANEVAL - manual evaluation module
6. GEOEVAL - geo-evaluation module
7. DISPLAY - module for displaying previously generated maps
8. HARDPLOT - plotting module.

Input

Input to the system is carried out in four stages:
1. initializing the system (INIT) ;
2. entering the land evaluation rules (READEVAL);
3. digitizing the overlay of the agro-ecological map and the soil map (GEODIGIT);
4. updating the existing data (UPDATE).

The initialization is carried out by module INIT. The data needed to set up the system are entered here. These include the names and codes of all agro-ecological zones, soils, crops, 'climatic potentials' and 'soil constraints' which are to be used by the system. The dialogue between the user and the system is in tabulated form using the screen-oriented facility provided by Turbo PASCAL. Output of this module is a number of sequential files, each one containing the data relating to one of the items mentioned above.

After the initialization, the land evaluation rules are entered by invoking module READEVAL. At a scale of 1:2.5 million Zambia consists of 60 agro-ecological zones, and at this scale the rules use 11 major soils, 13 crops, 11 'climatic potentials' and 24 'soil constraints'. Obviously, if the suitabilities for every combination of zone/soil/crop have to be included in the system, then the number of items to be entered is very large. To avoid this problem all possible combinations are assumed to belong to suitability class 1 for every 'climatic potential' and 'soil constraint', and only combinations which have suitability classes other than 1 are entered specifically. The READEVAL module creates two files for each agro-ecological zone: one contains all the data relating to the 'climatic potentials' for a zone, and the other contains the 'soil constraint' data.

Digitizing of the overlay of the soil map and agro-ecological map is carried out by module GEODIGIT. During the digitizing process, each geo-unit is assigned an agro-ecological zone number and a soil identifier so that there is a direct correspondence between the spatial data and the evaluation rules. The outcome from this module is a set of binary geodata files which are used by the plotting routines later on.

Occasionally, new agro-ecological zones, new crops or new soils may be introduced to the system, thus the data files have to be updated. This can be done by invoking the UPDATE module. Since the updating process is very similar to the data input in the READEVAL module, many of the procedures used in the READEVAL module are also used in this module. The update operation is limited to introducing new zones, new soils or new crops to the system.

Evaluation

There are two modules which are used to compute evaluations: MANEVAL, the manual evaluation module, and GEOEVAL, the geo-evaluation module. The evaluation modules are able to compute two basic types of evaluation: firstly, "How suitable is a certain area for a particular crop?", and secondly, "What is the best crop to grow in a certain area?". The evaluation is computed by using either all 'climatic potentials' and 'soil constraints', or only some of them. As was mentioned earlier, the evaluation is based on a "worst case" principle: for a specified crop in a given region growing on a given soil, every potential and constraint has a certain suitability, and the lowest suitability class is taken to be the final result. The result of an evaluation is displayed in text form on the monochrome monitor (figure 2), and it can also be output on the printer.

GEOEVAL performs a similar function to the MANEVAL module except that the evaluation is made for all areas in a given region and the results are displayed in the form of a map on the colour monitor. A total of 15 suitability classes can be produced by the evaluation, but to present all of them at the same time on the same map would be difficult. Therefore the results are grouped into 5 categories: the first class is used for areas where the limitations on growing a crop are negligible, and the fifth class is used for areas where the limitations for growing a certain crop are very severe. Each class is represented by a different shading on the map displayed on the colour monitor. When the evaluation involves determining which is the best crop to grow, a different shading is assigned to each crop. Like the MANEVAL module, the tabulated results are also displayed on the monochrome monitor, or can be printed out. A file containing plotting instructions is generated and saved so that the map can be produced again at a later stage without having to re-compute the evaluation.

```
Result from Evaluation:
Zone : 3-e
Soil : Podzol
Crop : Wheat

Potentials :
Radiation, sunshine
Occurrence of frost
Occurrence of relatively low air humidity

Constraints :
Inherent nutrient availability
Rooting conditions

The result of the evaluation is :
Potential Class : 2
Constraint Class : 3
Suitability Class : 3
```

Figure 2. Text Output from the Land Evaluation System

Output

The last stage is to present the results of the evaluation, and in order to do this two modules are available: DISPLAY which draws a map on the colour monitor and HARDPLOT which makes a hard copy of the map on the plotter.

Module DISPLAY uses the file generated by the module GEOEVAL to draw a map showing the evaluation results. This module can also be used to check that the digitizing done in module GEODIGIT is correct. In the module HARDPLOT, plotting instructions are entered into a batch file, and the hard copy map is produced by executing the plotting instructions one at a time. The user may define the colours and types of shading of the hard-copy map. In addition text and a map legend can be defined and positioned by the user. An example of the map output is shown in figure 3.

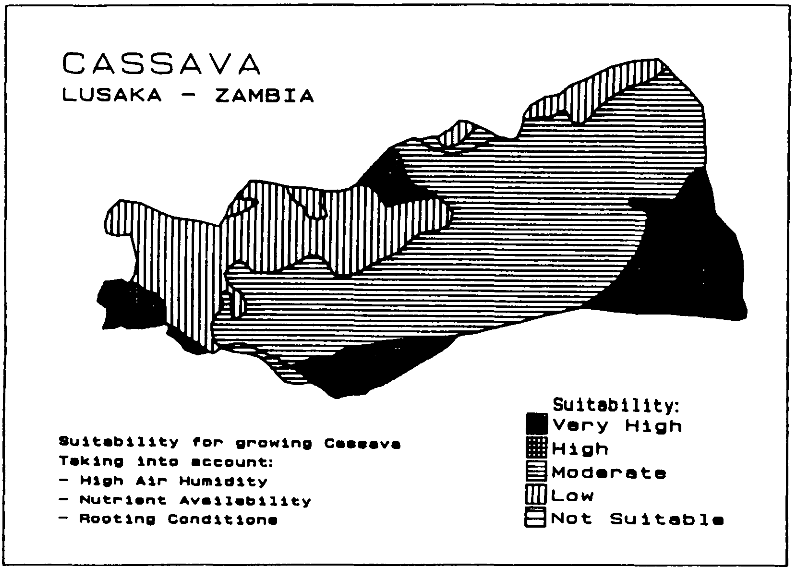

Figure 3. Hard-copy Output from the Land Evaluation System

A TOOL FOR PLANNING?

The intention behind the Land Evaluation System is to provide a tool for agricultural planning in the Third World. Such a system allows soil scientists to analyse the data they have collected. This task is cumbersome and time-consuming, as the methods employed are quite intricate. Precious time is saved by using computer assisted techniques. The professionals may allocate more effort to the enlargement of their data base, as well as spending time on refining the evaluation methods. Thus, the computer-based Land Evaluation System is a necessary tool in order to process data, and make soil information more rapidly available for planning purposes.

The value of such a system is, however, restricted by the data and knowledge represented by the software. As a tool for planning, the system must be applied to problems on the same level of generalisation as is provided by the background information. If the system is loaded with soil observations from a map with a scale 1:2.5 million, proper answers can only be given for questions aimed at that same level of detail. Advice given to the individual farmer or peasant concerning what crop to grow may then prove to be incorrect, as local conditions may vary rapidly over short distances. The crops found to be suitable in large regions, however, will provide central planners with basic information which can be used to allocate the right kind of resources and technical support to that area.

If, on the other hand, the Land Evaluation System is be used for planning on the micro-level in order to help the individual farmer on his piece of land, then the data used in the evaluation must apply to this level. The information about soils as well as agro-ecological conditions in the area under consideration must be sufficiently detailed in order to generate adequate advice.

Another aspect of this problem is to decide what is adequate information. The method of evaluation used in the system is based on a FAO scheme which has been adapted for Zambia by the Soil Survey Unit. Here, soil properties and ecological conditions are taken into account. Social and economic considerations may, however, be just as important in order to make a final decision in agricultural planning. It is not likely that a system like the Land Evaluation System will be able to cover all aspects of the decision-making process. Soils, local climate and other ecological factors may change more rapidly over space than can be taken into account by the data structure. Other factors, not even thought of in the general model, may be critical in a certain area. For example, a lack of transport facilities may prevent authorities from bringing in the neccessary technical support for growing new crops. Also, the same shortage would be an obstacle to growing cash-crops in remote areas, irrespective of the physical suitability of the land.

In Zambia, as well as other places, local knowledge must be applied to the information generated through the computer software, in order to maximize the decisions that are made. Thus, further research into Geographic Information Systems for planning purposes should take into account two aspects of integration of local knowledge: firstly, to formalize and integrate social and human factors in the evaluation rules; and secondly, to find out where the computer should halt processing, and let man enter informal knowledge and make decisions dependent on the local situation. It should be stressed that a system like the Land Evaluation System is an important tool which can be used to aid agricultural planning, but, at the end of the day, it is man's responsibility to ensure that the correct decisions are made.

CONCLUSIONS

The current version of the Land Evaluation System, clearly, is tailored to the Zambia situation. However, if the same FAO evaluation system is used, then new rules, which fit the conditions in other developing countries, can be added to the system. The comparatively low cost of the equipment could allow the system to be located in many field locations within one country, thus making the facilities available in just those areas which require them most.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of Stein Bie of the Norwegian Computing Center, the staff of the Soil Survey Unit, Mount Makulu, Zambia, and the Norwegian Agency for International Development (NORAD).

LITERATURE

Robb, M., Strand, G.H., and Wang, B. (1986), "Land Evaluation System for Zambia", Norwegian Computing Center Note, KART/01/86, 6pp.

Robb, M. Strand, G.H., and Wang, B. (1986), " Land Evaluation System for Zambia System Documentation and User's Guide", Norwegian Computing Center Note, KART/02/86, 54pp.