LINKING A GEOGRAPHIC INFORMATION SYSTEM TO FARM RECORDS AND CROP MODELS FOR FIELD MANAGEMENT

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Abstract

Interpretation of sugarcane field records can be greatly improved by linking them to a Geographic Information System database, which allows trends to be mapped and queries to be performed. Linking a Geographic Information System to a crop or irrigation model allows simulation of crop yield and irrigation water use efficiency for each field, based on field information.

The ArcView Geographic Information System was linked to the IRRICANE crop model, which simulated cane yields for a north coast farm. Observed sugarcane yield and soils data for each field was used in ArcView to map temporal and spatial trends in production and soil chemical and nutritional status, as well as to derive input data for the IRRICANE model. This paper discusses a method of linking a Geographic Information System to the IRRICANE model to establish benchmarks for crop performance and evaluate irrigation potential.

Introduction

A Geographic Information System (GIS) is a computer system which allows the input, storage, manipulation, analysis and presentation of data that has a positional (i.e. spatial) reference. Platford (1990) first described the use of a GIS in the South African sugar industry. The capabilities of a GIS to address some industry challenges were illustrated by:

- Wallace (1993), who described digital surface modelling applications.
- Schroeder *et al.* (1994), who investigated trends in soil acidification in South African cane fields.
- Hellmann *et al.* (1995), who describe the use of GIS to link field records and Fertiliser Advisory Service (FAS) soil data in order to investigate variations in yield with different field conditions and crop growth cycles.
- Wallace (1995), who reviewed GIS technical developments at SASEX and summarised current research initiatives.
- Wallace (1996), who applied a GIS based soil loss equation to estimate soil erosion on a 20 000 ha catchment.

GIS applications range from simple mapping and trend analysis to complex scenario modelling (de Jager *et al.*, 1998). Visualisation by mapping variable soil and yield data shows how changes in soil nutrition affect sugarcane production. A more powerful application is through linkage of a GIS to process models, where the GIS is used to describe input data to the model (e.g. soils data) and present and analyse output data from the model (e.g. benchmark observed against potential yield).

This paper is divided into two sections. The first section evaluates briefly a method of linking a GIS to soils and yield records and concentrates on the analyses carried out on the field record relational database within the GIS. The second section of the paper describes linking GIS to the IRRICANE crop model. Application of the GIS-IRRICANE link is illustrated for a farm on the KwaZulu Natal - North Coast.

Linking GIS to Farm Records

A GIS is able to query multiple data sets simultaneously and is therefore useful to researchers and farm managers as a decision support system. Hellmann *et al.* (1995) explored the use of GIS for interpreting sugarcane yields for a specific study area. Soils data from the FAS and yield data from the Field Record System (FRS) were used.

Many other sources of data can be integrated in the GIS (see Figure 1). These include pest and disease records, cane quality returns and financial information. Analyses across the different data sets can be performed on the field information relational database in the GIS. An example would be querying yield decline relative to pest and disease trends.

Problems in linking data files to GIS

The capture, preparation and linking of data into a GIS is usually the most time consuming stage and may take up to 90% of the total project time. To link a database to a spatial reference, common positional identifiers are essential. The field numbers listed on the farm map are usually selected as the entity for linking records to the digital map. Tables 1 and 2 illustrate typical field production and soil records. Field data often requires manual editing, to remove inconsistencies, before being joined to the field map relational database.

Problems in linking such data files to the GIS digital field map include the presence of alphabetical and ASCII characters in the data table *field number* reference. This prevents linking of the field data to the *field number* of the digital map. Another problem is inconsistent field numbering rules and file structure. Further complications arise when the '<'

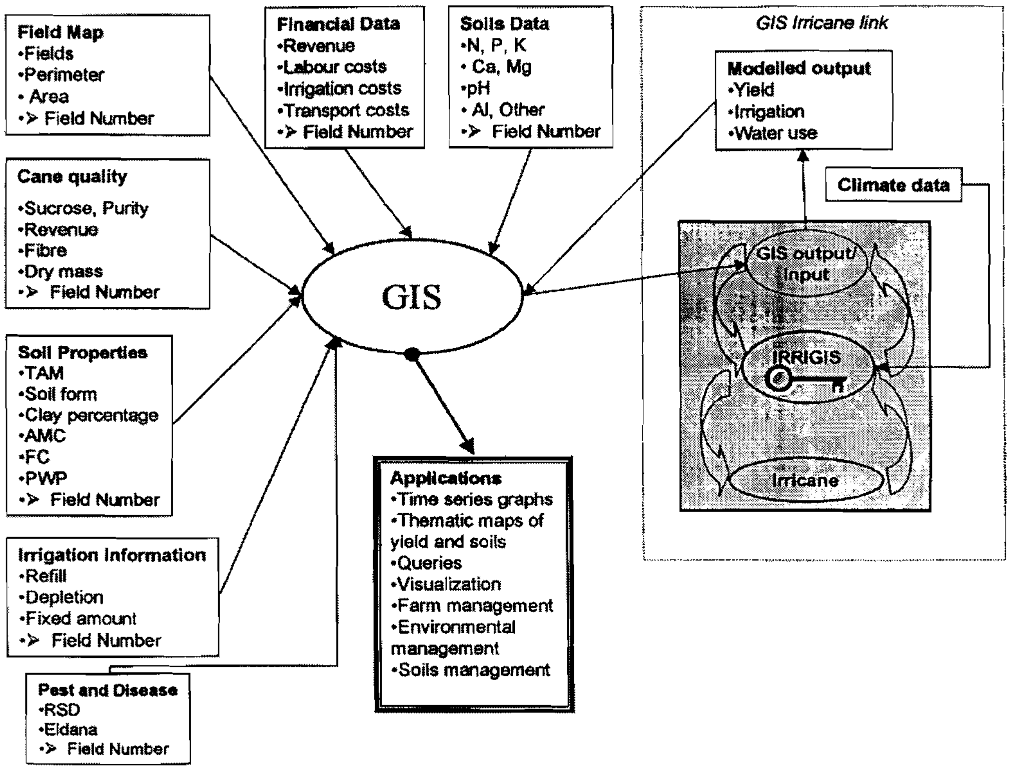

Figure 1. Flow chart illustrating the linkage between different data sources and the GIS. The flow of data between the GIS, IRRIGIS and IRRICANE are illustrated.

Table 1. Example of field production information for a selected farm block comprised of several fields.

Farm field information	Area (ha)	1987/88	1988/89	1989/90	1990/91
General crop data	3.8				
Variety N12					
Tons cane harvested (t)		266.48	195.02	296.14	257.58
Area harvested (ha)		3.8	3.8	3.8	3.8
Average age of crop harvested (months)		10	12	12	11
Tons cane per hectare (t/ha)		70.13	51.32	77.93	67.78
Tons cane per ha per month		7.01	4.28	6.49	6.16
Tons cane per 100 mm rain (t/ha/100 mm)		7.21	2.4	7.16	6.5
Rainfall recorded during growing period of crop harvested (mm)		972	2137	1088	1043

or '>' sign occur in the database and an absolute value cannot be determined for the variable.

Care should thus be taken in structuring field record databases to ensure they are compatible with GIS software which could be used for analysis purposes.

Evaluation of trends with a GIS

Having established a suitable field records structure, a GIS analysis can include thematic mapping and time series plots as well as spatial queries on the data. Examples are given below for illustration.

Based on the format of data given in Tables 1 and 2 the GIS was able to thematically map field by field variations in sugarcane variety, age and yield as well as soils information such as soil form, pH, magnesium, calcium, potassium, phosphorous and nitrogen contents. Time series graphs can be prepared to indicate changing soil and yield characteristics over time. These graphs are activated on selection of a field (see Figure 2). The graphs are flexible and allow any

Table 2. Example of field soil survey results from the FAS database.

Field number	Parent material	Form	Crop	Sampled ate	N class	pH	P (kg/ha)	K (kg/ ha)
109-A	UCR	FW	R	800115	5	4.95	> 180	209
109-A	UCR	FW	R	820811	5	4.8	> 180	303
109-A	UCR	FW	R	830829	5	4.9	137	83
109-A	UCR	FW	R	840920	5	4.6	155	96
109-A	MES	FW	R	861209	3	6.1	21	> 4050
109-A+A1	MES	BO	R	851129	1	5.25	139	146
109-A1	UCR	BO	R	800115	5	4.85	84	209
109-A1	UCR	BO	R	820811	5	4.8	146	90
109-B	UCR	BO	R	800115	5	4.95	> 180	258
109-B	UC4	BO	P	820811	5	5	108	63
109-B	UCR	BO	R	840920	5	5.1	146	576

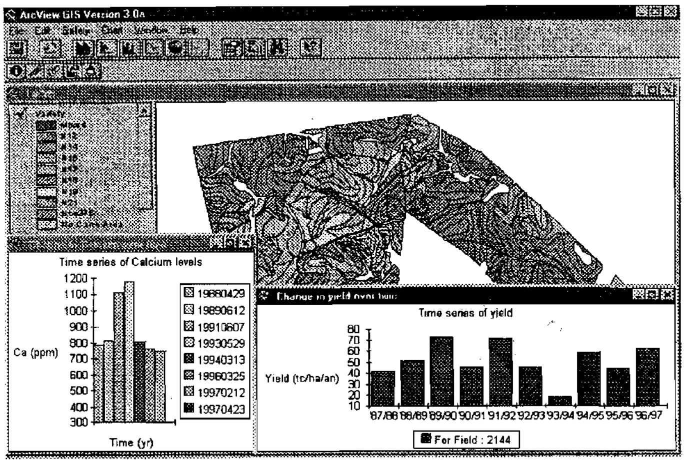

Figure 2. Thematic map of sugarcane variety and time series of changing yield and calcium levels for a selected field as seen within the GIS.

combination of data to be charted together or separately in a host of different formats.

A useful application of the GIS is its ability to query the field records within a relational database. This allows the user to explore relationships between variables in the data. A great deal of analytical work can be achieved by statistical analysis of the field data. For example, all fields of a selected variety occurring on a chosen soil type, yielding above a given threshold, can be identified. The inclusion of data from other sources, such as pest and disease information, serves to strengthen or refute the possible interrelationships that may exist between the different variables and cane production. The significance of the different variables can also be isolated.

There are several limitations to simply mapping soil characteristics and yield. Climatically South Africa has erratic rainfall, which makes it difficult to compare crop performance between years. The crop performance relative to the soil and the growing season climate conditions needs to be determined. This introduces the concept of a model for benchmarking crop performance. Furthermore, models that utilise a water balance approach can provide information such as expected yield increase with irrigation, thereby improving investment decisions and irrigation scheduling (Singles *et al.*, 1999; Schmidt, 1996).

Linking GIS to IRRICANE

The GIS was linked to the IRRICANE sugarcane simulation model on a field by field basis for a north coast farm. IRRICANE computes the water balance using daily weather data, soils and crop cycle information, as well as irrigation management information (Singels *et al.*, 1998). IRRICANE also computes sugarcane yield from daily transpiration (Singels *et al.*, 1999).

Structure of GIS – IRRICANE link

A GIS Graphic User Interface (GUI) was designed to set the simulation parameters required by IRRICANE. Simulation is initiated and controlled from the GIS GUI while the user is unaware of model calculations in the background. An output file from the GIS, containing the field and irrigation parameters is passed to the IRRICANE interfacing program IRRIGIS (see Figure 1). This Visual Basic program was designed to read the GIS output, simulate the results using IRRICANE and finally write the results to a file for the GIS to import.

The simulation parameters that are specified in the GUI include; the plant or ratoon date, the simulation period, crop age and irrigation parameters such as soil refill level, depletion level, application amount and timing. The GUI simulation settings along with the field TAM values and the meteorological file reference number are written into each record of the spatial database for transfer to the IRRICANE model. It is possible to specify different crop growth cycles for all fields. In the analysis given below a single 12-month cycle was assumed for all fields since detail on field planting and harvesting dates was not available.

The Visual Basic IRRIGIS interface interprets the data exported from the GUI for IRRICANE and extracts rainfall data for the specified crop cycles and period of analysis. IRRICANE results are rewritten into tabular format for transfer back into the GIS where model estimated yield potential and other information can be mapped spatially for each field. Time series plots of annual rainfed and irrigated yield for each field can be displayed.

Evaluation of GIS – IRRICANE link

The benefits of linking a GIS and IRRICANE are illustrated below:

- Observed yield benchmarked against model estimated yield potential.
  Field record data for the north coast farm consisted of crop age and yield for each harvest block for the period 1987/88 to 1996/97. Each block contained multiple fields. The mean annualised yield per block was determined from the 10-year yield records. Potential yield was simulated for each field for a 12-month crop over the same 10-year period. Simulated yields were converted to block yields by area weighting field estimates to allow comparison with observed data.
  The results of the benchmarking exercise are illustrated in Figure 3, which maps observed yield as a fraction of model estimated yield potential. The results represent an index of field performance. The ratio was generally between 0,7 and 1,0 with an average of 0,83. A value of less than one is expected since the model predicts maximum yield potential, over the 10-year period of analysis, based on productivity achieved in experiment trials. In practice a 'management factor' needs to account for commercially achievable yields. Information in Figure 3 is useful to identify under-performing fields and initiate corrective actions. Figure 3 was based on average annual yield over the 10-year period. A more meaningful analysis would be to simulate and benchmark each crop during the course of the growing season. By including forecasts of expected rainfall until planned harvest date a field by field yield estimate could also be made.
- Assess potential yield increase with irrigation.
  This was determined by comparing IRRICANE estimated rainfed yield, based on the 10-year period of simulation, with IRRICANE estimated yield under full irrigation. Irrigation was applied in the model when soil moisture was depleted to 50% of TAM with the profile being filled to 80% TAM. Figure 4 maps the expected annual yield increment with irrigation under typical commercial grower conditions.

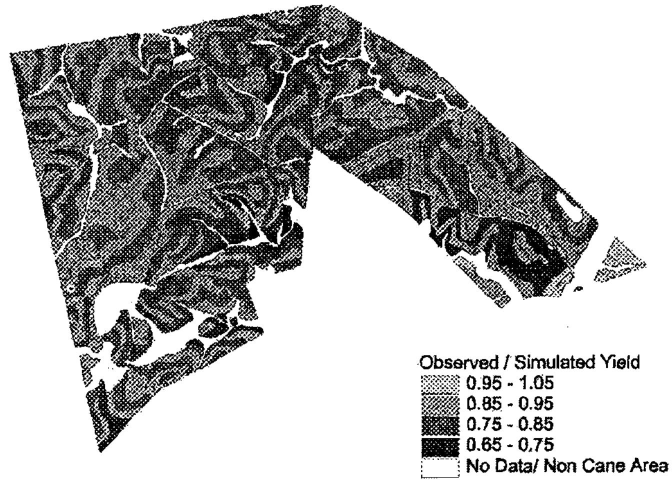

Figure 3. Thematic map of yield performance.

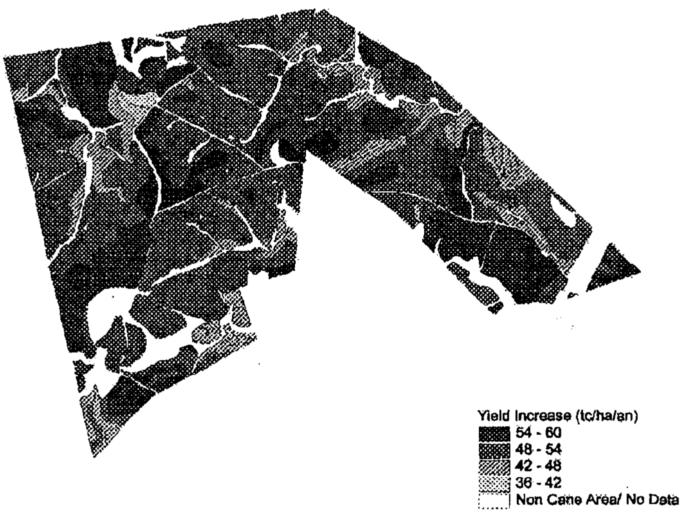

Figure 4. Estimated annual yield increase (tc/ha/an) with full irrigation. A management factor of 0,70 was assumed.

The yield increase with irrigation ranged between 35 and 58 tc/ha/an. As expected the yield increase was greatest in fields with low TAM. This is because soils with high TAM are able to sustain crops in dry periods under rainfed conditions, whereas shallower soils with low TAM would be more affected by periods of low rainfall.

It should be noted that the IRRICANE model is largely TAM driven and accurate determination of TAM for each field is important. TAM is defined as follows:

$$TAM = ERD \times AMC$$

$$AMC = 10 \times [FC - PWP]$$

Where: TAM is the Total Available Moisture in mm
ERD is the Effective Rooting Depth in m
AMC is the Available Moisture Capacity in mm/m
FC is the volumetric water content at Field Capacity expressed as a percentage

PWP is the volumetric water content at Permanent Wilting Point expressed as a percentage.

For this study the FC and PWP values were derived from known field clay content using relationships derived by van Antwerpen *et al.* (1994). Effective rooting depth (ERD) was interpreted from the soil form, land slope and topographical position of each field. Based on the above each field was assigned one of eight classes of TAM for use by IRRICANE.

Discussion and Conclusion

The linking of field records to a GIS assists in interpreting trends and querying relationships across different data sets. The preparation and linking of data to a GIS is time consuming, when the databases have not been structured correctly.

Linking of data for a test farm to the GIS served as a platform for researching the development of links between the GIS and IRRICANE model. The link provides a powerful tool for undertaking scenario modelling. The illustrative examples given in this paper include benchmarking observed yields against simulated yield potential and determining yield increases with irrigation. Although only one crop cycle and one irrigation strategy was investigated in this paper the GIS – IRRICANE link developed allows for different irrigation scheduling combinations and different crop cycles to be assessed.

Much research is being directed into weather generators and rainfall prediction models (Geng *et al.*, 1986; Pickering *et al.*, 1994; Masson *et al.*, 1996). The use of these generators as a rainfall source for IRRICANE in yield forecasting has great potential.

One of the most useful applications of spatial modelling is the simulation of yield at a mill area scale. Required for this exercise are meteorological data field/farm boundaries, soil properties and crop cycles. The mill records could be used to benchmark past yields, and using current and forecast meteorological data, predict a season's crop. SASEX is currently investigating this in another project being undertaken by the University of Natal (Lumsden *et al.*, 1998).

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EVALUATION OF THE SIMTRANS MODEL AND ITS USE IN A WORKING ENVIRONMENT

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Introduction

Simtrans, a computer software model which simulates the road haulage of sugarcane, was developed by the Department of Agricultural Engineering at the University of Natal, Pietermaritzburg. This communication deals with the evaluation and validation of the model.

To perform model simulations using Simtrans, inputs include the profile of the route to be represented, a speed curve, vehicle parameters and payload. The route profile deals with the gradients of the route and not any corners or sharp bends. The speed curve restricts the vehicle's speed to predetermined realistic values.

The research undertaken included assembling route profiling methods, evaluating the effects of varying the speed curve and comparing the model simulations with real data measured using a Machine Performance Monitor.

Summary

Two route profiles, namely Kevard to Sezela and Ashbrook to Sezela, were studied. These routes represent a mixture of highway (Ashbrook), and hilly areas (Kevard). Each route was profiled in three ways, namely, off orthophotos (1:10 000), by hand held Global Positioning System (GPS) and using a more sophisticated GPS. A specialist GPS firm, Green Belt Mapping, did the sophisticated GPS profiling. For the purposes of this report, the Kevard to Sezela route with its observed and simulated data will be examined.

The orthophoto method involved using a measuring wheel to find distances between contours and manually calculating the heights along the route. This was a lengthy and tedious process. A Trimble Geo Explorer was used for the hand held GPS method. The route was driven and height readings were taken wherever possible. The readings were put together to form the profile. This proved to be difficult because the GPS needed to sight at least four satellites before it could register a reading. Due to the hilly areas, this was a great problem. It was also not safe to stop the vehicle in traffic to wait for satellites to register. The route profile done by Green Belt Mapping proved to be very accurate and not far off the profiles of the other two methods.

Simulations were run with each of the profiles, using the same parameters (vehicle type, payload and speed curve) for all the simulations. Comparisons of simulations were made, with respect to trip time and fuel consumption.

Actual data were collected by means of the Machine Performance Monitor, which was attached to a Mercedes Benz 2636 that was hauling cane along the routes that had been profiled. The device was set up to measure fuel consumption, gear, vehicle speed and engine speed. However, problems due to the harsh working conditions were encountered. For instance, ash from the cane and dust from the roads caused problems with the computer, and the fuel consumption device caused fuel starvation to the engine.

The collected data could then be observed and compared with simulated data. The software allowed the user to call up an observed data file and a simulated file, with its route profile and speed curve, and graph them together to be analysed. The Green Belt Mapping route profile was used for these simulations, as it was believed to be the most accurate. Simulations and comparisons were performed using three different speed curves for each of the two routes, so as to see the sensitivity of the simulation in the region where power is not limiting.

The speed curves used were (i) 80 km/h throughout, (ii) a slightly more accurate curve which ranged between 50 and 80 km/h, and (iii) an accurate and realistic speed curve which closely represented actual speeds obtained.

Results of comparison for Kevard to Sezela route

The observed and simulated times, speeds and fuel consumption are shown in Table 1.

Table 1. Comparison of observed and simulated times, speeds and fuel consumption.

		Time (seconds)	Avg speed (km/h)	Fuel cons (litres)
Observed		3 416	37,4	18,626
Simulated	(i)	3 603	34.3	31,163
	(ii)	4 670	27,2	33,781
	(iii)	4 147	30,6	32,818

Discussion of results for speed curves (i) to (iii)

(i) This speed curve did not take into account any slowing down for corners and downhills, and was set at 80 km/hr throughout the route. As a result, the two graphs (simulated and observed) were quite far off in parts where