INTERPRETING FARM SUGARCANE YIELDS USING A GEOGRAPHIC INFORMATION SYSTEM (GIS)

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Abstract

A brief description of the Geographic Information System (GIS) operated at the SASA Experiment Station is given, and capture of the appropriate data for the Midlands South extension area is described. The ability of GIS to read external alphanumeric databases enabled the spatial data of GIS to be linked to the Field Record System (FRS) and Fertilizer Advisory Service (FAS) databases. Editing and cleaning the data before processing was found to be necessary. A farm with the necessary field records was selected to investigate the variation in yields obtained from different fields in the same growth cycle. Spatial presentation of the data assisted in determining queries which needed to be made and identified a possible geographic reason for the yield variation. The exercise identified aspects which require further investigation.

Introduction

A Geographic Information System (GIS) comprises of hardware and software designed to support the capture, management, manipulation, analysis and display of spatially referenced data. A GIS has been in operation at the SASA Experiment Station (SASEX) since 1989. The ReGIS GIS software package used by SASEX is a locally developed product which is marketed world-wide. The functions and features of the GIS have been described by Dinkele (1991) and Platford (1990).

Most sugarcane growers in South Africa have sugar industry quota maps with farm and field boundaries and aerial photographs to help them associate their visual impressions of crop, soils and slopes with the actual positions on the farm. Other climatic maps (rainfall, temperature, etc.) are available to help in reaching management decisions. All of these maps are integrated in the GIS through a process of digitising the existing line maps and processing the resulting data into the GIS. Where existing maps are not available, a Global Positioning System (GPS) can be used to map field boundaries. The GPS uses signals transmitted from orbiting satellites to determine co-ordinates on the earth's surface. The positional data can then be imported easily into a GIS (Harrison *et al.*, 1992). The database files from the Field Record System (FRS) and the Fertilizer Advisory Service (FAS) are then attached. When completed, the data is used to produce maps of different types for the interpretation of spatial and attribute data sets.

Rainfall and its distribution can be considered the most important factor in determining the yield obtained from a particular field. Numerous other factors such as variety, soil type, soil fertility, field aspect, growth cycle and crop status will also have an impact on the yield obtained.

As a result of the many factors involved, interpretation of field yield data from records is difficult and is customary to summarise data to simplify interpretation. Summarising usually reduces the data to a single factor and differences in yield are often ascribed to this single factor. In contrast, the GIS offers a spatial view of the fields being investigated. Factors such as slope, aspect and elevation can be readily visualised. Other databases can then be accessed to supply information on soil type, soil fertility and yield data. Viewing in this manner assists interpretation of data and also identifies possible statistical comparisons that could be analysed further, using the procedure described by Hellmann (1993).

Project

One of the objectives originally set for the GIS was the use of farm data to assess productivity. To ensure that the assessment was meaningful it was essential to have accurate records of ground slope, soil type, rainfall, temperature and crop management factors such as yield and fertiliser and herbicides applied. A farm with real data sets was required. The exercise examined the problems that arose when capturing and interpreting spatial and recorded farm data at this farm scale.

In 1989, trial areas were mapped in the Midlands South extension area (lat. 30:02:S, long. 30:14:E and lat. 29:49:S, long. 30:41:E) using the original UNIGIS software. Cadastral and field boundary information was captured using Surveyor General (SG) diagrams and SASA quota maps. Terrain models were obtained from the SG office and also by digitising the contours on orthophotographs. During 1992/3, catchment studies were started on the Umkwahumbe river for the local Conservation Committee. As there was good spatial data for large areas it was decided to use a farm as an example, and real farm data to establish a fully relational database. The validity of using a GIS to answer queries from farmers or extension officers, could then be examined.

The local extension officer selected a farm which had a suitably large data set of FRS, FAS and other records. The farm, Henhouse Pty Ltd (lat. 29:58:35:S, long. 30:35:52:E) has FRS records dating back to 1986, FAS records dating back to 1980 and a variety of soil, elevation and fertility factors.

Editing and cleaning data

Although the SASA quota map for the farm had already been captured in the GIS, some field numbering and boundary updates were necessary. Field numbers in the FRS and FAS databases did not correspond exactly with the numbering on the farm map, and considerable effort was required to align the numbering systems to obtain the exact match required by the computer.

For the map data to link with the field records, GIS data needs to be 'clean'. This entailed interactively editing the minute errors which are inevitable during the digitising phase and which are visible only when the maps are highly magnified. Such errors include discontinuous line strings and minute undershoots or overshoots at line joins.

Once the data was clean, it was possible to ask the system questions based either on the attribute data (e.g. FRS), or on the physical or spatial properties of an area or a combination of both.

Farm description

The farm was described by creating the following maps:

- A three dimensional diagram produced from the Digital Terrain Model (DTM) described by Wallace (1993) and presented in Figure 1.
- A 10 m interval contour map (Figure 2), colour coded to match the three dimensional diagram.
- A field boundary map (Figure 3) based on the current industrial quota map.
- A terrain aspect map (Appendix 1) identifying the four aspects N to E, E to S, S to W and W to N.
- Soil parent material map (Appendix 1).
- A soil form map (Appendix 1) established by interpreting the soil pit information supplied by the farmer. This map was simplified by grouping the following soil forms together:
  Humic (H): Nomanci, Inanda, Kranskop and Magwa
  Well drained (W): Avalon, Clovelly, Griffin, Hutton, Oakleaf, Shortlands and Swartland
  Poorly drained (D): Cartref, Fernwood, Longlands and Westleigh
  Glenrosa (G): Glenrosa.
- Soil clay content categorised according to the groups: <15%, 15<25%, 25<35% and >35% (Appendix 1).
- Phosphate fixation indicated by the following PDI values: weak >0,4, moderate 0,2-0,4 (M) and strong <0,2 (S); if more than one soil sample result was available, the lowest value was selected.
- A map indicating the Aluminium (Al) status of a field. As threshold value is related to clay content, the extraction query was simplified by using the Exchangeable Aluminium Index (EAI) to 100 g clay ratio of 3,5 as the threshold value (Moberly and Meyer, 1975). To allow for sampling variation, an additional category for ratio values falling between 2,5 and 3,5 was included to indicate those fields where the Al values were approaching toxic levels. If more than one sample result was available, the highest value was selected.

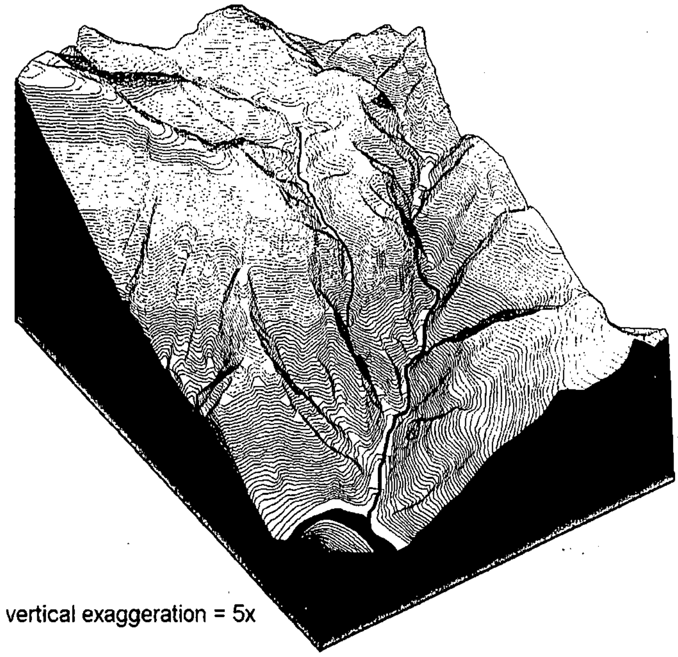

FIGURE 1 A 3-dimensional diagram of the farm produced from the Digital Terrain Model

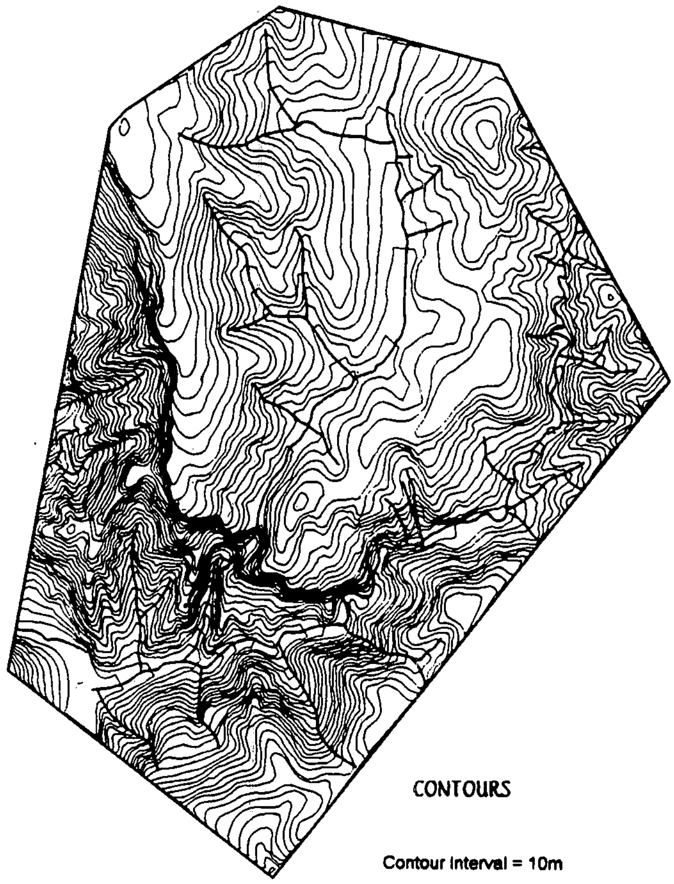

FIGURE 2 A GIS generated 10 m interval contour map

FIGURE 3 A GIS generated field boundary map high-lighting the fields to be investigated

Soil depth measurements were unfortunately not available. This factor would also help to explain many of the yield anomalies found when interpreting yield data.

Interpretation query

In order to eliminate interactions with different seasons, it was decided to investigate the yield data from fields harvested in the same season and which had grown through a similar cycle. Previous analyses of yield data have indicated that there could be considerable variation in cane yields for fields with similar growth cycles. Data from fields previously harvested during August and November 1990 and harvested during the August to September period in the 1992-93 season were extracted for the investigation.

Rainfall for the period January 1990 to December 1992 is presented in Figure 4, and shows that good rains fell during the first summer's growth but were below average for the second summer.

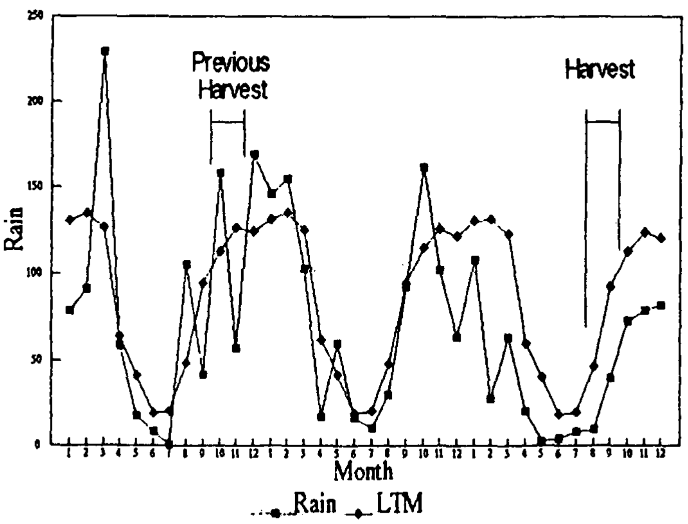

FIGURE 4 Rain and the long term mean rainfall recorded at the Powerscourt met. station for the period January 1990 to December 1992

Results

GIS

All extraction queries directed at the various databases were successfully carried out, the only requirement being that the number identifying a specific cane field be identical in all databases.

Yield data

Yield data and associated field numbers extracted from the FRS database are presented in Table 1.

Fields were divided into two groups:

- (HY) High yield (>90 tc/ha): fields 403, 594, 551, 506 and 542
- (LY) Low yield (<80 tc/ha): fields 401, 582, 541 and 552

Of the nine fields extracted, eight had been planted to variety N12 and one to variety NCo376. The ratoon status of the HY group tended to be marginally older than the LY group.

The fields extracted were then highlighted on the quota map which had been produced.

All crops harvested from a selected field were used to determine the mean tc/ha yield for that field. This yield was then compared with yields obtained from fields with a similar growth cycle. This established whether the yield performance of the selected field was historically above or below average. A summary of yields and yield performance status is presented in Table 2.

With the exception of field 551, which had yielded above average in the 1992 season only, all fields in the HY group had historically produced above average yields. In the LY group, all fields had a history of producing below average yields with the exception of field 541, which had only performed below average in the 1992 season.

Topographical, soil and fertility information

Yield maps were overlaid on farm description maps to establish the pertinent details for each of the fields. The aspects investigated are summarised in Table 3.

Table 1

Yield, variety and crop status information for fields grown from summer 1990 to summer 1992

Map No	Field No	Plant date	Area (ha)	Var	Crop	Previous h/date	Harvest date	Age (mth)	Rain (mm)	Tons cane		Rel sucr	
										t/ha	mth	s %	t/ha
1	403	Nov-87	2,0	N12	2	Nov-90	Aug-92	21,5	1320	109	5,1	17,6	19,2
2	594	Sep-84	4,4	N12	4	Nov-90	Sep-92	21,9	1327	105	4,8	16,8	17,6
3	551	Oct-83	2,0	N12	4	Nov-90	Sep-92	22,4	1333	103	4,6	14,9	15,4
4	506	Sep-83	4,2	N12	5	Oct-90	Aug-92	21,4	1329	95	4,4	16,9	16,0
5	542	Oct-83	12,5	N12	4	Nov-90	Aug-92	21,6	1335	93	4,3	17,3	16,2
6	401	Oct-87	3,3	N12	2	Nov-90	Aug-92	21,5	1320	78	3,6	16,6	12,9
7	582	Oct-83	3,2	N12	4	Nov-90	Sep-92	22,1	1327	77	3,5	16,2	12,5
8	541	Oct-85	1,1	N12	3	Oct-90	Aug-92	21,4	1335	73	3,4	18,7	13,6
9	552	Sep-85	2,5	N376	3	Nov-90	Sep-92	22,4	1332	50	2,2	15,8	7,9

Table 2

The mean tc/ha yield and the historical performance status of each field

Map No	Field No	Mean yield performance				Comparative fields	
		Crops	Age	tc/ha	tc/ha/mth	tc/ha	% mean
1	403	4	19,7	95	4,8	87	110,4
2	594	5	19,2	95	5,0	83	115,1
3	551	4	21,3	80	3,7	84	94,5
4	506	5	18,3	103	5,6	84	123,5
5	542	4	21,0	92	4,4	85	108,2
6	401	4	20,2	78	3,8	87	89,5
7	582	4	21,3	75	3,5	84	88,9
8	541	4	20,5	88	4,3	87	102,2
9	552	4	21,0	72	3,4	87	83,5

Table 3

A summary of field data obtained from overlaying the field boundary map on the farm description maps generated by GIS

Map No.	Field No.	Slope position	Aspect	SPM	Soil group	Clay %	PDI	EAI: 100g clay
1	403	T/M	SW	TMM	G/D	25-35		
2	594	M/B	NE	TMO	D	< 15		> 3,5
3	551	T	E	TMM	G	> 35	S	> 3,5
4	506	B	E	TMO	D	< 15		
5	542	M/B	NE	TMO	W	25-35		
6	401	T/M	SE	TMM	H	< 15		> 3,5
7	582	T	E	TMO	H	> 35	M	> 3,5
8	541	T	NE	TMO	W	25-35	M	> 3,5
9	552	T	E	TMM	H	> 35	S	> 3,5

Slope position: T = top, M = middle, B = Bottom
Soil parent materia (SPM): TMM = Table Mountain Mistbelt, TMO = Table Mountain Ordinary
Soil group: G = Glenrosa, H = Humic, W = Well drained, D = Poorly drained
P fixation (PDI): M = Moderate, S = Strong

Differences between the two yield groups were found to exist for slope position, soil form, clay content, P fixation and Al toxicity.

The historical soil analysis data for each field was extracted from the FAS database to further investigate P fixation and Al toxicity (Table 4).

The Exchangeable Aluminium Index (AEI):100 g clay ratio and the Aluminium Saturation Index (ASI) were calculated from the Al, K, Ca, Mg and clay content values recorded in the FAS database.

The application of lime or gypsum had to be obtained from other sources as this information was not recorded in the database.

Aluminium toxicity

Apart from field 401, no pre-plant samples indicated the existence of Al toxicity; the EAI:clay ratio values greater than 3,5 were obtained with subsequent soil samples. It is of interest that in field 594 where toxic levels of Al have developed, cane yield does not appear to have been affected although no corrective measures have been taken. The ASI values were included as this aspect of soil fertility is currently under investigation (*Schroeder, personal communication). It is being proposed that an ASI threshold value of 40% be used to indicate Al toxicity for variety N12 and a value of 20% for all other varieties.

It is not clear why dolomitic lime was applied to fields 403 and 542, whereas lime may have been applied to field 506 to correct a possible Mg deficiency. The application of lime or gypsum to fields 582, 541 and 552 to reduce the ASI values appears to have had no effect on cane yields.

Phosphate fixation

P fixation was a problem in three LY fields and one HY field. Soil P values, as indicated in the FAS data, were sufficiently high for it to have been unnecessary to apply a supplementary broadcast application of phosphate. The application of dolomitic lime and/or gypsum does not appear to have had an effect on the yield status of fields, except in the case of field 551. As mentioned previously, this field was the only one which had a history of below average yields, with a high yield in the 1992-93 season. It is possible that the strongly P fixing nature of this field was corrected by the application of gypsum in 1989.

Discussion

Viewing the fields spatially showed that the HY fields were not grouped together, nor were the LY fields. High and low yielding fields were found adjacent to each other, e.g. fields 403 and 401 and fields 551 and 552. The data query facilities provided by the GIS made it a simple task to extract information pertaining to a particular field or group of fields to ascertain which factors might be affecting yields.

Soils and aluminium toxicity

The low yielding fields were located on the humic or well drained soils and where Al toxicity was present. Identifying Al toxicity before planting is essential as the most effective way of eliminating it is by the incorporation of lime prior to planting. This investigation indicated considerable variation in Al values for samples taken from the same field. Possible reasons for this are:

- increased soil acidity with continuous cropping which, although often associated with lighter textured soils, is not necessarily confined to these soils (Schroeder *et al.*, 1994). In most of the fields investigated, although the EAI:clay ratio increased with time it was only in field 594 that the pH indicated some declining pattern.
- sampling procedure: nutrient levels in the soil are not present in uniform amounts, and the recommended procedure for taking a soil sample is aimed at obtaining a sample which represents the average condition in the field. The random nature of the sampling procedure could result in samples that either over or under estimate the levels of a particular nutrient in the field. The difference between the samples taken during July and November 1985 for field 541 (Table 4) clearly demonstrates this. In most cases

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Table 4

The historical soil analysis data for each field and a record of the lime and gypsum applications

Map No	Field No	Date	PDI	pH	N cat	kg/ha				ppm Al	Clay %	EAI: clay	ASI %	Applied lime/gypsum
						P	K	Ca	Mg					
1	403	Jun-87	0,66	5,05	4	62	249	879	182	15	30	0,6	5	1987-5t dolomitic
2	594	Jul-84		4,60		23	157	459	132	8	0		5	
		Nov-86		5,30	1	62	195	814	144	3	0		1	
		Jan-88		4,90	1	37	85	1208	110	7	14	0,6	2	
		Jun-89		5,00	1	46	76	418	99	9	0		7	
		Dec-90		4,75	1	65	65	283	58	52	8	7,2	39	
		Nov-92		4,75	1	77	148	148	51	32	10	3,6	34	
3	551	Mar-83	0,08	4,75		17	391	1194	429	45	40	1,3	10	
		May-84	0,33	4,60		15	333	931	155	93	33	3,1	26	
		Jun-89	0,14	4,80	3	49	274	909	207	143	48	3,3	34	1989-5t gypsum
		Nov-92		4,70	3	18	486	549	81	101	30	3,7	35	
4	506	Sep-86		4,85	1	64	137	909	94	13	0		5	
		Jan-88		4,80	1	50	456	1633	76	11	14	0,9	3	1989-1t dolomitic
5	542	Mar-83	0,59	4,70		39	315	389	168	15	0		8	1983-2t dolomitic
		Sep-87	0,47	5,05	3	34	207	697	240	19	30	0,7	7	
		Jun-89	0,58	5,10	4	44	274	852	281	19	30	0,7	6	
		Dec-90	0,65	5,25	3	66	249	555	144	24	22	1,2	12	
6	401	Jun-87		4,80	1	38	258	481	155	80	11	8,1	32	
7	582	Mar-83	0,21	4,65		46	213	965	324	32	29	1,2	9	
		Sep-87		4,80	4	93	391	776	211	79	35	2,5	23	
		Jun-89	0,35	4,90	4	66	184	670	166	104	47	2,5	33	1989-5t gypsum
		Nov-92		4,60	3	69	321	481	94	146	31	5,2	48	
8	541	Jul-85	0,33	5,00	3	44	180	1656	477	20	30	0,7	4	
		Nov-85	0,50	4,80	3	14	326	420	121	118	28	4,7	43	
		Sep-87		5,00	3	75	249	396	121	66	20	3,7	31	
		Jun-89	0,66	4,75	3	49	141	389	105	79	20	4,4	38	1989-1t dol+3t gyp
9	552	Jul-85	0,16	5,10	3	38	294	1359	429	39	36	1,2	8	
		Jan-88		4,85	4	82	411	1300	137	115	30	4,3	25	
		Jun-89	0,23	4,65	3	53	256	596	157	171	48	4,0	46	1989-5t gypsum
		Nov-92		5,10	3	12	582	1635	452	8	37	0,2	1	

corrections can be made where a nutrient has been under estimated. In the case of Al toxicity this is not possible.

Where Al toxicity is suspected, it is suggested that the soil sample be taken from the poor growth areas before plough-out and the resulting recommendation be used for the plant crop. Although this could result in areas of the field being over fertilised, the cane is likely to produce higher yields and prevent a premature plough-out of the field.

It is interesting that, despite the high EAI:100 g clay ratio, the cane in fields 594 and 551 still produced high yields. Schroeder *et al.* (1993) reported that Al is unlikely to have a negative effect on yield if the Al:sulphur ratio is less than two. Sulphur values for these fields were not available and it is felt that obtaining these values may provide some answers to the responses.

Recent research indicates that varieties N12 and N16 are more tolerant to Al toxicity than varieties NCo376 and NCo293 (** Meyer, unpublished data). The relatively high ASI values recorded in the HY fields 594 and 551 indicate that the proposed ASI threshold value of 40% for variety N12 may need to be re-assessed.

Slope position

Assessing a field in relation to its position on the slope is possible using the spatial presentation provided by GIS. The HY group of fields were all situated at either mid or bottom slope positions, whereas the LY group were all situated in the top slope position. In addition, the soils in most of the HY fields were associated with soils containing an E horizon or plinthic layer. The LY fields were associated with well drained soils. It is considered that fields situated lower down the slope and with a subsoil layer impeding drainage, receive extra moisture from higher up the slope by the lateral movement of this water.

The rainfall distribution presented in Figure 4 indicates that extra water, as a result of high rainfall during the period March 1990 to October 1991, could have maintained the high moisture status of the lower lying fields during the dry summer months of 1991-92. This aspect needs to be investigated further and the intention is that fields in similar slope positions and with similar soil type conditions be identified using GIS, and the yields investigated. The growth model being developed at SASEX would assist in identifying when extra water could have been available for lateral drainage.

Conclusions

The GIS operating at the SASA Experiment Station can assist in the interpretation of farm yield data. This is achieved by using both the spatial presentation and data query facilities of GIS. The primary requirement is that numbers identifying each field be identical in all databases. This is likely to be a problem and, at best, some editing of each database will be required.

In the investigation carried out, the LY field tended to be associated with humic or well drained soils, soils which were moderate to strong P fixing, the presence of aluminium toxicity and fields in a top slope position. The HY fields were associated, in most instances, with soils which had an impermeable subsoil layer, aluminium toxicity development with time and fields in a mid to bottom slope position.

Recent and current research on aluminium being carried out by SASEX (Al:S ratio, varietal tolerance to Al and the Aluminium Saturation Index) will no doubt explain some of the Al toxicity anomalies found in this investigation. It is recommended that a biased soil sample be taken where Al toxicity or P fixation is suspected, so that these problems can be dealt with when establishing a new crop.

This investigation also suggests that further work be carried out that compares the performance of cane growing in the top, mid and bottom slope positions.

The study presented in this paper indicates that the yield obtained from a specific field is determined by more than one factor. It should be kept in mind when interpreting farm yield data that yields are unlikely to be affected by a single factor.

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APPENDIX 1

GIS generated maps describing the farm in terms of soil parent material, soil forms, soil clay content and slope aspect.