GEOGRAPHIC INFORMATION SYSTEMS AS DECISION-SUPPORT IN THE SUGARCANE INDUSTRY

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ABSTRACT

Geographic information systems (GIS) technology enables the analysis of data according to their spatial relationship. After a brief description of the computer hardware and software available, the procedures and basic requirements, the paper reviews the application of GIS in the sugarcane industry, particularly in South Africa, Australia and Mauritius. Specific examples to illustrate its potential as a decision-support tool are given for Mauritius and Australia. Prospects for future development are examined in the light of advances made in the field of information technology. These include improved techniques of photogrammetry, remote sensing, digital terrain modeling and crop growth modeling for improving management practices to ensure better productivity and environmental protection.

Keywords: Sugarcane, GIS, information technology, database, thematic maps, productivity analysis, DTM.

INTRODUCTION

A geographic information system (GIS) is a database management system that stores a range of information on objects according to their spatial position and is supported by powerful electronic mapping capabilities. The overlaying of geographically referenced maps and their related attribute data allows their integration and spatial analysis to extract productivity-related information. This technology has been exploited in various fields, especially by organizations that use location as a factor in their planning and analysis activities. Considerable data from various sources can be summarized and expressed as single maps and other graphic forms that are easily interpreted. Thus productivity analysis enables spatial patterns to be discerned with respect to physical variables, inputs and agronomic practices, being particularly useful as a management tool in agriculture. It is ideally suited for the sugar industry because of the semipermanent nature of cane production; the location of blocks under cane does not change from year to year, which facilitates the interpretation of information. Furthermore, the extensive records maintained by sugar mills for their own plantations or for their independent growers provide an excellent base.

GIS technology has a relatively short history, but because of its numerous advantages it has emerged as one of the fastest growing areas of interactive computer graphics. What makes it a powerful tool is its visual technology, which promotes a better understanding of the spatial relationship of features and the timeliness with which documents are produced.

This paper reviews the development of GIS in the cane industry, referring to specific applications to highlight its potential as a decision-support tool.

HARDWARE, SOFTWARE AND BASIC CONSIDERATIONS

Hardware

A GIS can be implemented on a wide variety of computer platforms ranging from personal computers (PCs) to mainframes. Microcomputers, however, should have a minimum configuration comprising at least a 486 DX processor, 8 Mb RAM, 50 MHz clock speed and 500 Mb hard disk. For backup storage a CD-ROM or, better still, a WORM will be more convenient than a streamer or tape.

Software

A vast array of GIS software is available on the market; however, those known to be in use in the cane industry include ArcInfo, Genamap, UNIGIS, MapInfo and GRASS. ArcInfo, which has been at the forefront of GIS development, is available to run under UNIX on workstations and under DOS and Windows for the PC version.

GIS software usually consist of a main module and several optional ones. Thus for ArcInfo, the optional TIN module would be required for Digital Terrain Modeling (DTM) for ground elevation studies. Several other modules
have been developed for DTM studies.

A desktop data visualization software, known as ArcView, has also been developed for ease of data analysis and management. It can be used on a PC to access the main GIS database and extract information as maps/plans, in tabular form or as charts. An alternative software to ArcView is the MapInfo for PCs, which can be used to access a GIS developed on any platform.

The compatibility between different software packages is not universal. Thus digitized data from some products cannot be transferred to others (e.g., UNIGIS data can be exported to ArcInfo but not vice versa). Nowadays many software incorporate modules that perform data conversion and enhance compatibility (e.g., ARCCAD).

**Basic considerations**

An important aspect for a GIS is data capture. Only when a sufficient amount of data have been captured, can a GIS become usefully operational. Also the quality of the data is vital. Not only should data be accurate and standardized but they should also be as up to date as possible for timely action and hence efficiency as decision-support (Fig. 1).

In a GIS for agriculture, one should distinguish among:

- Base maps giving fixed data such as land parcels, roads, rivers, altitudes, soil characteristics and climate ranges
- Variable physical data such as weather, soil moisture, etc.
- Variable inputs: crop and variety, irrigation, fertilizers, pesticides, agronomic practices including manpower, equipment used and costs
- Agricultural outputs: yields, losses, etc.
- GIS-derived products: maps, field plans, reports, models, etc.

The capture of the fixed physical and graphical data is done by digitizing the relevant maps. This requires maps on a stable medium and digitizing of high standard so as to avoid problems of edge matching when map sheets are combined. The proper editing of these maps is also of utmost importance.

New techniques supportive of GIS are now available for the direct capture of certain attributes such as the X, Y and Z coordinates for specific points on the map using the Global Position System (GPS) or scanning aerial photographs where appropriate maps are not available.

Real time data capture can also be envisaged from instruments such as lab equipment, automatic weather stations, etc. The use of bar codes is increasingly being used for referencing such data.

Some organizational issues need to be considered to ensure the success and efficiency of a GIS. Whether the system is a stand-alone or in a network is important. Data capture can be centralized or left to the end users, but it is important to avoid duplication of effort. Thus processing and digitization of fixed geographical entities like base maps are best left to a central body. In many countries cadastral and land resources maps are produced by government bodies and may be available in digital form if required.

Other issues are related to:

- Compatibility of hardware and software
- Data quality and standardization of data capture
- Confidentiality of information
- Legislation regarding protection of data

**GIS DEVELOPMENT IN THE SUGARCANE INDUSTRY**

The development of computer technology has enabled huge data storage and analysis opportunities, presenting new possibilities in data management and information extraction. Thus traditional databases for computer use have been restructured, compiled and analyzed to satisfy requirements.

In the sugar industry databases containing data on land, climate and crop have been compiled for quite some time to:

- Enable analytical investigation for identifying productivity constraints and the possibility of increasing sugar production per unit area (Julien et al 1984)
- Provide guidelines on agricultural policies concerning the sugar industry (Lemaire et al 1991)
- Output relevant updated information for extension work (Coale & Lentini 1991).
The overall objective is to optimize land use and maximize profitability. These databases however lacked the GIS features for spatial data analysis and graphic display. GIS with relevant databases has been appraised and utilized in the sugar industry mainly in Australia, South Africa and Mauritius.

In Australia the use of GIS for commercial application was first demonstrated to the sugar industry in 1989 and its advantages and potential were outlined by McKenzie (1990). Earlier applications had been more research oriented (Capelin 1979). The GIS as an essential component within a cane-land management information system (MIS) to assist in improving productivity was described by Keig et al (1991). The MAPINFO package was utilized to produce simple colored farm maps with related data on cane variety, crop class and yield. Such thematic maps proved to be very effective in communicating productivity-oriented information including soil characteristics, enabling extension officers to help farmers identify reasons for poor cane performance and take remedial action.

At South African Sugar Experiment Station (SASEX) a GIS has been used to output up-to-date farm maps with legally accepted accuracy to allow spatial or locational analyses from the linkage of digitized maps to topographic and crop characteristics. This has helped decision-makers find solutions to their queries (Platford 1990, Platford & Dinkele 1992). Thus the UNIGIS DTM module has been utilized for the design of field layouts, siting of terraces, analysis of slopes, derivation of isohyets and isolines for soil physicochemical properties (Wallace 1993). Subsequently, the use of GIS at SASEX evolved toward productivity analysis with a focus on agronomic issues (M.G. Wallace, pers. comm. 1995).

The initial steps toward developing a GIS in Mauritius stem from the creation of the Land Index database of all physical and agronomic characteristics of cane fields. Its use was oriented toward productivity studies that helped retrieve low-yielding plots, identify constraints to productivity and optimize crop production within a national policy for crop diversification in cane areas in order to achieve a greater degree of self-sufficiency in food (Anon. 1990). The Land Index database has been developed using the SQL relational database management system. Because of the many advantages for storage and retrieval of this system, the Land Index database rapidly evolved towards a GIS, once the relevant cartographic data were digitized (Anon. 1992).

The following is a discussion of specific applications in Australia and Mauritius.

**Australia**

A wide range of government and sugar industry authorities in Australia use GIS, having developed various applications of the technology as described below.

- **Digital cadastral database**. The Queensland Dept. of Lands has developed a digital cadastral database (DCDB)
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covering about 80% of rural land in Queensland, mainly occupied by the sugar industry. The DCDB is an up-to-date electronic map of property boundaries with associated information such as ownership, size, tenure conditions (free- or leasehold) and geographic features such as rivers and streams, roads and railways, etc. Appropriate sections of the electronic map, which constitutes the useful base layer for GIS, can be purchased in the form of large digital files on magnetic tape or computer floppy disk.

- **Resource management and planning**: Since 1970 the Queensland Dept. of Primary Industries has been identifying areas suitable for cane growing. Through collaborative research involving the various members of the sugar industry, databases have been constituted on the extent of land available in relation to the industry's long-term need to support economically viable processing factories. Such land is quite limited and is subject to strong competition. GIS and other information systems are being used to help strategic planning to retain the integrity of cane lands, ensuring better use of existing infrastructure such as roads and tramlines, drainage channels, etc. Emphasis on soil conservation and land management in the sugar industry dates back from the 1960s. Recently the farming community has become concerned about the sustainability of farm practices including control of runoff and retention of areas of desired vegetation. With GIS software installed on PCs, extension officers are able, under a property management planning program, to promote a system to improve the sustainability and profitability of farms.

- **Productivity analysis**: Analysis of yield data is essential to growers who want to make comparisons of profitability among their farms. Such information can help identify reasons for differential yields throughout cane-growing areas and provide a reference for varietal performance. Data on sucrose levels can be a good guide for selecting blocks to be harvested (Chappell et al 1991).

A system of productivity analysis based on the DCDB was advocated by Wegener et al (1992). Base maps of cane lands with property boundaries were overlaid with field maps used by the mill's cane inspectors or aerial photographs. With the integration of productivity information such as field identification, cane variety, harvest date, sucrose content, delay between harvest and milling, etc. stored in a database that could be interrogated, various maps and reports can be produced to study productivity problems. It has thus been possible to highlight the wide yield variation (3- to 5-fold) that occurs across common environments with similar production inputs (Wegener et al 1992, Lee-Lovick et al 1992). Such use of GIS can prove invaluable to guide management in the cultural practices to be adopted.

- **Research applications**
  - **Remote sensing**: Lee-Lovick & Kirchner (1990, 1991) used GIS technology to help interpret remotely sensed data of cane lands from the multispectral scanner and a thematic mapper on the Landsat 5 satellite. In view of inconclusive results, this technology cannot be contemplated at present.
  - **Economic analyses**: Wegener (1991) used GIS software to illustrate results from a linear programming analysis of the preferred pattern of cane production in the Moreton Mill area. Input data required for a linear programming analysis of various land use options was generated by the database management program and the resulting output illustrated with maps drawn using GIS software.
  - **Environmental monitoring**: Thomas et al (1994) and Kapitzke et al (1994) reported investigations into integrated stream management, taking into consideration the combined effects of agricultural practices, development projects and farm layout, as well as the location of nonagricultural activities, on water quality. Extensive use of database and mapping facilities was made by Bramley et al (1994) in their study of nutrient loadings by one of the major rivers flowing through cane-growing land in NE Australia.

**Mauritius**

GISCAANE, a PC-based GIS for managing cane lands is in operation in Mauritius since 1992 (Anon. 1992). The software tool used to manage the system is PC ARC/INFO. The fast development of GISCANE was achieved by integrating the existing Land Index database, which contains the attribute data on soil, climate and crop characteristics of cane lands on the basis of individual fields. In the case of the miller-planter, each cane field is identified by the estate, section and field number, while the identity of a cane field belonging to a small planter is represented by the factory area, locality, sublocality, block and field number.

The objectives of GISCANE are:

- Carry out geographical/spatial and statistical analyses geared towards maximizing productivity on cane lands
- Provide up-to-date information on the relationship between land, climate and the cane crop
Carry out "what if" scenario analysis in terms of land use planning, yield potentials, etc.

Recently a PC-based computer application (SIRITELL) has been developed to allow access to information from GISCANE and Land Index and other specific databases at MSIRI. Such information is made available on diskettes to growers and agriculturists either directly or through extension services.

**Thematic maps.** Following the compilation of updated maps of different fields (blocks) on the larger sugar estates and their digitization, the various attributes for each field from the Land Index database can be transferred to their specific location in the GIS, enabling the output of simple or combined theme (attribute) maps such as variety distribution, ratoon category, yields, production costs, pesticide use. The descriptive (textual) information related to each field is thus converted into graphic forms that highlight the spatial relationships.

Recommendations on agronomic practices such as cane varieties or fertilizer applications are made according to soil, altitude and rainfall. These too can be expressed as maps for different field blocks on an estate. An analysis of spatial variability of agronomic output for various fields can be made in relation to recommendations, allowing the analysis of productivity problems and their probable causes for eventual remedial action. Such thematic maps are being increasingly produced for management purposes; e.g., food crop suitability maps, irrigation suitability maps, etc.

**Variety recommendation.** The variety breeding and selection program in Mauritius emphasizes adaptation to agroecological zones determined on the basis of soil type, rainfall and altitude, as well as susceptibility to diseases that prevail in different regions according to climatic factors. Thus GIS analysis of the distribution of fields of a given variety on an estate—which involves combining different thematic maps of planting program, soils, climate zone, disease distribution—readily highlights those fields that are correctly or incorrectly cropped.

**Yield analysis.** Yield variation on an estate can be due to various factors such as variety, soil type, ratoon category and management. A study conducted on an estate highlighting the spatial distribution of yield indicated that poor yields were all grouped at a given site. A careful analysis revealed that this site-specific yield problem was the consequence of a deficiency in irrigation distribution.

**DTM.** Topographical studies are particularly useful to increase the efficiency of agricultural equipment and for farm planning to ensure environmental protection. DTM proved successful as a decision-support in setting up a Center Pivot irrigation system in Mauritius (Jhoty et al 1994). The siting of this equipment must take into account existing obstacles such as electricity poles, trees and roads, as well as the slope variations within the project area. The center of the system as well as the path of wheels are crucial considerations. In this case, a map of slope class was generated from a digitized 2-m contour map (using ARCTIN) to highlight problem areas and slopes > 30%. This enabled the best siting of the center of the pivot and the ideal length of the different tower spans to be determined. The terrain elevation profiles were generated along chosen radii, as well as along the path of the wheels, indicating the cut-and-fill needed to optimize wheel movement and clearance between the pivot arms and the crop canopy. Similar DTM analysis would also be useful for siting drip and surface irrigation schemes, and drainage control.

**PROSPECTS AND CONCLUSIONS**

Although the application of GIS in the sugar industry is still in its preliminary phases it is already proving itself an important management tool for monitoring agronomic practices such as scheduling of plantation, irrigation, etc. It is believed that with the support of new technologies such as digital orthophotography, remote sensing and GPS data, the production of farm maps and new approaches to land planning, productivity analysis and environmental risk assessment will all be enhanced. GPS receivers are envisaged for field mapping, establishing ground control points, stereo plotting or digital orthophotographic mapping and for providing spatial variability characteristics related to the soil and crop required in precision farming (Stafford & Ambler 1994). Also the data collected through these new technologies are easily interfaced into a GIS.

Digital orthophoto techniques or soft copy photogrammetry can accelerate map production so as to meet the challenges of creating new field layouts to enable complete mechanization of cultural operations.

Remote sensing is expected to provide multivariate data for the GIS on the monitoring of land use, especially on the loss of agricultural land to other land uses. The use of GIS for environmental risk assessment is likely to develop further to monitor areas of pollution from agrochemicals, soil erosion and water pollution by urban and industrial waste and effluents.

GIS technology could conveniently assist in spatial modeling exercises to estimate cane production from large
regional areas. Much of the input data needed for crop modeling can be stored in GIS databases and retrieved as needed to run a crop simulation model according to some spatial pattern. With the increasing availability of long-range climate forecasts, there is interest in spatial modeling techniques to estimate cane for harvest from whole mill areas prior to the start of the crushing season and for other management purposes. GIS technology could be used to supply input information and to interpret results from such modeling activities.

REFERENCES


L'AIDE DES SYSTEMES D'INFORMATIONS GEOGRAPHIQUES A LA PRISE DE DECISIONS DANS L'INDUSTRIE SUCRIERE

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RESUME
Les systèmes d'informations géographiques (SIG) permettent d'analyser des données en fonction de leur relation spatiale. Après une brève description des méthodes utilisées, des matériels et des logiciels informatiques disponibles, cette communication passe en revue le développement des SIG dans l'industrie sucrière, principalement en Australie, à Maurice et en Afrique du Sud. Des exemples spécifiques d'application en Australie et à Maurice sont exposés pour mettre en exergue le potentiel de cette technologie comme aide à la prise de décisions. Les perspectives d'avenir telles que: les techniques améliorées de photogrammétrie, la télédétection, les modèles numériques de terrain et la modélisation de la croissance des cultures, sont analysées à la lumière des progrès accomplis dans l'informatique.