APPLICATION OF PRECISION AGRICULTURE TO SUGAR CANE

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ABSTRACT

This paper focuses on the application of Precision Agriculture to sugar cane in an attempt to reduce spatial variability and improve production of a case study field. The first task was to undertake yield mapping and for this a unique yield mapping system was developed. The resultant yield map displayed yield variations from 70t/ha to 220t/ha. Next, a directed soil-sampling regime was implemented based on the yield map and other soil related maps. The results of the soil tests indicated a strong negative correlation of crop yield with the sodium and magnesium content of the soil. To overcome this yield-limiting factor, gypsum will be applied at variable rates over the field. A simple economic analysis is conducted based on the cost saving resulting from optimised gypsum input. The results show the viability of precision agriculture when applied to sugar cane in this situation.

INTRODUCTION

Sugar cane is an economically important crop in many countries around the world. In Australia it is the second largest export crop, contributing more than one thousand million dollars to the economy annually (Queensland Sugar Corporation). The average crop yield in Australia is 80 t/ha and at the normal price of $30/t returns a gross of $2400/ha, so sugar cane could be regarded as a high value crop per hectare. It is also a high input crop with up to 800kg/ha of fertiliser applied per annum. With this combination of high value and high inputs, it could be argued that sugar cane is a good candidate for Precision Agriculture (PA). For this reason, the National Centre for Engineering in Agriculture (NCEA) in Australia has been working on the application of PA to sugar cane for three years.

This paper reports on the first application of precision agriculture to sugar cane. The site was a 1000ha farm operated by DAVCO farming at Ayr, North Queensland, Australia. For this paper, a single field was selected to be representative of the whole farm. The field is defined as Field 7A in farm plans and is approximately 117 ha in area. The paper is divided into three sections describing the site specific procedures carried out on the field. These were yield mapping, directed soil sampling and variable rate application. For the yield mapping a unique system was developed to produce the first ever yield maps of sugar cane. Next, the soil sampling was carried out with the assistance of the yield map. The results of the soil tests indicated a strong negative correlation of crop yield with the sodium and magnesium content of the soil. Variable rate technology will be used in the coming southern summer to apply gypsum with the aim of overcoming these yield-limiting factors. Finally, to show the viability PA in this situation, a simple economic analysis was conducted using three scenarios. These matters are now discussed in more detail.

YIELD MAPPING

There are no commercially available yield monitors for sugar cane. In many countries around the world sugar cane is still cut by hand, however in the more advanced countries the standard mechanical means of harvesting is the 'chopper harvester' which was developed in Australia. This harvester is unique in its gathering and processing of the crop and for this reason no technique existed for measuring the mass flow rate through the machine. Therefore yield mapping was not possible. The NCEA has conducted research on this problem for 3 years, focusing on developing a suitable sensor. Four different measurement techniques have been developed and trialed in the field. The techniques range from direct mass sensing to volume measurement and also indirect techniques involving measurement of power consumption. Each technique has displayed advantages and disadvantages. After extensive field trials the final technique selected was the direct mass measurement technique. A provisional patent has been acquired and this system is currently undergoing a premarket test with five units in the field. It is anticipated the system will available for full release in 1999.

A prototype system has operated successfully for the 1996 and 1997 seasons with various sensing techniques. Figure 1 shows the calibration results for the two indirect sensing techniques during part of the 1996 season. Each data point represents a daily total and compares an indicative sensor reading with the total crop material cut for the day. The calibration curve derived for this field was used to post calibrate the yield data to maximise the yield map accuracy.

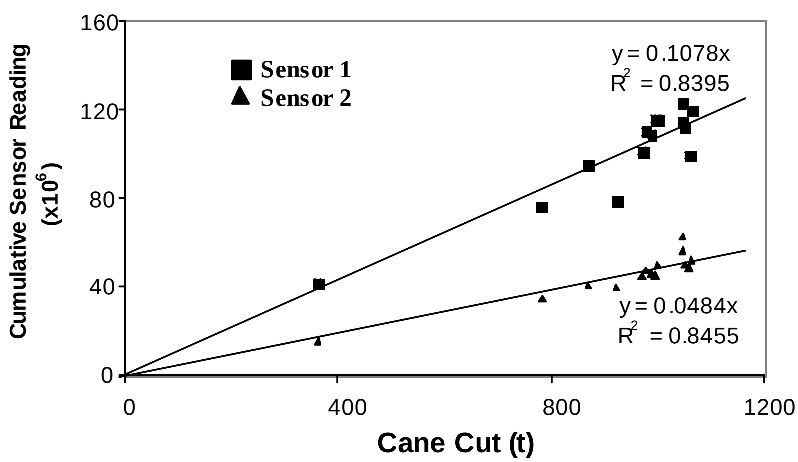

Figure 1. Calibration results for sensors.

Yield maps were produced using ESRI’s Arcview®, a general purpose GIS package. The data were imported and then smoothed by a simple technique written with Arcview's programming language, Avenue. The technique consisted of smoothing the data points by placing a 20 by 20m grid over the field and calculating the average yield reading for each grid cell. Approximately 100 data points were found in each grid. More complicated interpolation techniques were not implemented due to the significant computation time required for even this simple smoothing technique. In total the 117ha field considered here contained approximately 350,000 data points. For this paper the grid yield map was further processed in the contouring package, Surfer® to produce a black and white map suitable for publication. The resultant yield map (Figure 2) showed significant signs of yield variation. In the field under study the average yield was 120 t/ha and the yields were normally distributed around this value with a standard deviation of 25t/ha. The lowest yield was 70t/ha ($2100/ha) and the highest was 190t/ha ($5700/ha). It was encouraging to find a close correlation between the high and low yield areas found on the yield map and those displayed on an infrared aerial photo of the field taken previously.

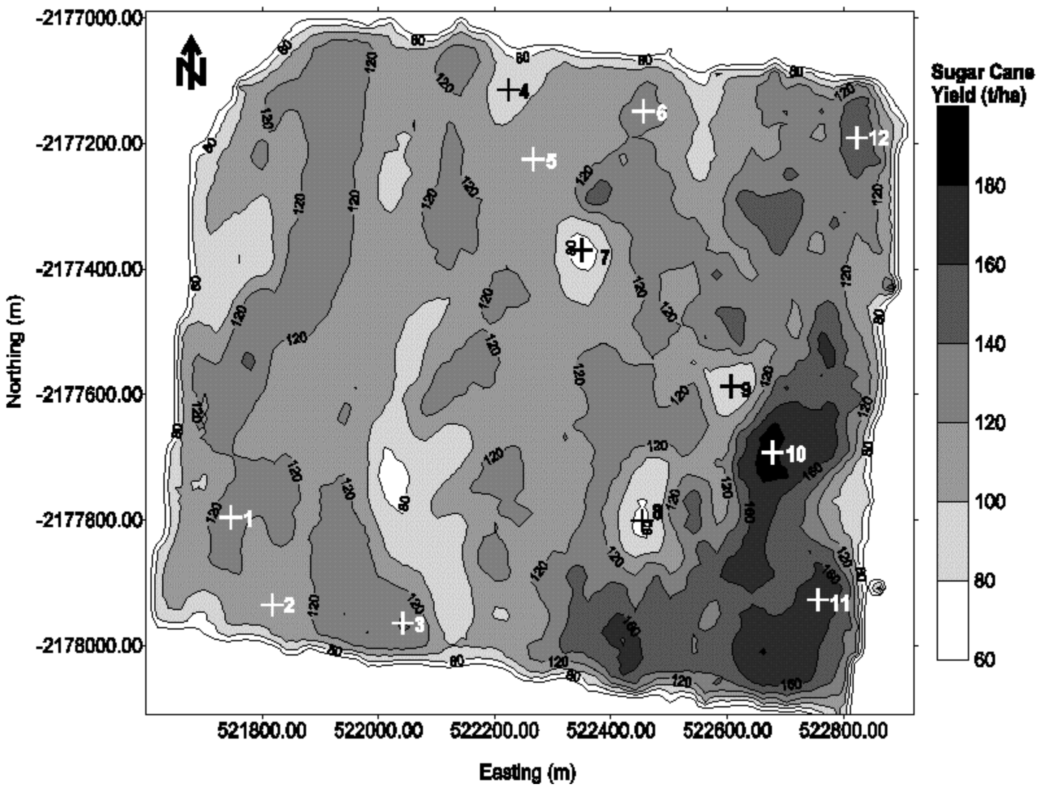

Figure 2. Yield map of field under study.

The history of this field should be discussed to provide an insight into the cause of the yield variation. The field is situated in the newly developed Burdekin River Irrigation Area (BRIA) and has been in production for seven years. Prior to this it was laser leveled to improve irrigation and drainage. It is this levelling which has caused the higher areas to be scalped of their top soil and the lower area to be filled. The scalping exposed a highly sodic subsoil which has poor structure and greatly reduced infiltration and water holding capacity. This severely limits yield in these areas, particularly under fully irrigated conditions. A cut/fill map has shown that these scalped areas occur in the same places as the lower yielding areas on the yield map. It is also noteworthy that the largest yields are found in the south eastern corner of the paddock where the area was filled with up to 0.5m of imported top soil. With this history, the farmer expects that the yield variation is due to the adverse effect of sodicity on soil structure, and plans to rectify the problem with variable rate gypsum amelioration. The soil sampling provides evidence to support this line of action.

DIRECTED SOIL SAMPLING

Pocknee et al. (1996) defined the process of directed soil sampling as dividing a field into smaller units as required by, and based on, the patterns present within the field, and then of sampling each of these units individually. In this case the maps available to determine the ‘patterns present within the field’ were a yield map, a laser leveling cut and fill map, soil survey map and infrared aerial photos of a mature crop. After examination it was believed the yield map represented the most recent and representative information. Therefore based on the yield map it was decided to choose 12 sample locations over the field. The sites were chosen to cover the full representation of the yield variation. From the yield map six different yield intervals were definable. They were 60-80t/ha, 80-100t/ha, 100-120t/ha, 120-140t/ha, 140-160t/ha and 160-220t/ha. Two replicate sites were selected for each yield interval, making a total of twelve sampling sites. The selected sites are shown on the yield map.

Differential GPS technology was used to navigate to the selected positions. At these sites, five samples were taken within a radius of 15m and mixed together to give a representative sample. The sampling method involved a coring tube and a jackhammer. Samples were taken at a depth of 0-25cm and 25-50cm on advice from extension staff (Ham, G. 1996, pers. comm., 2 Sept).

The total of 24 samples (12 sites X 2 soil depths) were dried and sent to the INCITEC soil laboratory in Brisbane. The soil samples (0-25cm) were analysed for: Soil Colour (Munsell), Soil Texture, pH, Organic Carbon, Nitrate Nitrogen, Sulfur, Phosphorus (BSES), Phosphorus(Colwell), Potassium, Calcium, Magnesium, Sodium, Chloride, Electrical Conductivity, Copper, Zinc, Manganese, Iron and Boron. From these results the Cation Exchange Capacity, Calcium/Magnesium Ratio, ESP and Electrical Conductivity(se) were calculated. A summary of the soil analysis results is given in Appendix A.

A simple linear regression was conducted for each soil variable versus yield. For analysis purposes the yield of the sample points was taken as the median of the yield range appropriate to that point. For example, point 1 lies on the yield range 120-140t/ha and therefore the yield is taken as 130t/ha.

The results of the correlation analysis confirmed what was expected but also provided additional information. Of the top soil parameters analysed, sodium, chloride, electrical conductivity, Ca/Mg Ratio and calculated electrical conductivity (se) were significantly correlated with crop yield ($F<0.01$). Magnesium and ESP were marginally correlated with yield (approx. $F=0.05$). Of these variables the best linear correlation came from sodium and calculated electrical conductivity (se) accounting for 69% and 67% of the variation respectively.

The strong negative correlation of yield with sodium is expected and will be discussed later. The strong negative correlation of electrical conductivity with yield is caused by the effect of sodium on electrical conductivity rather than the direct effect of electrical conductivity on yield. The high negative chloride correlation is related to the inability of the high sodic soils to leach the chloride from the topsoil. The only positive correlation with yield was found with the Ca/Mg ratio due to the positive effect of Ca on the sodic soil.

Of the subsoil variables measured, most were significantly correlated ($F<0.01$) with yield. They were: pH, sulphur, phosphorus, magnesium, sodium, electrical conductivity, CEC, ESP and Ca/Mg Ratio. The uncorrelated variables were potassium, calcium and potassium(nitric). The strong correlation of yield with most of the variables is due to the interdependence between them. This interdependence is primarily due to the weak leaching nature of the soil. The highly sodic soils allow less infiltration and therefore less leaching, resulting in higher concentrations of the measured parameters.

An interesting correlation was the negative relationship of phosphorus with yield. This could be due to a build up of residual phosphorus in lower yielding areas after seven years of uniform application. This result would indicate that variable rate application of this input could take advantage of this factor and save on input costs.

As noted above, the correlation of yield with sodium was strong, accounting for 62% of the variation. Surprisingly the best correlation was found with magnesium, accounting for 75% of the yield variation.

The high sodium content of these soils is not believed to be toxic to cane plants. Instead, the effect on yield is manifested through deterioration of soil structure. Increasing levels of Exchangeable Sodium Percentage (ESP) cause clay particles to disperse when the soil is wet. This is associated with sealing and crusting of surface soils, and dense subsoil clays which resist penetration by roots. Even if water does penetrate the surface it is held strongly in very small pores formed in the dispersed soil. It is difficult for roots to withdraw this water and the end result of sodicity is water stress. Both water infiltration and water storage in the soil are reduced. When a sodic soil is wet, the clay is dispersed and has a very low bearing capacity. When dry, sodic soils are very hard and poorly structured.

Figure 3 shows the sodium and magnesium levels (top and subsoil average) plotted against the crop yield. Although sodium has a strong overall negative correlation to yield, the relationship is not as linear or obvious as expected. Below a yield of 130t/ha the relationship is pronounced, but above 130t/ha there seemed to be little or no reduction in sodium for a large increase in yield. This raised the question as to what is causing the 70t/ha reduction from 200t/ha down to 130t/ha when sodium seems to be relatively constant. At this point the effect of magnesium was examined more closely.

At the higher yield levels the relationship of yield with magnesium was very pronounced (Figure 3). Bakker et al. (1973) found that the water content for dispersion of a magnesium-sodium soil was only about half that of calcium-sodium soil. This is also supported by Ellis and Cardwell (1935) who note that magnesium as opposed to calcium may promote the dispersion of clay from a soil. Therefore it is likely that the combination of magnesium with the sodium magnifies the adverse soil properties which lead to a reduced yield. In fact, Bakker and Emerson (1973) state that ‘it is clearly inadequate, when attempting to define a sodium affected soil, to use ESP (exchangeable sodium percentage) as the only criterion. However, to give equal weight to sodium and magnesium does not seem justified’. In Figure 3 it is assumed that magnesium is only ‘half as bad’ as sodium and therefore when plotted together, magnesium is weighted as half it’s actual soil proportion i.e (0.5Mg + Na). The linear correlation of this quantity with yield is notable, having an R^2 of 0.96.

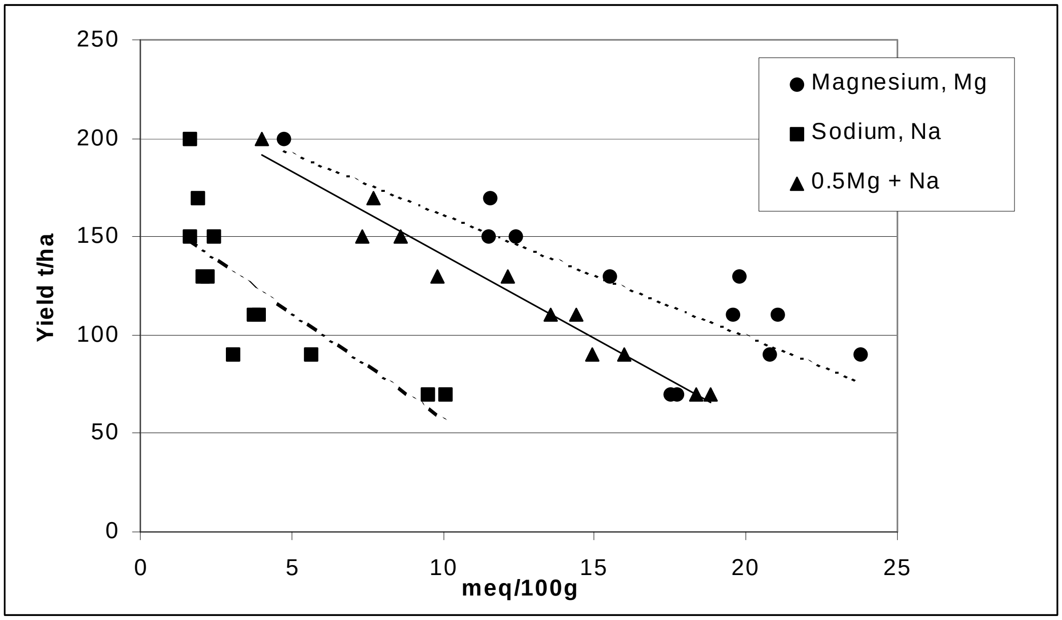

Figure 3. Linear correlation of crop yield with magnesium (Mg), sodium (Na) and a combination of magnesium and sodium (0.5Mg + Na).

Table 1 . Correlation results

Variable	**Gradient, m ((t/ha)/(meq/100g))**	**Intercept, c (t/ha)**	**R^2**
Magnesium, Mg	-6.1496	222.87	0.68
Sodium, Na	-10.921	165.93	0.64
Combination 0.5 Mg + Na	-8.4557	225.13	0.96

Another important point which this work revealed is the futility of using random soil samples when making input recommendations at the block level. If soil sampling was conducted randomly across this field in an attempt to gauge the level of sodicity, the resultant data would be pointless due to the randomness of the soil parameters which would result. Even if numerous samples were mixed together there is no guarantee that a representative sample would be achieved. It is obvious therefore that individual or mixed soil samples should not be used to make blanket field recommendation for crop inputs. This may be a reason for the general distrust by farmers of soil analysis results. The use of yield maps can greatly improve sampling strategies and in doing so provide a great deal more agronomic information on which to base recommendations, even at the field scale.

VARIABLE RATE APPLICATION

The soil analysis results have shown a clear negative relationship between the sodium and magnesium content of the soil and crop yield. Now we can use this relationship to develop a prescription for the field.

Sodic soils are probably the most expensive soils to reclaim. To reclaim the soil, sodium must be leached away and replaced with calcium. To do this, subsurface drainage is necessary to allow sodium to leach from the soil. Gypsum (at least 10 tonnes per ha) is used as a calcium source. The next step is to rip with a tine ripper to open the soil without turning it over. These actions will allow water to move through the soil, removing sodium and replacing it with calcium.

The current technique for gypsum application is the use of a ten tonne spreading truck fitted with hydraulically driven rate control. A variable rate controller will be purchased to automatically control the gypsum rate as defined by the application map. The application map will look exactly the same as the yield map given in Figure 2, except that the legend will be adjusted to represent the gypsum requirements. These requirements will be calculated using the prescription equation defined in Figure 4. This equation was developed by defining the two endpoints. These were, 20t/ha of gypsum for the worst areas yielding 70t/ha and no gypsum (0t/ha) for the best areas yielding 190t/ha. Between these points the prescription rate was assumed to be linear. This prescription is not based on any scientific facts except that these are the usual rates specified for blanket applications. This is one of the problems and is the reason why response trails will be conducted to develop more useful prescription equation.

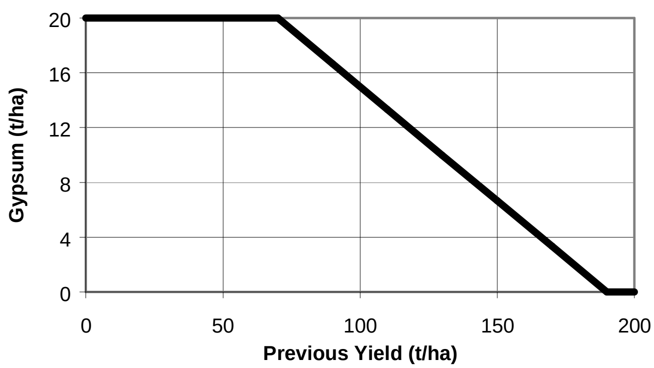

Figure 4. Recommendation equation for gypsum application

Trails will be implemented using strips of constant application rate along the length of the field. The position of these strips will be selected to cross as many different yield regions as possible. During the writing of the prescription map these changes will be made will be automatically implemented during application. In the following harvest, yield mapping will be conducted over the field. The yield response will then be determined at each point along the trial and a response curve developed. This will allow a more informed decision to be made about further application. Currently the economic analysis is somewhat limited by the fact that the response curve is unknown. Trials have been conducted but only on a whole field basis and with coarse changes in the application rate. By conducting strip trials across this block a much greater understanding of the response will be gained.

A more precise response curve will also allow the comparison between gypsum application and other remediation techniques such as importing topsoil from outside the field or removing the areas from production altogether. In fact, it may be more feasible to import a large quantity of quality top soil and spread it over the field than apply gypsum. This assumes there is an excess of topsoil nearby, which is the case in this situation.

Economics

At the normal application rate of 10t/ha, gypsum application costs $1000/ha, and is therefore a high cost input. This offers the possibility for substantial economic benefit if the gypsum application rate can be controlled according to needs. By reducing the amount of gypsum required, input costs will be reduced, while optimum placement of gypsum will increase production.

For this economic analysis, the economic return is calculated for gypsum being applied at an optimum rather a blanket rate. Three scenarios are compared, and the cost of each is calculated as the cost of the crop input (gypsum) and the cost of lost production if insufficient input is applied. These scenarios are:

1. PA optimised gypsum distribution so that the correct amount of gypsum is applied in each area. There is no production lost and there is no over application cost.
2. Application of gypsum with a blanket distribution at the maximum recommended rate of 20t/ha. This results in no production loss but there is an overapplication cost on most of the field.
3. Application of the same total amount of gypsum as the PA optimised scenario (1) except as a blanket application over the field. The input cost is the same as for the scenario (1) but there are production losses as some areas are under applied

A number of assumptions were made in the analysis. Firstly, it was assumed that the prescription equation given in Figure 4 is optimal. That is, if gypsum is applied at a greater rate than given by the prescription then it is wasted. Also if the gypsum is applied at a rate less than the prescription, then loss in production results. The rate of production loss is assumed to be 2.5 tonne of cane per year per tonne/ha of gypsum not applied. This figure is calculated from measured yield increases of 25t/ha for gypsum application rates of 10t/ha (Ham, 1986). For these calculations it has been assumed that one gypsum application is sufficient for one cane crop cycle of 5 years. Therefore every 1t/ha of gypsum under-applied results in 12.5t/ha of lost cane production over the 5 years. With the price of sugar cane at $30/t, this implies a total loss in returns of $375/ha over 5 years.

The yield distribution used for the calculations is shown in Figure 5 and comes directly from the yield map in Figure 2. The shape of this distribution determines how much gypsum is applied for the PA scenario (1). It also determines how much gypsum is over applied in scenario (2) and how much lost production results from scenario (3). The flatter the distribution (higher variability) the greater the advantage of adopting PA.

The total cost of implementing PA was calculated as $5829 ($49.82/ha). This figure is calculated in Appendix B and takes into account all costs associated with PA including yield mapping, soil sampling and variable rate application. The costing assumptions are quite conservative and even if this figure was doubled it would not affect the outcome of the analysis substantially.

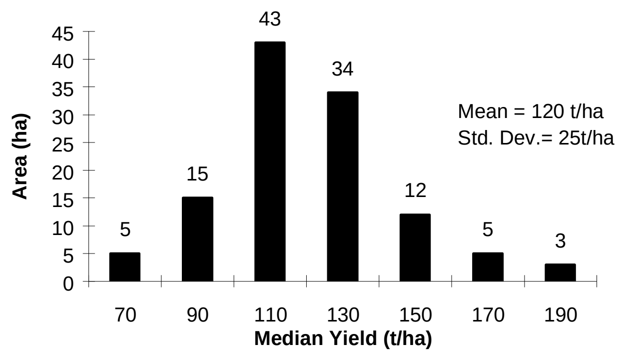

Figure 5. Histogram of crop yield for the field under study.

The outcomes of the calculations for the three scenarios are shown in Figure 6. The total cost of the PA optimised scenario (1) over the field was $141,829 ($1212/ha). The 20t/ha blanket application (2) resulted in $234,000 ($2000/ha) total cost. In scenario (1) a total of 1360t was applied, which when spread evenly over the 117ha field is equivalent to 11.62t/ha. Scenario (3) therefore involved a 11.62t/ha blanket application and its cost totalled $207,656 ($1775/ha). These results clearly show the benefit of PA, with scenario (1) showing an improvement of $92,171 ($788/ha) over the 20t/ha blanket application (2) and a $65,827 ($563/ha) improvement over 11.62t/ha blanket in scenario (3). These savings are measured over 5 years.

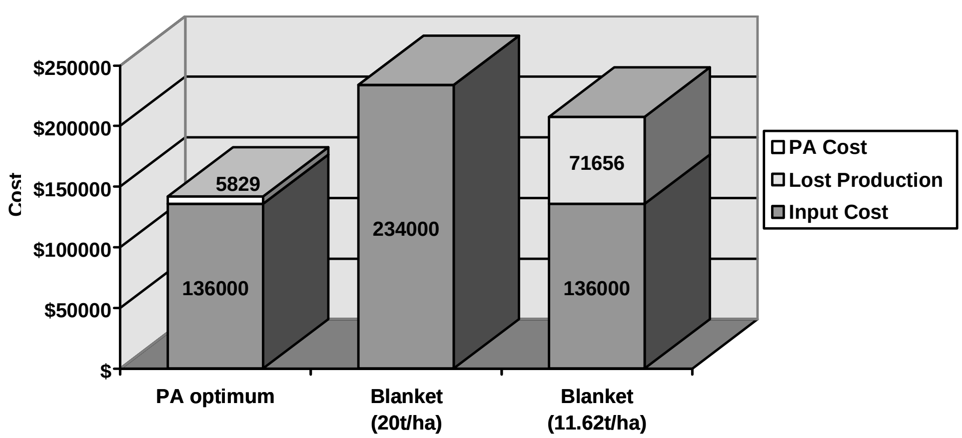

Figure 6. A cost comparison of various of application scenarios over 5 years for the field under study.

It should be remembered that this is a very simple analysis which incorporates several assumptions. Further field trials need to be conducted to develop a better recommendation equation and response curve. A more accurate assessment of these factors would result in a much more reliable and robust economic analysis. However, with the information that is available this economic analysis provides a reasonable estimate of the benefits of PA in this situation. It could be applied to any crop situation to gauge the potential savings. The main variables are the level of variability, the cost of the input and the value of the crop. If all of these variables are high then significant savings are possible with PA.

CONCLUSIONS

A case study was carried out to assess the potential for applying PA principles to sugar cane. A field was selected and various PA techniques applied to it. Firstly yield mapping was conducted. This involved developing the first yield mapping system for sugar cane which has operated for two seasons with positive results. The resultant yield map of the field under study displayed significant yield variation from 70t/ha to over 190t/ha. Soil sampling was then conducted to determine the cause of the yield variation. Linear correlation analysis of soil parameters against yield found results which confirmed what was suspected. High sodium levels in the soil were producing a soil with poor structure which minimises water infiltration and storage. It was also revealed that magnesium was playing a significant part in the problem and exacerbating the effect of sodium. Based on these results variable rate gypsum application has been planned and will be conduct this year. Economic analysis of the situation has shown benefits applying PA of at least $65827 ($563/ha) over five years when compared withstandard management of blanket input application.

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REFERENCES

Bakker A.C. and W.W Emerson, 1973, The comparative effects of exchangeable calcium, magnesium, and sodium on some physical properties of aggregates from subsoils of red-brown earths. II. The permeability of Shepparton soil and comparison of methods. Aust. J. Soil Res. 11, 143-50

Bakker A.C., W.W Emerson and J.M. Oades, 1973, The comparative effects of exchangeable calcium, magnesium, and sodium on some physical properties of aggregates from subsoils of red-brown earths. I. Exchange reactions and water contents for dispersion of subsoil aggregates from Shepparton fine sandy loam. Aust. J. Soil Res. 11, 143-50

Ellis, J.H., and O.G. Cardwell, 1935. Magnesium clay solonetz. Trans 3rd int. Congr. Soil Sci. Vol 1, pp. 348-50.

Ham G.J., 1986. Modifying irrigation water for soils with low infiltration rates. Proc. Aust. Soc. Sugar Cane Technol. 1986 Conference

Pocknee S., B.C. Boydell, H.M. Green, D.J. Waters and C.K. Kvien, 1996. Directed Soil Sampling. *In* P.C. Roberts et al. (eds.) Proceedings of the 3rd Intl. Conference on Precision Agriculture

Queensland Sugar Corporation, Queensland sugar in focus, Brisbane, Australia

APPENDIX A - SOIL ANALYSIS RESULTS

		Soil sample results (0-25cm)															
Point po No.	Yield t/ha	pH (1:5 Water)	Organic C %C	Nitrate N mg/kg	Sulfur mg/kg	Phosphoru mg/kg	Phosphoru mg/kg	Potassium meq/100g	Calcium meq/100g	Magnesiun meq/100g	Sodium meq/100g	Chloride mg/kg	Electrical C dS/m	Copper mg/kg	Zinc mg/kg	Manganes mg/kg	Iron mg/kg
1	130	7	1	6	5	18	9	0.35	12.04	8.76	0.7	15	0.05	1.8	0.3	15	33
2	110	7.9	1	0.7	3	24	4	0.32	14.02	9.83	1.12	15	0.06	1.4	0.1	9	17
3	150	8.3	1	35.9	2	31	6	0.28	12.04	6.59	0.73	15	0.06	1.2	0.3	9	13
4	90	7.5	0.9	0.7	4	17	6	0.45	18.17	11.52	1.19	35	0.06	1.7	0.3	14	30
5	110	7.5	0.8	0.9	5	21	13	0.41	14.77	9.98	1.39	40	0.07	1.9	0.4	13	32
6	130	7.2	1.5	0.6	5	20	12	0.37	11.33	6.9	0.88	30	0.05	1.8	0.6	28	29
7	70	7.4	1.1	0.4	8	10	4	0.2	5.95	6.65	2.23	75	0.08	1.4	0.3	23	21
8	70	7.6	1.1	0.5	5	9	3	0.17	4.97	6.43	2.48	90	0.1	1.2	0.4	19	20
9	90	7.7	1.4	0.7	6	14	4	0.32	8.98	8.81	1.63	40	0.06	1.1	0.7	18	14
10	200	7.4	0.9	0.4	3	16	8	0.21	6.49	3.53	0.72	20	0.04	0.9	0.7	22	22
11	170	8.2	1.5	0.4	3	64	11	0.38	9.72	6.22	0.81	20	0.05	1	0.7	21	14
12	150	6.9	1.5	0.3	7	11	7	0.26	6.59	4.73	0.76	25	0.05	1.2	1	40	21

Continued

					Soil sample results (25-50cm)												
Boron mg/kg	CEC meq/100g	ESP	Ca/Mg Rat	se dS/m	pH (1:5 Water	Sulfur mg/kg	Phosphoru mg/kg	Potassium meq/100g	Calcium meq/100g	Magnesium meq/100g	Sodium meq/100g	Electrical C dS/m	Potassium meq/100g	CEC meq/100g	Ca/Mg Rat	ESP	se dS/m
0.69	21.86	3.2	1.37	0.2	6.8	4	11	0.38	12.99	11.03	1.54	0.05	2.43	25.95	1.18	5.93	0.2
0.77	25.3	4.43	1.43	0.3	8.1	3	13	0.26	9.28	9.73	2.63	0.09	2.32	21.91	0.95	12	0.4
0.73	19.65	3.71	1.83	0.3	7.9	5	11	0.19	7.3	5.79	1.67	0.06	2.45	14.96	1.26	11.16	0.4
0.77	31.34	3.8	1.58	0.3	7.5	4	13	0.46	17.84	12.27	1.85	0.13	2.91	32.43	1.45	5.7	0.6
0.94	26.56	5.23	1.48	0.3	7.3	2	13	0.39	14.18	11.06	2.51	0.12	2.72	28.15	1.28	8.92	0.5
0.77	19.49	4.51	1.64	0.2	6.9	4	11	0.38	12.36	8.61	1.19	0.08	3.2	22.55	1.44	5.28	0.4
1.45	15.04	14.83	0.89	0.4	8.7	6	14	0.29	7.62	11.07	7.26	0.37	3.11	26.25	0.69	27.66	1.7
0.03	14.06	17.64	0.77	0.4	9	4	14	0.26	10.16	11.07	7.58	0.52	3.09	29.08	0.92	26.07	2.3
1.48	19.75	8.25	1.02	0.3	8.8	3	16	0.3	11.47	11.96	3.99	0.25	3.85	27.73	0.96	14.39	1.1
0.57	10.96	6.57	1.84	0.2	6.8	10	9	0.31	8.54	5.98	0.92	0.05	3.75	15.76	1.43	5.84	0.2
1.45	17.14	4.73	1.56	0.2	7	6	11	0.28	7.28	5.34	1.09	0.04	3.14	14	1.36	7.79	0.2
0.64	12.35	6.15	1.39	0.2	6.3	10	8	0.3	8.3	6.76	0.85	0.05	3.12	16.22	1.23	5.24	0.2

APPENDIX B

Table 2. Cost associated with application of precision agriculture to the field under study.

Item		Cost ($/ha)	Cost ($ for 117ha field)
Cost of yield mapping			
Capital Cost			
Yield monitor, $8 000 at 200ha per year over 5 years*		8.00	936.00
DGPS $4000 at 200ha per year over 5 years*		4.00	468.00
Beacon Differential Correction		0	0
Mapping Cost		6.00	702.00
	Total	18.00	2106.00
Cost of soil sampling			
Sampling Cost			
DGPS already purchased		0	0
Soil coring hardware $4000 at 200ha per year over 5 years*		4.00	468.00
Labour 2 men x 1 days labour x $150		-	300.00
Soil analysis 24 samples x $50		-	1200.00
Data analysis and prescription map Generation		10.00	1170.00
	Total	-	3138.00
Cost of variable rate application			
Capital Cost			
VRT controller $5000 at 200 ha per year over 5 years*		5.00	585.00
DGPS Already purchased		0	0
	Total	5.00	585.00
	Overall Total	$49.82	$5829.00

* Assumes hardware is used for remediation of 200ha per year for 5 years before obsolescence, which is quite feasible for a large farm or cooperative.