Tropical Agricultural Research Vol. 7 1995, 1 - 12

Development of Optimum Crop Distribution Spatial Model Using GIS Capabilities

W.P. Ranjith Premalal, J.C. Taylor[1], A.C. Bird[1] and N.D.K. Dayawansa[2]

Department of Agricultural Engineering
University of Peradeniya
Peradeniya.

ABSTRACT. The addition of spatial dimension into classical economic jargon through Geographic Information System (GIS) modelling would make the life of the real world economists exciting, and it also opens up a new era in practical applications of well-known economic theories. The technological platforms of GIS functionality which forecast to be on all the desktops by year 2000 would provide algorithms for natural resources management including ecological, economical and social data analysis.

In this study, an attempt was made to demonstrate a methodology in developing a model of optimum crop distribution for land resource management through the extensive use of GIS modelling capabilities. The optimum crop distribution is based on the premise that the economic return obtainable is being maximized, while resources are mobilized in a limited range depending upon their availability, feasibility and sustainability for optimum crop productivity. The constraints considered in this study included land capability or soil type, crop productivity, market price, production and transport costs, post harvest losses and social costs. It is expected to provide with a thematic map to the end-user indicating the spatial extents of each crop attribute with exact geographical reference for management decisions.

INTRODUCTION

The ever increasing demand for the optimal use of land resources has emphasized the necessity for better techniques in the acquisition and analysis of data concerning the spatial distribution of relevant characteristics of earth surfaces and climatic variations to ensure sustainable utilization of these resources.

---

[1] Rural Land Use Department, Silsoe College, Bedford MK 45 4DT, UK.

[2] Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya, Peradeniya.

Traditionally, spatial data with geographical reference has been acquired and rendered into pictorial form to accomplish variety of activities related to land resource management. With the introduction and dissemination of high speed computers and of data capture and display devices, the importance of developing a computer-based system of efficient and cost effective land resource data management was made possible. As a result, database systems for spatial data, commonly named as Geographic Information Systems (GIS) were designed and developed enabling the acquisition, compilation, analysing and displaying the topological and geometrical interrelations existing between spatial properties and non spatial attributes of different entities (Burrough, 1986).

The use of GIS technology has been expanding at nearly an exponential rate over the past few years. Because the wide spread application of GIS technology is relatively new, a major challenge is faced in application of this new tool in land resource planning and management. This is further aggravated by variability and the time dependent nature of the land resource information.

Successful planning and management of land resources rely heavily on topography, geology, geomorphology, lithology, soil type, land use/ cover and, climatology of the area. The collection of all these data along with the traditional hydro-meteorological records within a GIS environment allows gathering a comprehensive knowledge on the actual potentialities and constraints for efficient and effective land resource planing strategies (Castle and Wood, 1994). Further, in-built modelling capabilities of GIS provide the capabilities of simulating the real world scenarios and predicting the future trends highlighting the possible modifications required for better results. In addition, GIS modelling algorithms also provide the basis for incorporating economic analysis of market oriented information into land resource models to enable the user to derive an economically feasible strategy for profit maximization while being ecologically sustainable.

The main objective of this study was to demonstrate a methodology for developing a model of optimum crop distribution for land resource management through the extensive use of GIS modelling capabilities within a set of hypothetical parametric constraints. The optimum crop distribution is based on the premise that the economic return obtainable is being maximized while resources are mobilized in a limited range depending upon their availability, feasibility and sustainability for optimum crop productivity. The constraints considered in this study included land capability or soil type, crop productivity, market price, production and transport costs, post harvest losses and social costs. It is expected to provide with a thematic map to the end-user or farmer indicating the spatial extents of crop attributes with exact geographical reference.

MATERIALS AND METHODS

Data

In this hypothetical case, four different crop types were considered and the corresponding parametric attributes of the four crop types are given in Table 1.

In addition to the tabulated basic data, the information on the location of the city or the market centre, road network, spatial distribution of soil types and boundary coordinates of the study area was collected from the existing agro-ecological and road maps. In this hypothetical case, only one market or city and linear road features were considered for clarity.

Estimation of economic returns

In order to calculate the economic return of a crop, the following basic equation was adopted.

$$E = Y(p-a) - Y(k1f1 + k2f2 + L1k1 + L2k2) - Sk1$$

where, E = economic return per unit area
Y = yield per unit area
p = market price per unit crop
a = production cost per unit area
$k1$ = onroad transport distances
$k2$ = offroad transport distances
$f1$ = transport cost per unit crop per unit distance travelled onroad
$f2$ = transport cost per unit crop per unit distance travelled off road
$L1$ = post harvest losses per unit crop per unit distance onroad
$L2$ = post harvest losses per unit crop per unit distance offroad
S = social cost per unit distance from city

Table 1. Hypothetical production statistics of the crops.

Parameters	Crop 1	Crop 2	Crop 3	Crop 4
Yield units per unit area				
Soil 1	20	60	10	25
Soil 2	10	40	12	20
Soil 3	15	30	14	30
Soil 4	12	30	8	20
Transport cost per unit crop per unit distance travelled				
Onroad	0.8	2	0.4	1
Offroad	1.6	4	0.8	2
Post harvest losses per unit crop per unit distance travelled				
Onroad	0.1	0.03	0.1	0.02
Offroad	0.2	0.04	0.25	0.03
Price per unit crop	15	12	20	18
Production cost per unit crop				
Soil 1	1	2	5	10
Soil 2	2	4	9	12
Soil 3	3	6	7	8
Soil 4	3	5	6	12
Social cost per unit distance from city	10	3	5	6

This study made the extensive use of the modelling facilities available in SPANS software. SPANS is an advanced GIS software which is based on raster quadtree structure for its analytical algorithms. The GIS spatial analysis is based on the dynamic allocation of attribute values *via* equation files (.INP files) which operate on classes within thematic maps (.MAP files) and columns within attribute tables (SPANS GIS, 1993). In this process, the model generates new pixel values which form a new map file. The final output map in this study was generated after each pixel had been assigned a maximum value depending upon each crop attribute and hence it was a register of optimum land use.

Buffer maps

The hypothetical market centre or city was considered to be a point feature, while the road network was assumed to be of a line feature. The spatial dimension and distribution of these is shown in Figure 1. The spatial distribution of 4 different soil types was assumed to be a random function as shown in Figure 2. In view of the transport distance, it is necessary to define on road and off road transport distances from the field to the market. Off road travel was defined as the shortest travel path from a field to a road and the on road travel was from off road intersection to the market. In the buffering process, on road required point to circle transformation while off road needed arc to corridor transformation function. The SPANS paths involved here are as follows:

TRANSFORM/ DATA TYPES/ POINTS TO MAP/ BUFFERS
TRANSFORM/ DATA TYPES/ VECTORS TO/ MAP

The road distance maps drawn consisted of buffer clases; and it was necessary to create attribute tables to assign the attribute values properly to the entities in the maps. Attribute tables defined the relationship between attributes and entities in the maps. On road and off road maps had attribute of distance from the town and the road, respectively. The SPANS approach was EDIT/ LIBRARY/ TABLE HEADERS/ <MAP NAME> EDIT. The number of class intervals in buffer zoning plus a zero class background value.

Editing of attribute tables was convenient in OS/2 system editor after exporting the tables, and subsequently the edited versions with .TBA extensions were imported back to SPANS and saved as .TBB files. The related SPANS approach was TRANSFORM/ EXPORT/ LIBRARY/ TABLE AND TRANSFORM/ IMPORT/ LIBRARY/ TABLE.

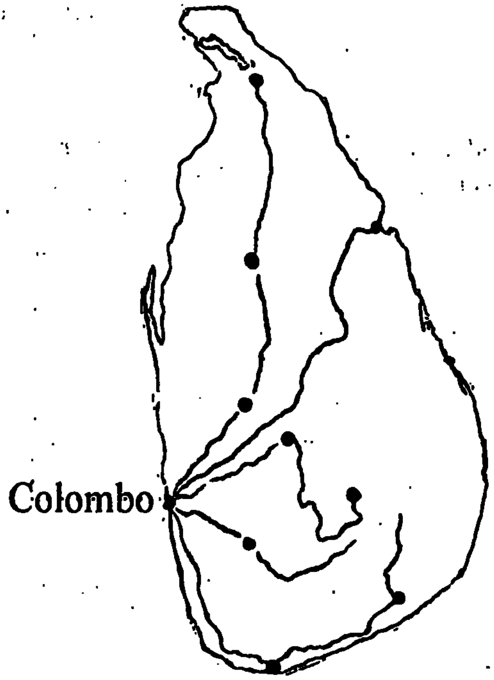

Figure 1. Road Map

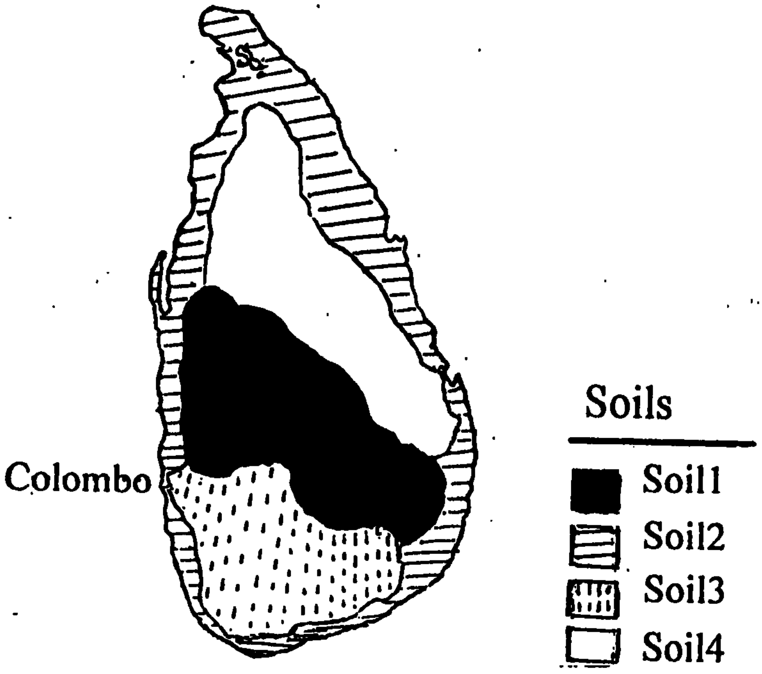

Figure 2. Soil Map

Attribute Annotations for crops

A similar sequence of operations were employed to define the cost of production and price variations of the crops. Since there were four crops with two attributes each (cost and price), there should be 8 fields with the number of records equals to five. The number of records corresponded to the four soil types and background value. In the definition of data types, reference should be made to the available information on price of the product and cost of production and in this case, the data type was set to floats and the format was fixed to 2.2 facilitating the addition of further data with decimal fractions.

Modelling equations

In this particular economic analysis, the specific significance of the use of GIS capabilities lied in the integration of parametric attributes with the corresponding spatial background. SPANS provides a wide range of modelling options in the form of equations in order to develop the link between the attribute parameters and spatial georeference. In addition to linear conversions, polynomial transformations have been made possible in SPANS modelling with the addition of some basic knowledge in algebra. The modelling function takes the following form in SPANS.

TABLE ('*table name*', CLASS ('*map name*'), COLUMN NUMBER)

In the modelling process to determine the optimum solution, several maps and tables were to be linked, modelled and assessed. Therefore, a variable was assigned to each and every function which call a different table/s or map/s, thus simplifying the entry of the functions into the equation without any confusion. SPANS supports this sort of simplification process and it could be seen to have further efficiency savings when the amalgamated final modelling equation was employed.

The OS/2 system editor was used to formulate the equation and this enabled to reach the Equation .INP file through SPANS. Four sets of equations were required to be introduced separately for each crop type along with the corresponding variables. An example of the equation for crop 1 is given below.

```
E crop 1 equation for crop 1

A1  =  Table ('crop1cp'), class ('soil'), 1);
A2  =  Table ('crop1cp'), class ('soil'), 2);
A3  =  15;
A4  =  Table ('onroad'),  class ('onroads'), 1);
A5  =  Table ('offroad'),  class ('offroads'), 1);
A6  =  0.8;
A9  =  1.6;
A8  =  sqrt (A4 * A4) - (A5 * A5);
A9  =  0.10;
A10 =  0.20;
A11 =  10;

A1* (A3 - A2) - (A1* (A5*A7) + (A8*A6)) - (A1*(A8*A9) + (A5*A10)) -
(A11*A4)
```

where,

A1 = crop1cp attribute table data from field 1
A2 = crop1cp attribute table data from field 2
A3 = price per unit crop
A4 = onroad attribute table data from field 1
A5 = offroad attribute table data from field 1
A6 = onroad transport cost
A7 = offroad transport cost
A8 = Pythagoras theorem which determines minimum distance to road from any point in the field
A9 = post harvest losses per unit crop per km onroad distance
A10 = post harvest losses per unit crop per km offroad distance
A11 = social cost per km distance travelled.

The final line of the equation takes the form of the relationship discussed under estimation of economic returns. It was necessary to check the validity of the formulated equations before attempting a comprehensive modelling practice. Hence, the soil map was displayed and query function was used over the study area to assess the reliability and acceptability of the outcome of the equation. In view of the modelling equation, it was apparent that economic returns from a crop should increase towards a road and also towards the town. There should also be significant differences across the soil boundaries. The Spans procedure involved here is given below.

```
VISUALIZE/ VIEW/ ENTITIES/ MAPS/ <soil>
VISUALIZE/ VIEW/ ENTITIES/ VECTORS/ <roads>
QUERY/ MODEL/ MAP/ <equation>
```

Classification definition and map generation

Before generating economic return maps for each crop, it was necessary to define a classification scheme to be used in the classification process. In this case, it was decided to employ a classification scheme with the following selected options.

mode - *value*
type of interval - *equal*
sort order - *ascending*
base class value - *class 1*

The classification range window was proceeded with 12 number of intervals, and minimum and maximum values were determined through a query process. In the query process, each crop equation was applied to the soil map and the minimum and maximum values were recorded as the cross-hair traversed the entire area. The number of intervals was chosen to be 12 to give a sufficiently large range of possible economic return values of the crops.

MODEL/ OVERLAY/ MAP was the SPANS process for generating individual crop maps through the utility of modelling equations. In this process, the quantile level was set to be 10. The generated economic return maps indicate the profitability of agriculture for each crop type.

RESULTS AND DISCUSSION

The maximum obtainable economic value for each crop was determined by combining the four individual crop modelling equations into a combined form. Using the modelling language, SPANS instructions were given to return the maximum value of any pixel after considering all the crop equations. The output map was classified in such a way that the returned value corresponded to a crop number. For instance, if a pixel had the maximum value for crop 3, the value returned to the output map would be 3. This made even the visual interpretation much easier.

The formation of the new equation was as exactly same as the equation given in modelling equations with the addition of a new variable made equal to the final line of each individual equation and referring the maximum value of each and every pixel by a number through 1-4. It also required to define a classification scheme with following specifications.

mode - *value*
type of interval - *equal*
sort order - *ascending*
base class value - *class 1*
minimum value - 1
maximum value - 4
number of intervals - 4

The additional definition required in the final equation took the following form and Q, R, S, T are the variables referred to the outcome of each individual equation. The SPANS procedure was MODEL/ OVERLAY/ MAP with 10 quantile level and through the above classification scheme. The optimum crop distribution map is shown in Figure 3.

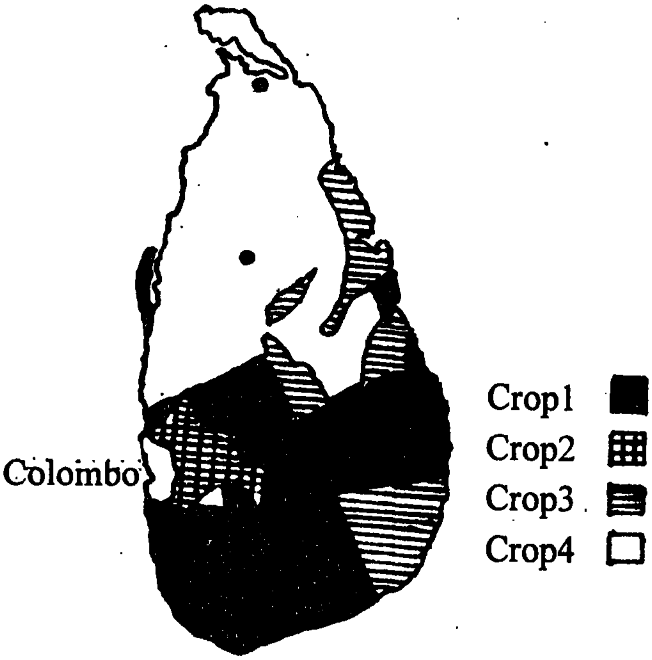

Figure 3. Optimum Crop Distribution Map

{ 1 if max (Q, R, S, T) == Q,
2 if max (Q, R, S, T) == R,
3 if max (Q, R, S, T) == S,
4 if max (Q, R, S, T) == T}

Optimum crop distribution map

This paper demonstrates a straightforward application of the modelling facilities available in SPANS to a simplified hypothetical case study. In order to develop a more realistic scenario, spatial location of additional markets or cities could be included instead of centralized monopoly. These point features could be entered as separate entities and buffer zones can be created around them as shown in the Modelling Equations. Subsequently, an equation could be formulated to determine the nearest point feature for market destinations. Facility to add fluctuations in price or yield is also a strong positive characteristic in SPANS modelling. Information on fluctuations could be incorporated and the model can be updated throughout the growing season to produce more accurate assessment. In reality, the transport cost and distance are not linear variables and the relationship is much more complex to represent in a simple correlogram. Topographic features have a greater influence on the travel time and the distance and SPANS provides facilities to model the impediments and thus account into attributes of accessibility and journey time in the modelling equations.

CONCLUSIONS

With the introduction of sophisticated modelling techniques in SPANS, quantitative assessment of land suitability has become practically possible. Qualitative representations in land suitability classifications only allows authentic visual comparisons but no realistic quantification to support policy decisions. SPANS modelling would enable to derive numerical values either on an absolute scale or on a normalized scale to convey the practical possibility in theoretical terms as a decision supporting tool. SPANS modelling capabilities have a great potential in application with reference to market research and surveys. It allows to represent of the spatial distribution of potential customers within a given set of facilities and constraints. This would also provide valuable information on simulation parameters on a numerical scale which would otherwise account for a considerable cost allocation for a real scale survey.

Satellite imagery provides a quick and continuous update of land cover information with rapid multi temporal coverage with respect to cropping calendar. SPANS modelling would reveal the best land cover distribution in terms of productivity once the requirements of different potential land uses and the existing environmental parameter distributions are defined. This would enable to make quick reference to what is achieved and what is optimum and also, the degree of deviation from the optimum with exact spatial identification.

In short, the addition of a spatial dimension into classical economic jargon through SPANS modelling would make the life of the real world economists exciting and it also opens up a new era in real world applications of well-known economic theories. Further improvements could be made through the incorporation of time series component into the spatial modelling efforts.

ACKNOWLEDGEMENT

The authors wish to acknowledge the provision of basic data structure and advise by Dr. Tim Brewer, Lecturer, Silsoe College, UK. Contributions from B. Castle and G. Wood are also acknowledged.

REFERENCES

Burrough, P.A., (1986). Principles of Geographical Information Systems for Land Resource Assessment. Oxford; Clasendon Press.

Castle, B. and Wood, G., (1994). Application of Geographical Information Systems. Report submitted to Rural Land Use Department, Silsoe College, UK .

SPANS GIS Technical Manuals (c) (1993). Intera TYDAC Technologies Inc., Ontario, Canada.