Mackay Sugar Limited

Australian Government
Sugar Research and Development Corporation

Increasing in-mill NIR effectiveness and communicating data to all sectors for improved decision making in the sugarcane value chain

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Sugar Research and Development Corporation

Final Report
Project CSR038

SRDC Research Project
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Executive Summary:

In 2005 Mackay Sugar introduced changes to their cane payment formula that primarily used Near Infra Red (NIR) data as the basis for grower payments. The cane payment system was based on the principle of sharing risks and rewards, and removing obstacles to cooperation between industry sectors.

The confidence gained from Mackay Sugar's introduction of NIR technology and it's subsequent acceptance by industry stakeholders in the Mackay Sugar region was initially the basis on which CSR developed a project proposal that sought as one of it's objectives to further advance NIR technology in association with Global Positioning Systems (GPS) into precision agriculture (PA). Advancement in PA offered an opportunity to improve the productivity, profitability and environmental performance of the growing and harvesting sector through the use of NIR generated data. To gain the necessary benefits, further development of NIR calibrations, particularly in plant nutrients needed to be undertaken.

At the commencement of the project CSR had an undertaking to introduce NIR technologies into their factories starting with an installation at Invicta Mill. Unfortunately after a series of events that eventually lead to CSR abandoning the introduction of NIR technology, the project was redefined at the start of the 2008 season under the management of Mackay Sugar staff. The failure of CSR to provide data as detailed in the original project proposal did have an effect on some outcomes and is reported in the details of the final report.

Literature research at the commencement of the project indicated that there was enough research conducted by other NIR researchers to show NIR had the capabilities to measure nutrient levels in prepared cane.

In order to establish the NIR calibrations for nutrient components in prepared cane, samples of cane fibre were collected by Mackay Sugar mill laboratories and sent to BSES for analysis. The results of these analyses were then coupled with NIR spectra for the sampled cane to enhance calibrations for plant nutrients with particular emphasis on Nitrogen (N), Phosphorous (P), Potassium (K), Calcium (Ca) and Sulphur (S). Calibrations were also established for several of the plant trace nutrient components.

The advancement of PA technology using NIR data required the project to firstly establish field trials with the view of investigating responses in NIR nutrient data to differing in field management practices. The establishment of field trials were undertaken by participating growers under the supervision of Tony Crowley (Independent Agriculture Resources). The field trials covered two sites in the Burdekin region and two sites in the Mackay region. The sites were soil tested and then strips established with varying rates of nutrients applied in each strip. Following nutrient application a series of leaf tests were undertaken with results used in interpreting what if any relationship existed between in field management practices and the resultant NIR cane analysis after harvesting.

As part of the project an electronic consignment application was developed to ensure that NIR analysis results could be related back to the source of the cane supply. This required the use of GPS technology on harvesters and haul outs and a customised Geographic information System (GIS) application (CHOMP) to establish the link between analysis results and the cane source.

Unfortunately, the relationship between NIR data and in field management practices was not as clear cut as first thought. This was partly due to the smaller number of strip trials being harvested and analysed as a result of CSR's decision not to proceed with NIR technology and secondly the lack of detailed knowledge of past management practices for those strip trial locations. Whilst the small number of valid sample points failed to establish a definitive link between in field nutrient practices and NIR results, the analysis of a larger dataset from the Mackay region in 2009 and 2010 indicated that Phosphorous and Sulphur nutrient uptake may be reaching a plateau at maximum levels of yield but data at the high uptake values is scarce. It must be noted that this data compared NIR nutrient results to yield and not to in field management practices as there was very little spatial data available that detailed management practices being undertaken.

The lack of farm management practice data has been addressed with the further development of the Agdat application during this project period. The Agdat application is a PC and Web based customised GIS application that allows the user to record details regarding in field farming operations at a spatial level. The legacy of this project will be the ability to now analyse data at a more refined spatial level than previously possible. With this improved level of in field data recording now available, at least one new project has been established that will now analyse the relationship between NIR derived nutrient data and in field management practices with particular emphasis on mill mud application rates.

The establishment of improved milling operation and control has been further developed using NIR derived data. NIR fibre results is used to better control the rate of maceration along the milling trains at Marian mill resulting in more consistent juice flows and ESJ brix control. NIR phosphate results are used to control the rates of phosphoric acid to the juice stream to improve juice clarification performances. Further to this, NIR total ash results are used to improve the flocculent addition rates resulting in a more consistent clarifier performance. Other Mackay Sugar mills use NIR total ash trends which have been incorporated and displayed in the mill control systems as visual aids to the operators.

The communication feedback to growers in regard to the relationship between NIR derived plant nutrient data, crop response and in field management practices has not yet been fully established. While this relationship is important, findings from the SRDC project BPS001 indicate that crop response may be driven by a variety of factors with nutrient application practices being one of many. It is suggested that further investigations need to be undertaken before nutrient practice management and its relationships to cane nutrient uptake can be fully understood and communicated to relevant industry sectors.

Background:

In-mill NIR can provide real-time continuous data on prepared cane for a several constituents at once using a range of calibrations.

The Burdekin and Mackay regional plans outlined adoption of precision agriculture (PA) and integration of information across the value chain as strategies for ensuring sustainability. PA offers an opportunity to improve the productivity, profitability and environmental performance of sugarcane production. NIR can provide a range of information on the nutritional status of sugarcane that can be attributed to a geographic position and provide information to fine-tune nutrient management at the rake scale.

In addition, NIR calibrations to assess cane quality provide feedback to harvesters and millers to enable more efficient operation and production.

To ensure that NIR data is related back to each sector, integrated information systems are essential. The functional specifications of systems trialled during the Mackay Sugar co-operative systems project (MSA003) have been used to develop applications that will enable productivity and NIR data to be disseminated back to the grower and harvesting sectors.

Inaccuracies in the current manual consignment system account for 30-40% of cane being assigned to incorrect paddocks from where it had been harvested. This level of inaccuracy is unacceptable if there is to be true representation of NIR measured levels of N, P, K and S from within the cane supply back its source.

The development of electronic cane consignment will reduce inaccuracies in the manual system by associating the bin being filled to the position of the harvester at the time of filling.

The benefit of the electronic consignment will be the ability to provide in-field mapping of cane constituents at the cane bin level rather than the paddock level through interfacing to the NIR system, and accurate determination of harvest location of bins from the GPS monitoring system. There is the potential for this to feed back valuable information to growers on the actual yields from individual bins within a paddock, related to location within the paddock, to allow for improvement in on-farm practices to improve productivity such as variable rate application of chemicals and fertilisers.

Nutrient deficiencies in cane lead to yield suppression, which in turn can negatively affect the growers' economic return. The ultimate test of nutrient deficiency is final yield and if yields do not differ across different levels of nutrient supply it is unlikely that the yields were limited by supply of that nutrient. Traditional methods of predicting (before harvest) or diagnosing (after harvest) nutrient deficiencies in sugarcane are to use soil testing and/or leaf nutrient analysis. Both of these methods involve sampling from across a block of sugarcane, with the samples sent to a commercial laboratory for analysis. Identified nutrient deficiencies from the analysis can then be subsequently corrected.

The CAS in-mill NIR has the potential to identify nutrient deficient cane and so allow diagnosis of the cause of the deficiency. Current methods are potentially more expensive that using existing NIR's in mills. So if the NIR can provide a similar accuracy of detection it will have a superior benefit: cost ratio than existing methods. Hence, judging the efficacy of the in-mill NIR for detecting nutrient deficiency needs to be done in the context of the current methods of detecting these conditions.

Objectives:

The aim of this project is to improve the utilization of NIR technology and precision agriculture in the Burdekin and Mackay districts to deliver economic and environmental benefits across the growing, harvesting and milling sectors of the sugar industry value-chain.

In particular, this project seeks to

1. Develop new cane quality information using NIR;
2. Process/analyse new information to develop better ways to manage each sector in the regional value chain; and
3. Distribute that information across the value chain to influence payment systems, decision making and profitability.

Statement of attainment for the above objectives

- New cane quality information using NIR:
    - Nutrient equations developed but require further work;
    - Phosphate in juice and total ash equations previously developed and utilised; and
    - MSL display cane quality indicators for bin wt ratio, EM (calculated) and Dirt.
- Process/analyse new information:
    - Electronic consignment methods developed to link NIR and other productivity information to harvest location;
    - Methods to visually display the productivity and nutrient data spatially through AgDat;
    - Phosphate in juice and total ash predictions used in mill factory control systems;
    - New payment equation utilised by MSL and display of cane quality parameters on web site; and
    - Nutrient application crop response as measured by nutrients in prepared cane (NIR or lab results) not able to be quantified at this stage.
- Distribute that information across the value chain:
    - MSL cane payment formula.
    - MSL mill operation control usage of NIR ash and phosphate in juice measurements;
    - AgDat further developed to provide a spatial repository of farm management practices and productivity data as well as measured nutrient levels in cane by NIR; and
    - Nutrient management decision tools not achieved.

Methodology:

Project Plan

Initially the principal stages of the project were:

1. Formation of a steering committee of industry, R&D and other service providers to guide the direction of the project. A PA users group would also be formed.
2. NIR Calibration and integration with cane and harvesting payment schemes.
3. Validating NIR responses in the field.
4. Information systems.
5. Mill validation and systems integration.

During the project there had been concerns raised by many project participants that the scope of this project was too wide, and that there are too many disparate outcomes expected at the end of this project. In 2008 CSR elected to withdraw from the administration of the project and MSL took control of the project with modification of the project plan to reflect a change in project focus. The harvesting payment scheme was removed and a larger focus on providing systems that will be able to link harvested cane location with cane productivity and nutrient data. Until this linkage was developed to a high degree of confidence then validating crop response to changes would be very difficult to achieve. MSL also viewed that there should be provision of a data repository, based on GIS information of farm blocks and paddocks, to allow for historical trending of productivity, nutrient and farm management data. To this end the project build on the foundations of electronic consignment and farm management systems developed in MSA003.

Due to the change in project administration from CSR to MSL the steering committee was reduced to members from BSES, CSIRO, MSL and an agronomist. The working group for Harvest payment/Cane quality was disbanded and the remaining working groups were reduced to members from MSL, Tony Crowley (IAR), CSIRO and BSES.

NIR nutrient equation development

The steering committee guided the Calibration Development working group in identifying which NIR calibrations to develop, improve and validate. Initial nutrient calibrations were based on data from other mills and showed enough promise to continue with sampling and analyses of both juice and prepared cane for nutrients.

Validation of NIR response in the field

To attempt to validate the response of the cane to fertilizer application, as measured by NIR nutrients in prepared cane, the project had to design and implement strip trials where fertilizer application could be accurately controlled. Usually this meant that the better farm managers were selected in order to provide consistent farming practices and harvesting operations to minimize the variability of factors other than nutrient application.

Year 1:Sites selected for the validation of NIR calibrations and strip trials established in ratoons (2006) and plant cane (pre 2007 harvest season).

Year 2: Ratoon trial results assessed and recommendations will be made for next series of strip trials (ratoons 2007 and pre 2008 harvest season).

Year 3: Plant crop and ratoon trials will be assessed. Full analysis of all trials and development of nutrient management recommendations for widespread application in the 2009 season.

The year three plan was not implemented due in main to the fact that the relationship between NIR derived plant nutrient data, crop response and in field management practices has not yet been fully established.

Information Systems

1. Establishment of electronic consignment application:
    - consulted with harvesting group to design electronic consignment screen application;
    - Installed GPS on harvester and haulout vehicles; and
    - trial of application using three independent harvesting groups.
2. Linking of NIR data to cane source:
    - consulted with software developers on user requirements;
    - Changes to CHOMP harvest management system; and
    - Linking NIR data to harvest position location.
3. Record in field farm management application ata spatial level:
    - Consulted with grower group to establish needs for web based spatial data recording application;
    - Functional specs prepared; and
    - application developed and implemented.

Mill validation and systems integration

The project was to investigate how combining an improved soluble Ash measurement using NIR with farming information can identify factors contributing to high ash levels and look at ways farm management and/or harvesting may reduce ash.

During the project the focus shifted from soluble ash measurements in juice to phosphate in juice and total ash in prepared cane due to the increased difficulties of processing muddy cane.

Outputs:

NIR Literature Review

A literature review (Attachment 1) of the use of NIR in prediction of cane or juice nutrient levels by CSIRO was provided to the steering committee to help assess which equations may be of benefit to the industry. A summary of the review is provided here.

The main use of CAS NIR spectroscopy in Australian sugar mills is to determine cane payment but there is potential for wider use of the information and data gained and reporting this information through the sugarcane value chain (Figure 1). A clear potential use for this newly acquired data is to report to the grower a range of nutritional information to assist the grower in growing the next crop.

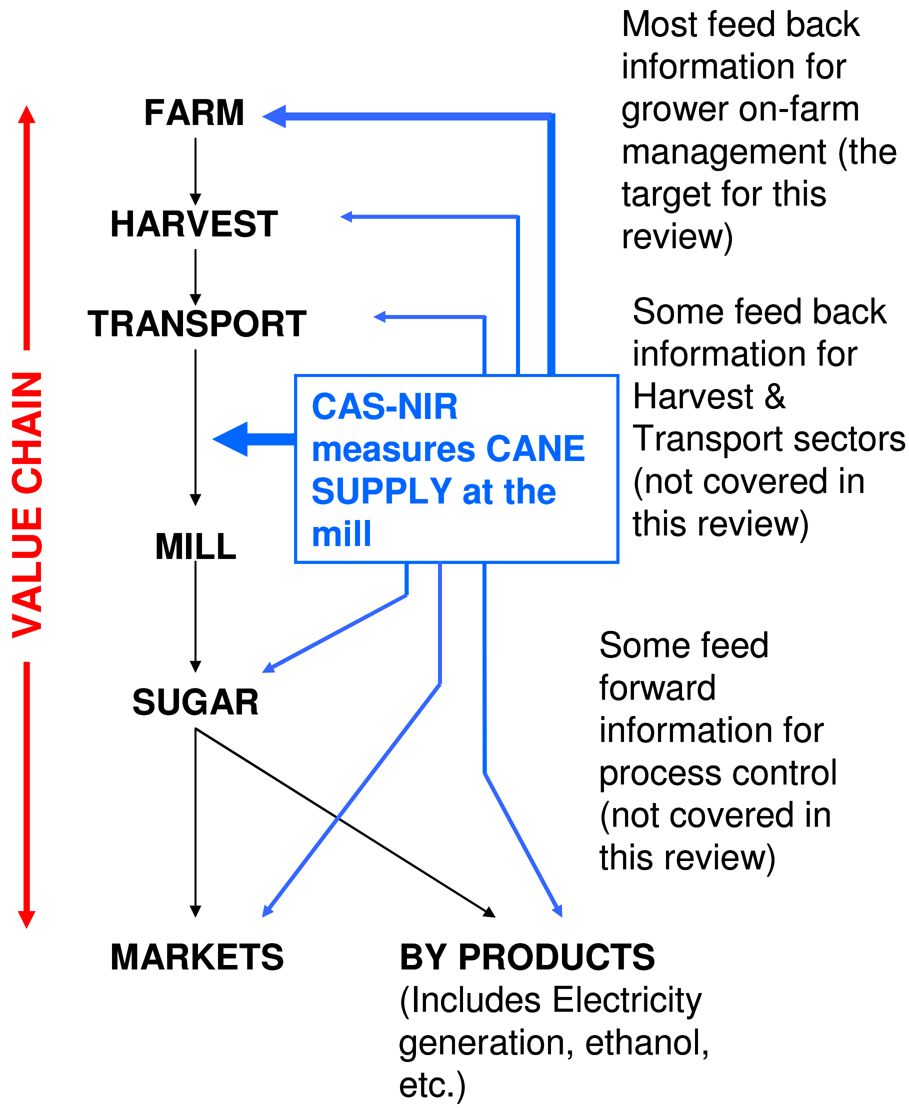

Figure 1 – Information flow through the value chain

The large number of calibrations already obtained for nutrient components of sugarcane stems indicates that CAS-NIR has potential in the measuring of these components in the cane supply. The sugarcane mill reporting systems are already in place to distribute this additional information to growers. However, there are issues with the interpretation of the results that need to be addressed.

What is unclear from literature is the influence of other factors on the measured component for the NIR spectra and subsequent calibration. If the element or component of interest is not directly measured by spectroscopy what potential is there for other factors to give rise to the determined correlation for this factor?

An example of an NIR measure of an organic component giving a measure of interest parameter is the South African stem borer. Here the measured organic compounds are thought to produce the stem resistance. Once this link is understood then interpretation of the data possible. This clearly illustrates the need to understand the link between the measured compound and the desired trait.

There is a need to set up trials that control for conditions that may mimic nutritional response and have parallel trials that induce the nutritional response while that nutrient is not in deficiency.

To have confidence in the NIR calibrations established for components measured with these distant relationships will require training sets that include some of the potential additional external factors. Such training sets can only be established if the response of sugarcane to nutrient of interest and other external factors is understood.

2006 field trial establishment

Strip trials established in Mackay and the Burdekin in 2006 were harvested in 2007, and the CAS-NIR's at Invicta and Racecourse mills were used to detect nutrient concentrations in the harvested cane. Where there was a nil fertiliser rate used in the trials (i.e. the Burdekin trail), the CAS-NIR detected lower N, P, K, and Mg concentrations in the cane.

Table 1 2006 Field trial fertiliser applications.

Description	**P (kg/ha)**	**K (kg/ha)**	**N (kg/ha)**	**S (kg/ha)**
Invicta				
Double Rate	56.0	221.6	441.1	44.0
High Rate	27.8	110.8	220.5	22.0
Low Rate	19.1	76.1	151.0	15.1
Nil Rate	0.0	0.0	0.0	0.0
Racecourse				
Product 1	18.1	114.8	206.4	17.2
Product 2	36.0	90.8	182.0	22.3
Product 3	36.0	91.8	193.6	17.2

Establishment of strip trials, 2007-2008

Based on the results from the 2006 strip trials, recommendations for the establishment, management, and sampling of the 2007-08 strip trials were be made with the nutrient application rates detailed in tables 2 and 3.

Pre-fertilisation soil tests and mid-season leaf sampling were performed to allow for standard crop nutritional indicators to be compared to the NIR data generated at the end of the season.

Table 2 Actual fertiliser trials for the 2007-2008 cane season.

Trial #	Treatment Details				
	Description	**P (kg/ha)**	**K (kg/ha)**	**S (kg/ha)**	**N (kg/ha**
Racecourse					
1	Nil P	0	95	20	156
1	Plus P	0	91	30	161
2	Nil K	18	0	18	164
2	Plus K	0	91	25	161
3	Nil S	14	91	0	151
3	Plus S	0	91	30	161
4	Very Low Fert	7	38	7	66
4	Low Fert	11	55	11	98
4	Standard Fert	19	100	20	180
4	High Fert	29	150	30	270

Table 3 Actual fertiliser trials for the 2007-2008 cane season.

Trial #	Treatment Details				
	Description	**P (kg/ha)**	**K (kg/ha)**	**S (kg/ha)**	**N (kg/ha**
Invicta					
5	Nil K	60	0	22	230
5	50 K	60	50	22	230
5	100 K	60	100	22	230
5	150 K	60	150	22	230
6	Nil Fert	0	0	0	0
6	Low Fert	19	76	15	151
6	High Fert	28	111	22	221

Unfortunately none of the Invicta trials provided any data and hence the following relates only to the strip trials undertaken in the Racecourse Mill harvesting area. The fertiliser rate applications for the two experiments are shown in Tables 4 and 5. The general site characteristics and description of activities are provided in Attachment 2.

Table 4: Fertiliser treatments for Experiment 1.

Trial #	Plot #	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)
Very Low Fert	1	66	7	38	7
Low Fert	2	98	11	55	11
Standard Fert	3	180	19	100	20
High Fert	4	270	29	150	30

Table 5: Fertiliser treatments for Experiment 2.

Trial #	Plot #	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)
Nil P	1	156	0	95	20
Plus S	2	161	0	91	30
Nil K	3	164	18	0	18
Plus P	4	161	0	91	30
Nil S	5	151	14	91	0
Plus K	6	161	0	91	30

As can be seen in Experiment 1, all of the major nutrients (N, P, K, S) increase together. In Experiment 2 the key treatments are Plot 3 (K limited), Plots 4 and 6 (P limited), and Plot 5 (S limited).

Soil Testing & Leaf Analysis

Soil tests from most of the experimental plots were taken at the initialisation of the experiment and the results detailed in Appendix A. Leaf analysis of all plots was taken during crop growth (Appendix B). Leaf analysis results are compared against critical values to estimate if the crop is deficient or sufficient for a particular nutrient (Table 6).

Table 6: Summary of expected nutrient deficiency from soil & leaf tests.

Experiment 1	Limiting Nutrient		Experiment 2	Limiting Nutrient	
	Soil	Leaf		Soil	Leaf
Plot 1	P, K	N	Plot 1		N
Plot 2	P, K	N	Plot 2		
Plot 3	K	N	Plot 3	K	N
Plot 4	No data	No data	Plot 4		
			Plot 5	S	
			Plot 6	P	

NIR nutrient equation development

An NIR (manufactured by FOSS International) was installed on the A train of Invicta mill in September 2006. The installation included the CAS (Cane Analysis System). Unfortunately the Invicta NIR had problems and the results did not align with the global calibrations developed by BSES Ltd to CSR's satisfaction. The Invicta NIR unit was not maintained during the trials and hence no data was recoverable from the unit. CSR has decided not to invest in NIR technology for cane payment.

Data was collected from Mackay Sugar's NIR at Pleystowe Mill. This data, and data from Maryborough and Mulgrave mills, was used to develop the initial calibrations for N and S. Samples from Mackay and Maryborough were analysed to determine calibrations for the other main nutrients. Data and samples from other mills during the 2006 season have been used to further developed several calibrations.

Unfortunately only juice samples were collected in 2007 from MSL but the project analysis technique had shifted to the use of prepared cane fibre samples as the preferred basis for the work. No individual fibre samples were analysed for comparison against the NIR calibrations in 2007 from Invicta due to concerns with the operation of the NIR unit. There were no direct comparisons with fibre lab sample results for 2007 season.

BSES have noted in their calibration work that there are basically 2 types of NIR instrument responses in the units installed in the Australian sugar industry. The difference occurs from changes in fibre optic response caused by using a different manufacturer for each type. The calibrations for nutrients have needed to be redone for each type in order to minimise the prediction errors. The Invicta unit is a type 1 whereas the Racecourse unit is a type 2. The type 1 calibration set covers the instruments supplied after 2003 whereas the type 2 calibration set covers the instruments prior to 2003.

BSES in their presentation to the project review meeting with SRDC representatives in April 2008 stated that the calibrations looked promising but required more data for both type 1 and type 2 instruments. They acknowledged that having two different calibrations significantly increases the sampling and analyses loads required to maintain the different calibrations but the calibration performance has improved.

The commitment to sampling was given by both MSL and CSR at the project review meeting with SRDC representatives in April 2008. The plan to address the issue was for MSL and CSR to provide approximately 150 fibre samples each from the 2008 season. Unfortunately CSR did not supply the samples due to the NIR unit not being maintained sufficiently to provide scanning data from it.

BSES updated the calibrations for nutrients including micro-nutrients in 2009, using the 2008 season sample results, and completed discrimination of the data based on NIR instrument type (ie. Type 1 & Type2).

There have been no further updates of the nutrient calibrations since 16/11/09 as no new laboratory data has been generated since that time. Additional data for the Nitrogen and Carbon calibrations became available on the 02/02/2010 from Racecourse 2009 samples and other samples sourced from outside this project and these calibrations where updated at that time. The separation of calibration data into the two known NIR instrument response types improved calibration statistics for all constituents, as shown in Appendix C.

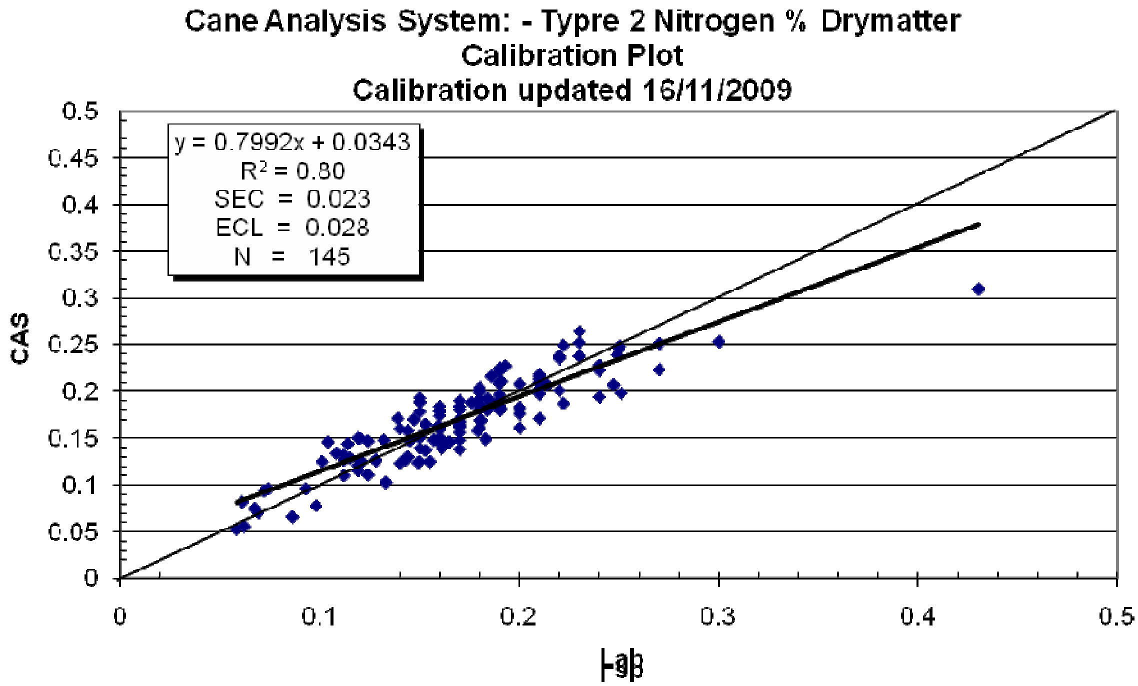

Figure 2 – Nitrogen NIR Calibration Plot

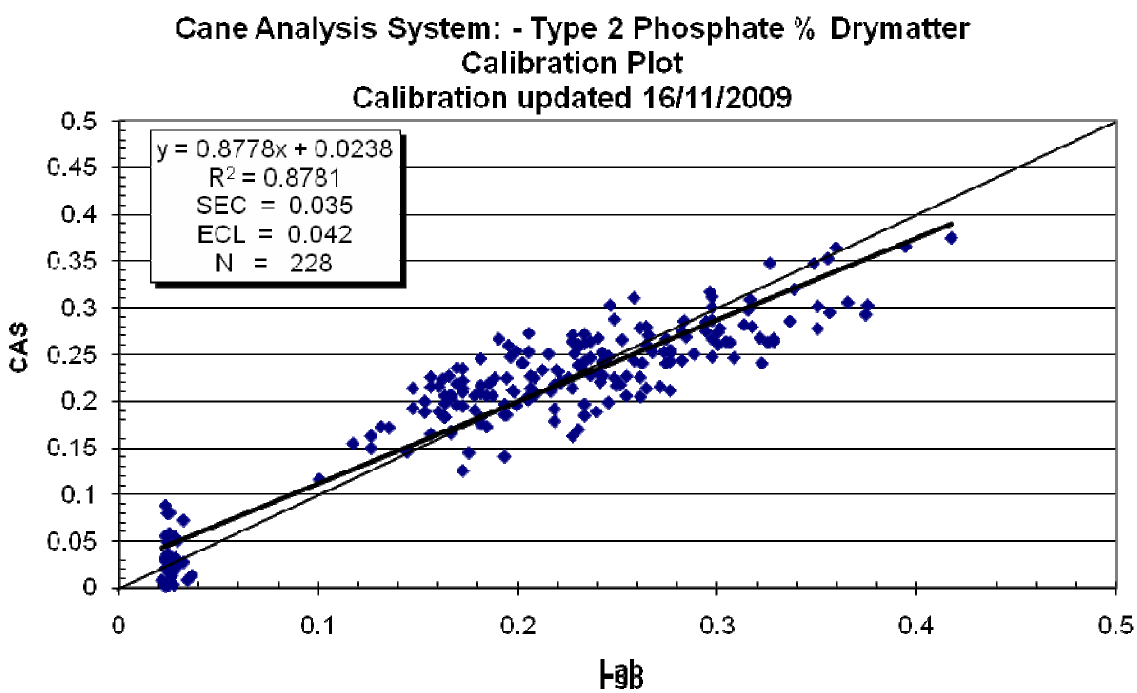

Figure 3 – Phosphate NIR Calibration Plot

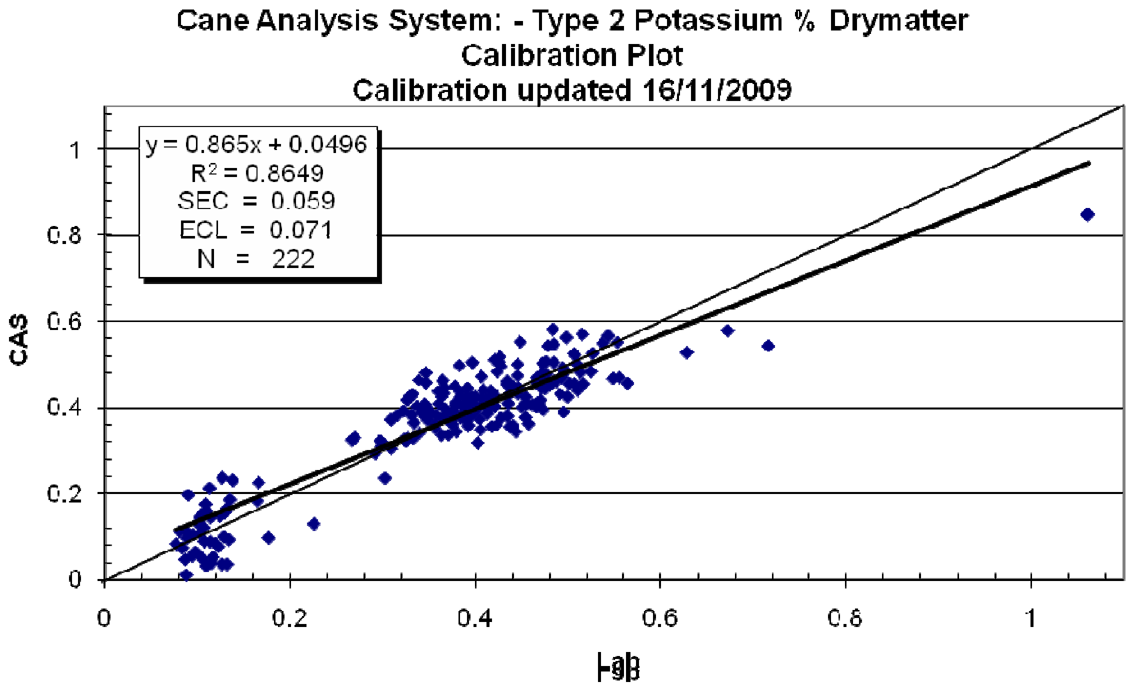

Figure 4 – Potassium NIR Calibration Plot

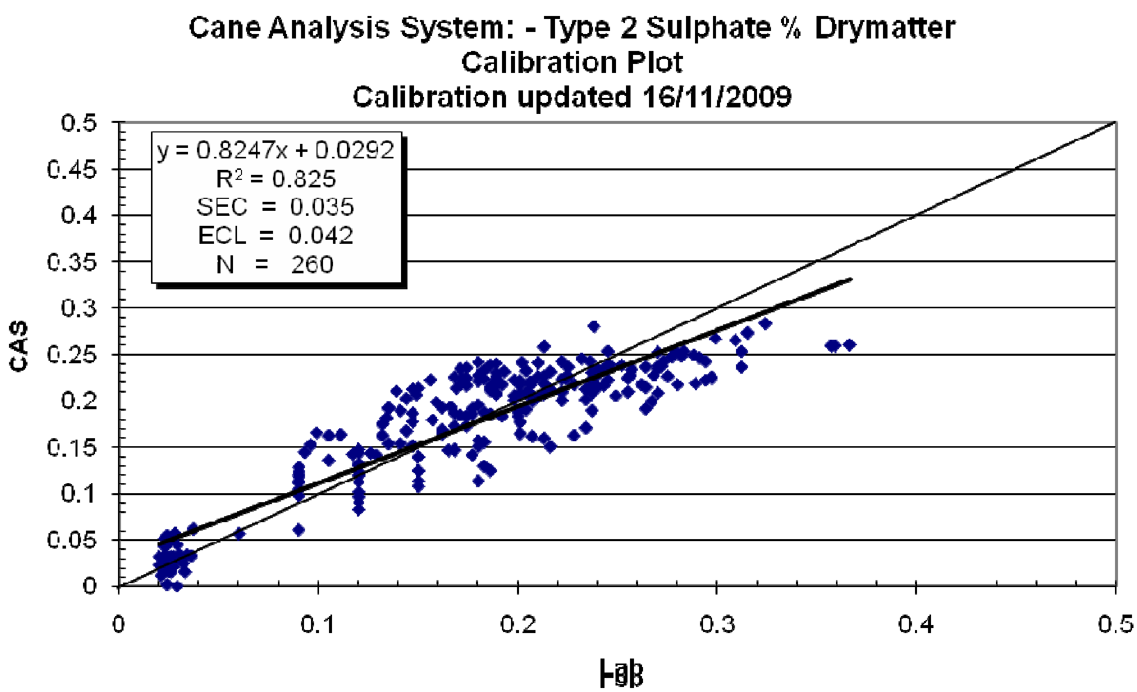

Figure 5 – Sulphate NIR Calibration Plot

Prediction results using these calibrations should not be used on other instruments and within other seasons unless validation data (a minimum of 30 checks) is collected to allow for the calculation of system bias for each constituent. The system bias changes from instrument to instrument and from season to season due to changes in instrument responses resulting from servicing events and component failures.

These changes make direct comparison of predicted results impossible without adjustment based on laboratory check analyses (Primary method) and as such unadjusted results can only be used to determine a samples relative result compared to the population within that instrument and seasonal data set.

Current calibrations will benefit from soon to be implemented NIR standardization techniques for CAS systems. These techniques will effectively remove the differences between instrument and allow the two calibration types to be combined without loss of analytical precision. These standardized nutrient calibrations could then be applied to any standardized instrument (existing or new) without the need for bias adjustments allowing results from different sites and seasons to be directly compared.

Field trial analysis and results

Results strip trials, 2006-2007

Two trials were established in the Racecourse mill region (Mackay) and the Invicta mill region (Burdekin) for the 2006-07 sugarcane growing season. Both trials used a NPKS fertiliser mix and varied the overall application of all nutrients together (Table 1). At the Invicta site this variation included 'Nil Rate'.

Table 7 2006 Fertiliser application trials results.

Description	P Rate (kg/ha)	K Rate (kg/ha)	N Rate (kg/ha)	S Rate (kg/ha)	CCS	Cane Yield (t/ha)	Sugar Yield (tS/ha)
Invicta							
Double Rate	56.0	221.6	441.1	44.0	14.50	112.24	16.27
High Rate	27.8	110.8	220.5	22.0	14.59	135.72	19.78
Low Rate	19.1	76.1	151.0	15.1	15.01	133.96	20.27
Nil Rate	0.0	0.0	0.0	0.0	16.30	72.69	10.97
Racecourse							
Product 1	18.1	114.4	206.4	17.2	15.81	106.79	16.97
Product 2	36.0	90.8	182.0	22.3	15.90	115.33	18.34
Product 3	36.0	91.8	193.6	17.2	15.87	116.26	18.45

Table 7 shows the cane and sugar yields from the two trials. At the Invicta site the yield for the 'Nil Rate' is 50% that of the maximum yield and at both sites there was a reduced yield with the highest fertiliser rate. The CCS results showed little difference when fertiliser was applied but the highest CCS was achieved in the 'Nil Rate' treatment at Invicta.

For the 'Nil Rate' the higher CCS did not offset the lower yield and hence the tonnes of sugar per hectare was the lowest in the group. The highest sugar yields occurred at the low and high application rates and reduced significantly at the double rate.

The Racecourse data was more difficult to interpret but may indicate a response in cane yield from increased N and K addition.

The concentration of seven nutrients in the harvested was estimated with the CAS-NIR at the two mills (Table 8). Where fertiliser was applied there was no significant change in the nutrient concentrations in the prepared cane. However, at the Invicta site the CAS-NIR detected a 5-fold increase in K and a 10-fold increase in Mg concentrations between the 'Nil Rate' and the fertilised treatments.

There was an approximately 50% increase in N and P concentrations when fertiliser was applied compared to the 'Nil Rate' treatment. There was no change in Na and S concentrations, while the Ca concentration was slightly higher in the 'Nil Rate' treatment.

Table 8 2006 Strip trials CAS-NIR results.

Description	Fibre K	Fibre Ca	Fibre Mg	Fibre Na	Fibre P	Fibre S	Total N
Invicta							
Double Rate	0.57	0.10	0.10	0.02	0.10	0.10	0.25
High Rate	0.59	0.10	0.11	0.02	0.09	0.10	0.27
Low Rate	0.55	0.09	0.09	0.02	0.08	0.08	0.25
Nil Rate	0.11	0.14	0.01	0.02	0.05	0.10	0.16
Racecourse							
Product 1	0.48	0.14	0.14	0.04	0.07	0.10	0.20
Product 2	0.48	0.15	0.15	0.03	0.08	0.11	0.22
Product 3	0.43	0.16	0.13	0.03	0.07	0.09	0.19

The lack of variation between CAS-NIR determined nutrient concentrations in plots where fertiliser was applied corresponds with the general lack of variation in the cane and sugar yield results. The small decrease in cane yield with the highest fertiliser rate in both trials appears to be due to a non-nutritional factor such as lodging.

The large decrease in cane yield when no fertiliser was applied is associated with lower concentrations of N, P, K, or Mg in the cane supplied to the mill. Surveys of the N concentration in cane supplied to mills from SRDC project CSE011 have shown that a concentration of 0.16% indicates a small likelihood of N deficiency in the crop. Similar data are not available for millable cane concentrations of the other nutrients and effects on cane growth and yield. However, comparing the nutrient concentrations in the "Nil rate" treatment from the Invicta trial with concentrations in all other treatments concentrations in fibre of K and P suggests that a concentration of 0.11 and 0.05 %, respectively, may indicate deficiency. Obviously a single observation as obtained from this experiment is not adequate for the basis of guidelines.

Where fertiliser was applied there was no change in nutrient concentrations determined by NIR. However, NIR did detect reduced nutrient concentrations where there was no fertiliser applied. This highlights the potential for NIR to detect nutrient management information from the millable cane supplied to the mill.

The results from the 2006/07 field strip trials were challenged, with questions raised as to why no change in nutrient concentrations was determined by NIR with a response from Dr Peter Stone, CSIRO Sustainable Ecosystems (Attachment 3).

Results strip trials, 2007-2008

It must be noted that only farms from Mackay district were sampled from the established strip trials during the 2008 season. No results were obtained from strip trails established in the Burdekin region due to reluctance by CSR to continue with NIR technology.

Further to this, no sampling from cane milled in the Burdekin was undertaken. It is noted that one farm that was set up for experimental sampling in the Burdekin was sold and subsequently no cane was harvested during the 2008 season.

The following discussion refers to the Mackay region strip trials only and is detailed in a report by CSIRO (Attachment 4).

Tables 9 and 10 below indicate which nutrient levels in the soils may limit cane growth. In Experiment 1 test results (Table 9) suggested that P and K were limiting in plots 1 and 2, and K was limiting in plot 3 (No soil test was done for plot 4). In Experiment 2 the soil test results (Table 10) suggested K was limited in plot 3, S was limiting in plot 5 and P was limiting in plot 6. These soil tests suggest that it is only these plots where a yield response will be seen due to varying nutrient supply. Also, only in these plots should there be deficient nutrient levels that could be detected by NIR.

The leaf analysis showed that in Experiment 1 (Table 9) N was slightly limiting in plots 1, 2 and 3. In Experiment 2 (Table 10) the leaf analysis showed N to be slightly limiting in plots 1 and 3. In none of the leaf analysis results are there any indications that P, K or S is limiting sugarcane growth. It is immediately apparent that the soil testing and leaf analysis results do not agree.

Crops in the different plots in the two experiments had the potential to display nutrient deficiency based on the results of soil and leaf tests. However, there was no correspondence in the potential limitations identified by these two established methods for predicting/diagnosing nutrient deficiencies. The agreement between yield response, the ultimate test of nutrient deficiency, nutrient application and the soil or leaf test results was inconsistent. This result was due in part to the experimental design, but also suggests the current standard tests for nutrient deficiencies are inexact.

Table 9: Expected nutrient limitations and yield from Experiment 1.

	Expected limitations		**Yield (t/ha)**	**NIR Measurements (mg/kg DM)**			
	Soil Analysis	Leaf Analysis		**N**	**PO_4**	**K**	**SO_4**
Plot 1	P, K	N	48				
Plot 2	P, K	N	59	255	3640	4430	2700
Plot 3	K	N	71	205	3060	4460	2680
Plot 4	No data		55	277	3490	4380	2460

Table 10: Expected nutrient limitations and yield from Experiment 2.

	Expected limitations		Yield (t/ha)	NIR Measurements (mg/kg DM)			
	Soil Analysis	Leaf Analysis		**N**	**PO_4**	**K**	**SO_4**
Plot 1		N	84	241	1750	4710	2120
Plot 2			90	276	1850	4880	2200
Plot 3	K	N	77	248	2110	4310	1890
Plot 4							
Plot 5	S		86	256	1710	4820	2170
Plot 6	P		74	226	2020	4290	2130

Another confounding factor in interpretation of this experimental program is that nutrients are not the only factors that can limit yield. Issues such as drainage, soil type, weed and pest pressure can vary over small distances and can have an impact on yield. This type of limitation is best resolved through replication of treatments and sites, to average out the limitations that may occur.

As a consequence of these results, the experiments were not the basis for a robust evaluation of the accuracy of the in-mill NIR for detecting nutrient limitations. Results from the NIR were no worse in predicting yield responses than the two standard methods. Experiments with a more controlled design are needed to better evaluate the in-mill NIR (and current methods) for detecting sugarcane nutrient deficiencies.

Evaluation of MSL 2009 data

During the 2009 season, MSL provided datasets, of yield and NIR nutrient information, with more accurate yield information as a result of GPS installed on some harvesters. Initially 287 block/paddocks were identified as supplying Racecourse with high quality yield data. Rakes were removed where they had no NIR data or were built with other rakes. In all a total of over 550 rakes were identified as having good yield and NIR data and these were averaged based on the block/paddock for each farm to provide an extra 220 data points for addition to the nutrient strip trial data from 2008.

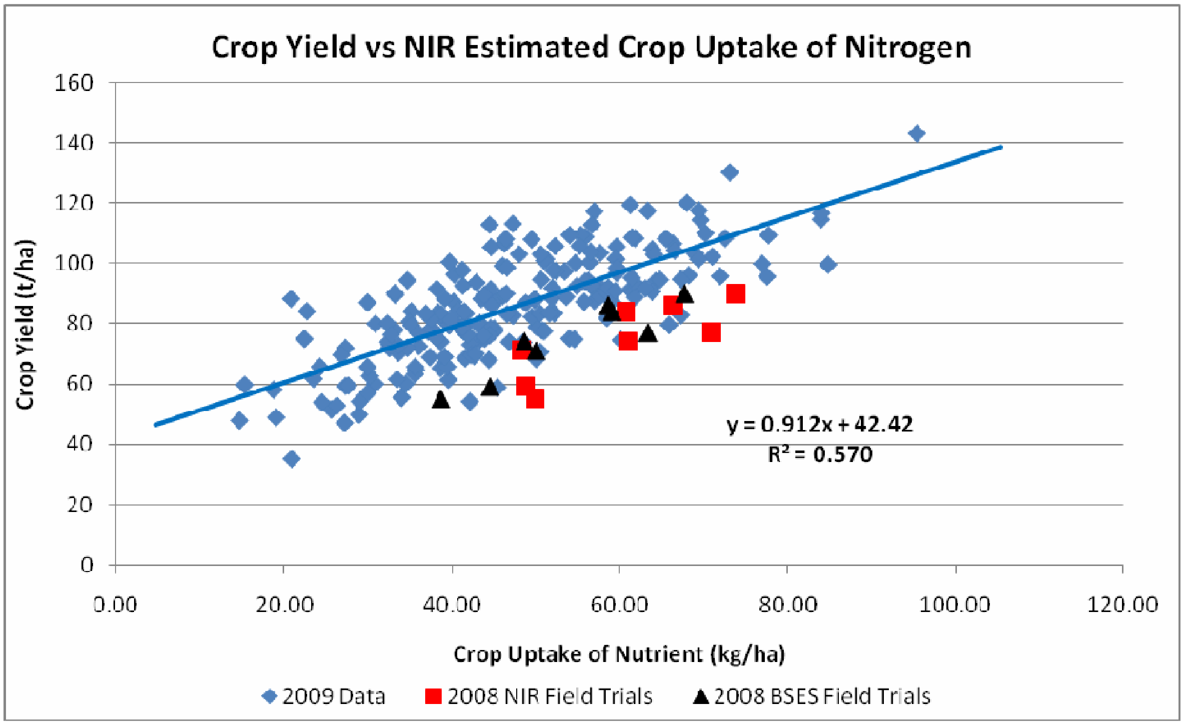

Figure 6 – Nitrogen Nutrient Uptake Plot 2009 Data

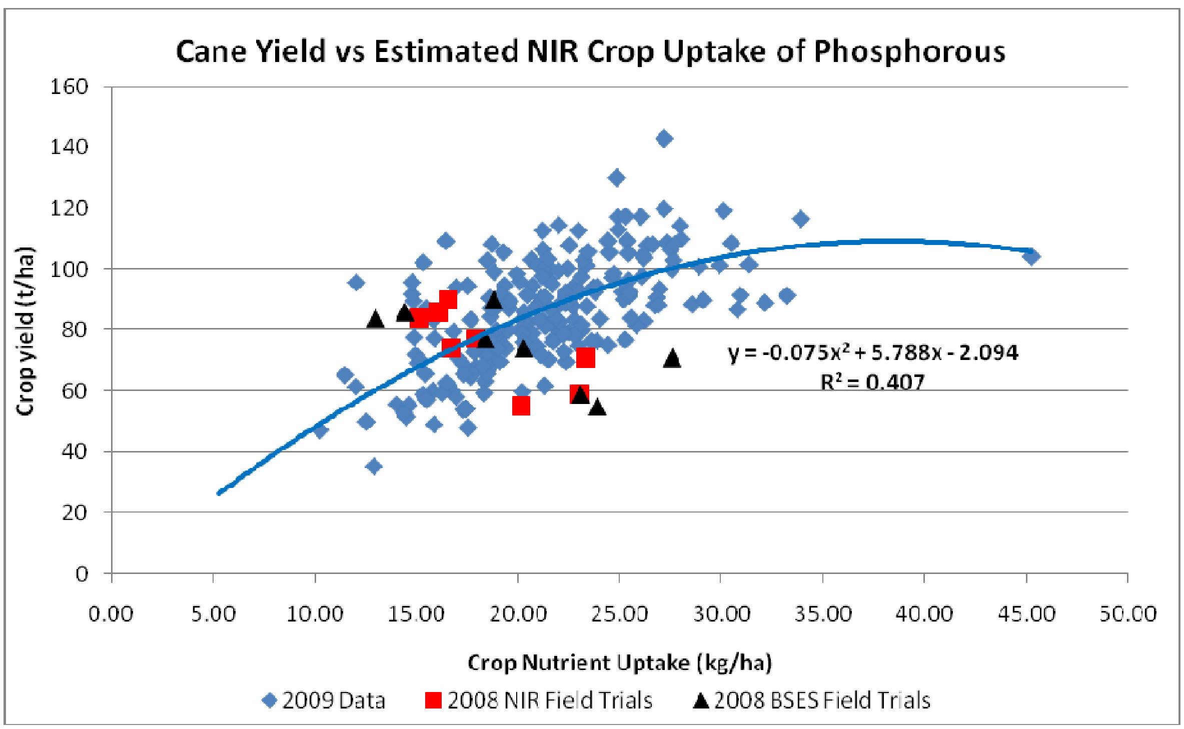

Figure 7 – Phosphorous Nutrient Uptake Plot 2009 Data

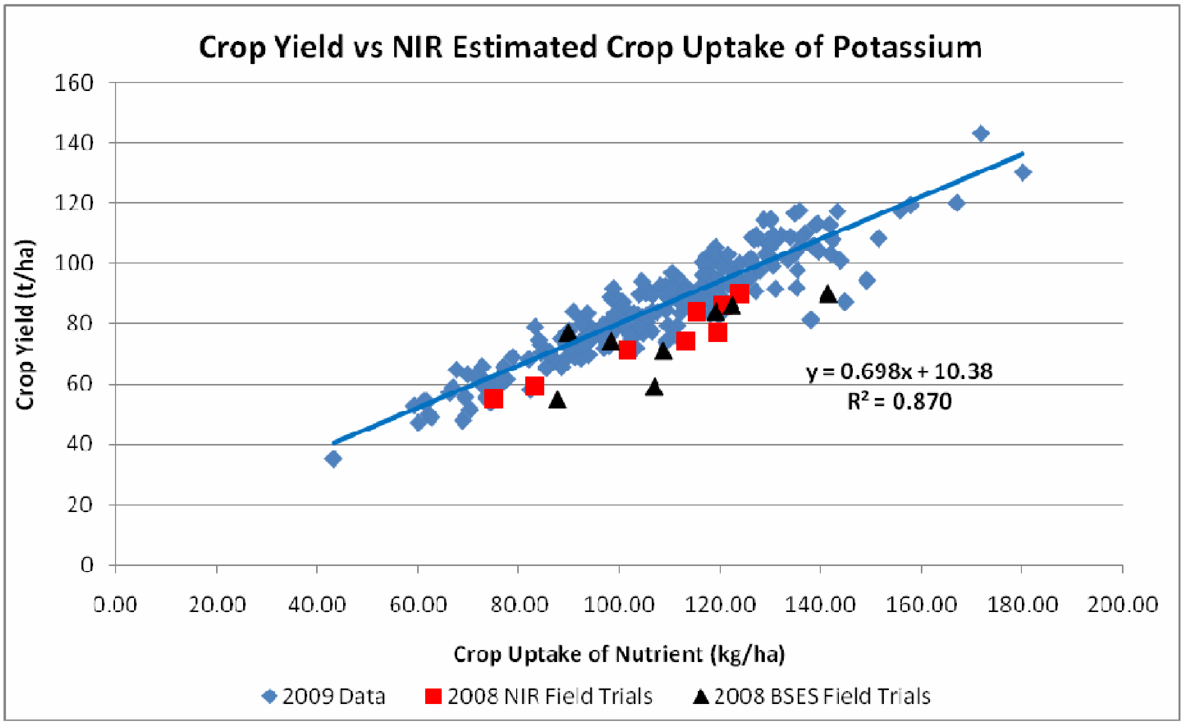

Figure 8 – Potassium Nutrient Uptake Plot 2009 Data

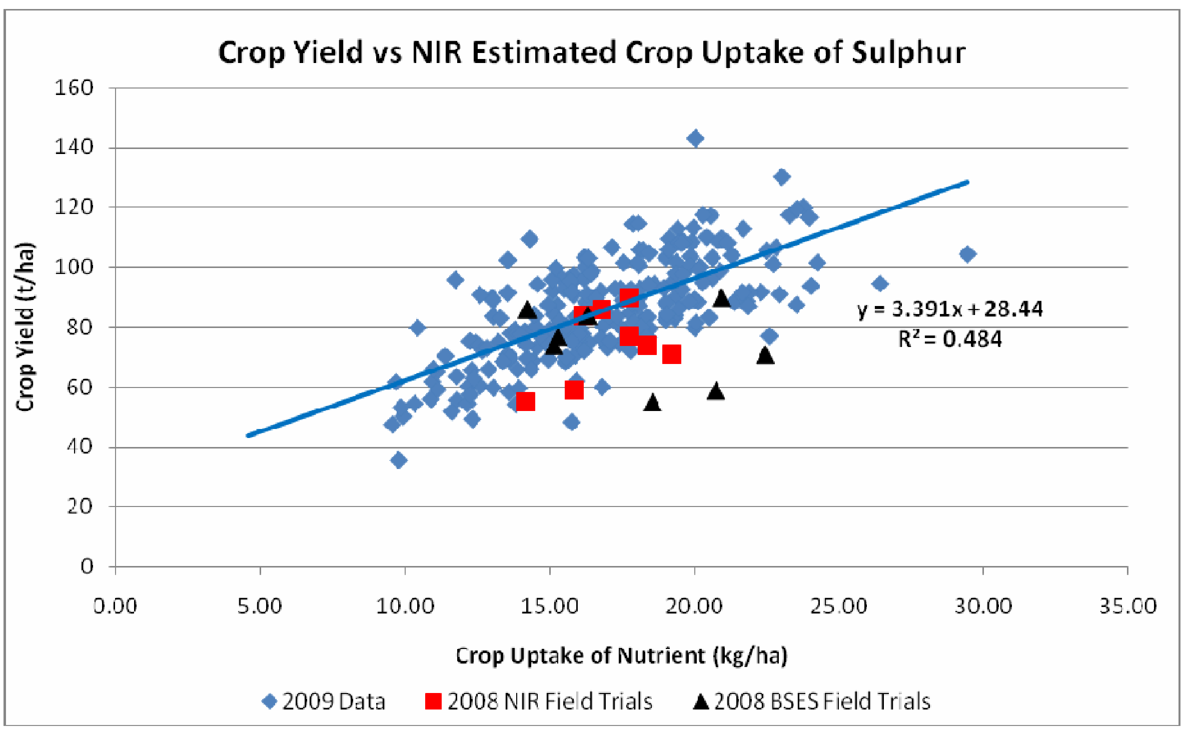

Figure 9 – Sulphur Nutrient Uptake Plot 2009 Data

When plotting yield versus nutrient uptake, results hint that for Phosphorous and Sulphur increasing nutrient uptake may be reaching a maximum level of yield but data at the high uptake values is scarce. On the other hand uptake levels of Nitrogen and Potassium continue to increase with yield which exhibits the characteristics of luxury feeding.

Again there is very little data available at the higher crop uptake rates making it difficult to determine if the yield response continues or not.

CSIRO applied innovative 'data mining' statistical techniques (regression tree analysis) to data from MSL during the 2009 season (Attachment 5). Regression tree analysis has a number of advantages over classical techniques, such as linear or additive models and was useful due to the diverse nature of the dataset. The dataset included categorical type variables (variety, class, location, etc.) and numerical type variables (nutrient concentration, month of harvest, etc.). All data recorded on each rake were included in the analysis to determine the factors most strongly associated with cane yield. Of all the predictors, phosphorous concentration proved the most important followed by sugar cane variety, although neither of these was found to be statistically significant.

The results of CAS-NIR data combined with a regression tree analysis shows promise as a way of determining yield-limiting nutrients in an intuitive decision tree format. Given that the 2009 dataset has not produced any statistically significant results, if the pattern is reproduced during the 2010 then this would boost the confidence of the analysis, potentially to cause-and-effect relationships. The addition of another season of data (i.e. 2010), together with more predictors such as nutrient ratios (i.e. following the 'DRIS' system), are all worth considering in the future.

Evaluation of 2010 data

The same decision methodology used in providing the extra data from the 2009 season was applied to the 2010 season data. In all a total of 14,725 rakes were identified as having good yield and NIR data and these were averaged based on the block/paddock for each farm to provide an extra 890 data points.

The performance of the calibrations during the 2010 season was difficult to quantify without the aid of laboratory validation data as is the normal practice. The 2009 data set was validated with laboratory data and comparison of the 2010 results with these data provided a means of gauging the prediction performance of the calibrations during the 2010 crushing season.

The first step in this process was to quantify the prediction bias for each constituent calibration. An estimate of these values was obtained by comparing the NIR constituent predictions for 2009 and 2010 that satisfied the following criteria:

- Same farm, block, sub-block
- Same variety and not plant cane in 2010
- Similar cane yields.

The screening of 2009 and 2010 nutrient prediction data for blocks that met these criteria resulted in 25 matches, 2010 nutrient calibration bias was calculated as the average difference between 2009 and 2010 predictions for each constituent and are shown in Table 11.

Table 11 NIR 2010 Bias estimates

Calibration	2010 bias adjustment
Cane Sulphate (SO4 % DryMatter)	0.000
Cane Phosphate (PO4 % DryMatter)	0.006
Cane Calcium (% DryMatter)	-0.003
Cane Potassium (% DryMatter)	-0.071
Cane Magnesium (% DryMatter)	-0.005
Cane Sodium (% DryMatter)	0.007
Cane Iron (% DryMatter)	0.008
Cane Aluminium (% DryMatter)	-0.047
Cane Manganese (% DryMatter)	-0.006
Cane Nitrogen (N % Dry Matter)	-0.077
Cane Carbon (C % Dry Matter)	-2.790

These adjustments where applied to the raw prediction data produced during the 2010 crushing season for all constituents. The adjusted results where then used to calculate cane nutrient uptake rates (kg/ha) for comparison with the 2009 calculated uptake rates and a reasonable match between data sets would indicate similar predictive performance from the calibrations for the 2009 and 2010 crushing seasons.

Comparison plots of the 2009 and 2010 data sets for Cane Nitrogen, Phosphorus, Potassium and Sulphur uptakes (kg/ha) are shown below.

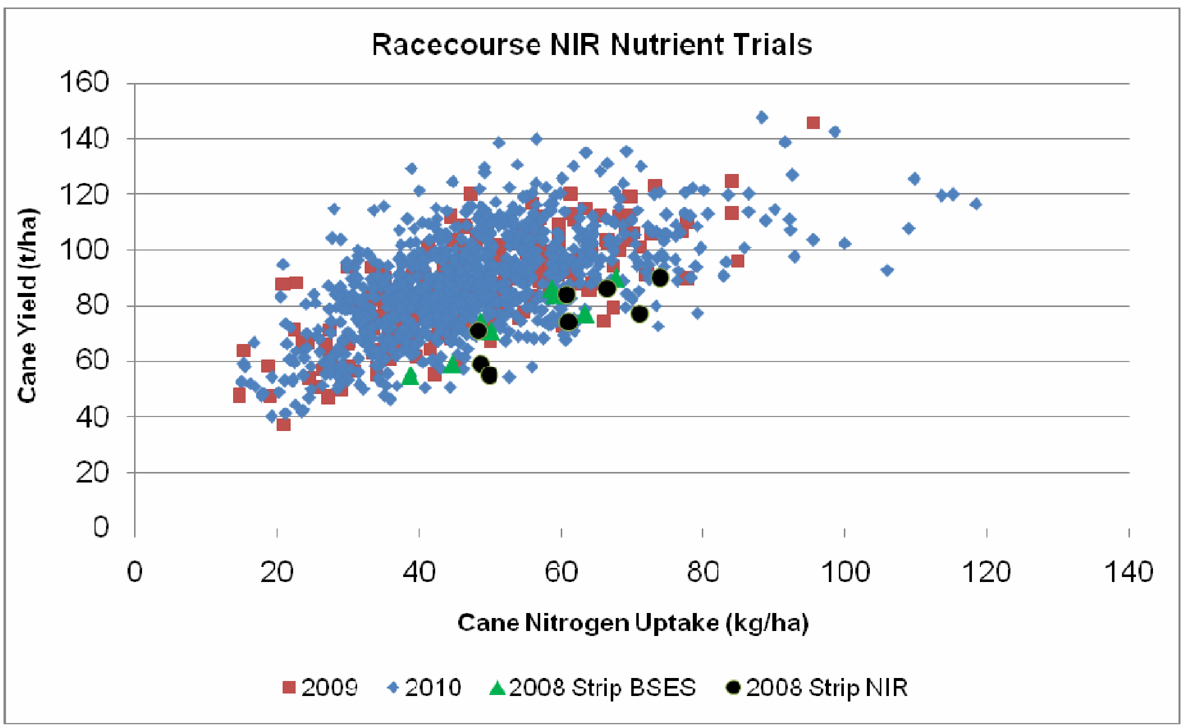

Figure 10 – Nitrogen Nutrient Uptake Plot 2010 Data

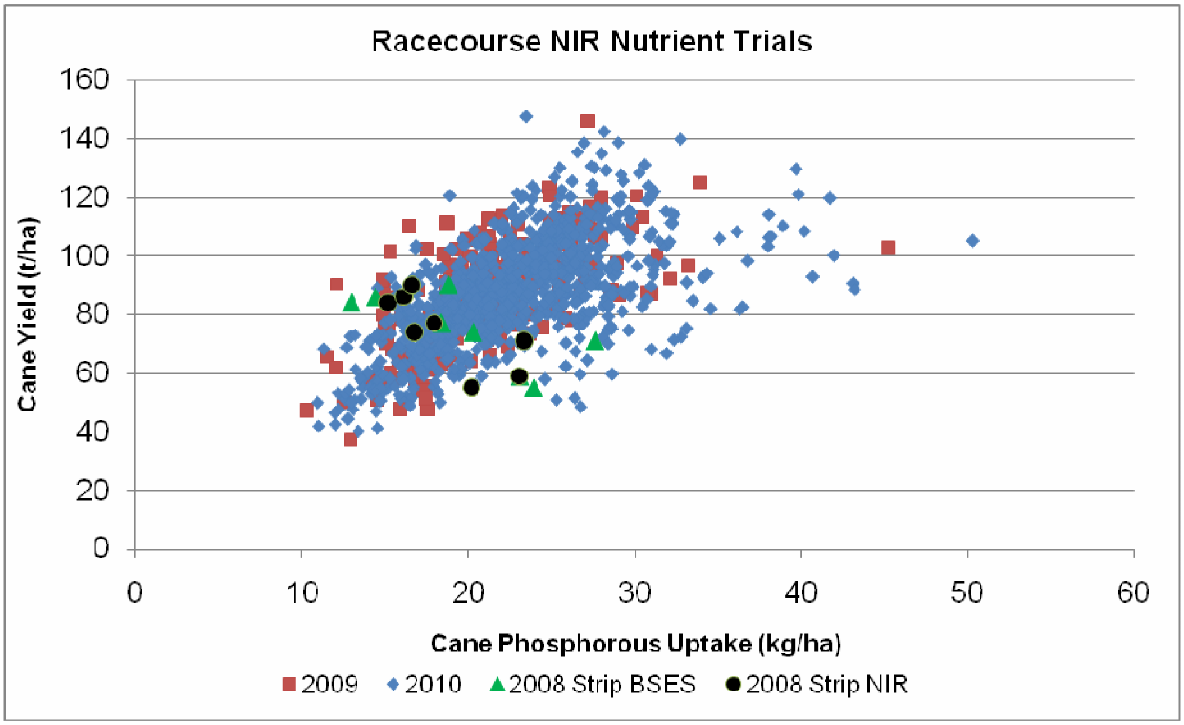

Figure 11 – Phosphorous Nutrient Uptake Plot 2010 Data

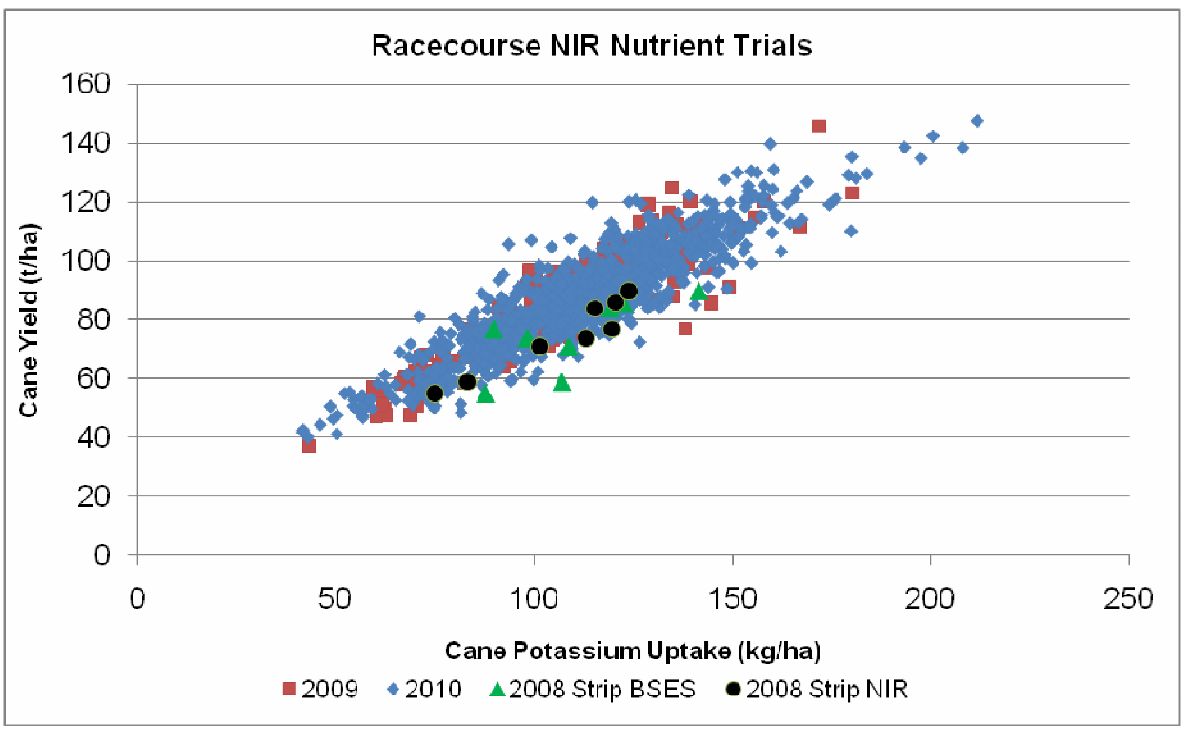

Figure 12 – Potassium Nutrient Uptake Plot 2010 Data

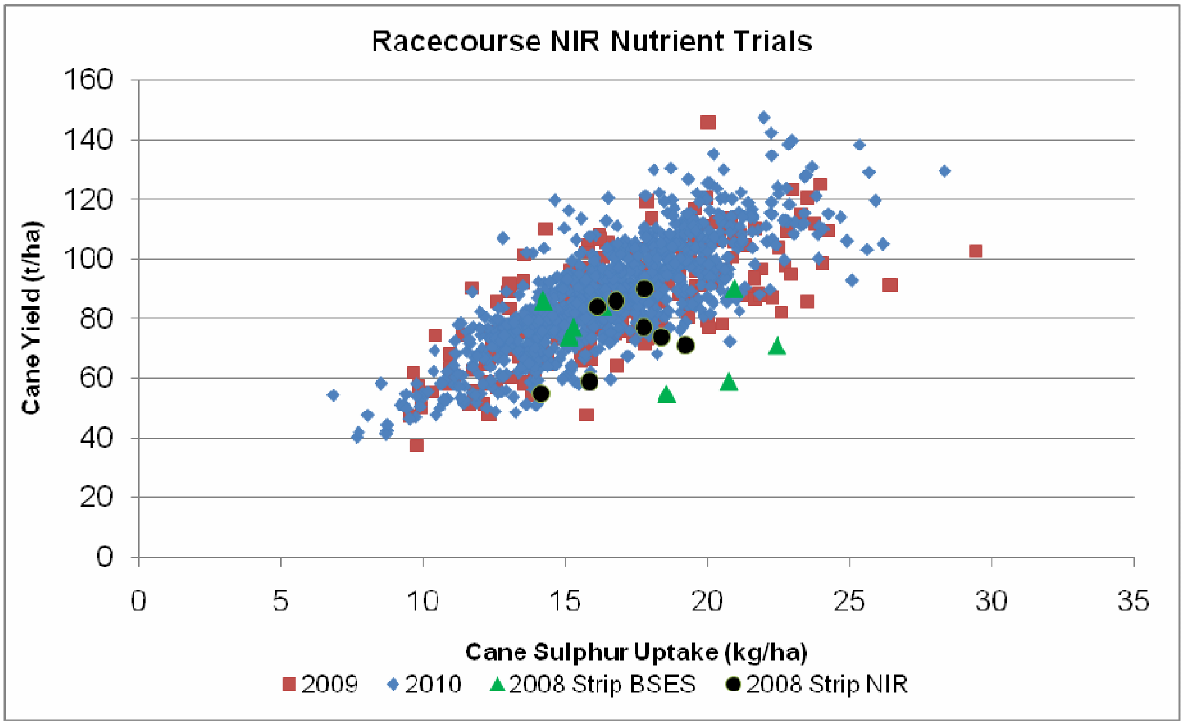

Figure 13 – Sulphur Nutrient Uptake Plot 2010 Data

The very good agreement between the 2009 and 2010 data sets for cane uptake of all nutrients suggests that the predictive performance of the calibrations during the 2010 season was similar to that obtained in 2009. The nitrogen and phosphorous uptake plots indicate a flattening out of cane yield as cane uptake increases past a certain point.

CSIRO applied another regression tree analysis to data from MSL for the combination of the 2009 and 2010 seasons (Attachment 6). Although not as strong an indicator as predicted for the 2009 data, Phosphorous was ranked as second behind Magnesium as a predictor for yield.

Farm Management Tools

Linking data to a patch of dirt (Electronic Consignment)

The traditional method of consignment consists of harvesting personal manually filling out paper based tickets with relevant data. Whilst this consignment system provides sufficient information for cane payment purposes, knowledge of the location of the harvester when each bin is filled can not be established using this system. To gain the full benefit of NIR information an alternative consignment system was developed.

Electronic cane consignment associates bins being filled with the position of the harvester at the time of filling via the use of GPS technology. One of the main benefits of electronic consignment is in-field mapping of cane constituents is at a finer resolution than can be achieved via traditional cane consignment methods. This can allow the data to be spatially represented thus providing valuable feed back to growers on the actual yields from where individual bins were harvested, along with the related cane constituents from that harvest location. An ASSCT paper has been presented on electronic consignment (Attachment 7).

The data for analysis within the electronic consignment project can be broken into two main groups. These are the data collected through the in-field device (haul-out GPS location and consigned bins) and the NIR analysis and weighbridge information.

Figure 14 is a diagram highlighting the linkages between the different datasets to determine the location of the harvester, the bin being filled and the resultant NIR data for that bin.

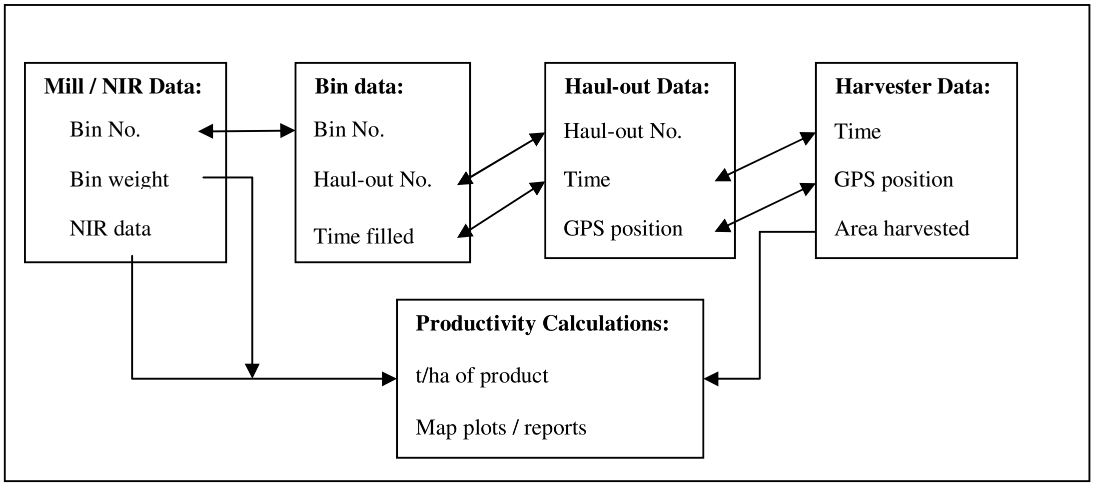

Figure 14 - Linkages between NIR, bin data and harvester location

The calculation of area harvested is based on the methodology used by the AgDat Harvest Management module. The Harvest Management module allows users to track the progress of the harvest and to associate attributes of the delivered cane with the area of land from which it was harvested. This then allows for laboratory data such as PRS, Fibre and NIR nutrient information to be mapped to the location from which the cane was harvested through an easy to view map interface. This process is greatly streamlined by using vehicle tracking on the harvesters to interpret the areas cut each day (AgDat Interpolator).

AgDat

The analysis of spatially derived data is a primary function of Geographic Information Systems (GIS). GIS applications without front-end customization often require specialized operators to manage and interpret the various spatial datasets which would severely limit the exposure of the data to a wider industry audience. AgDat was identified by the project investigators as a suitable tool to be used to disseminate the relevant NIR and associated spatial data to the wider grower, harvesting and productivity advisor sectors of the industry.

AgDat is a customized GIS application that was developed by Agtrix Pty. Ltd. They have developed the product in C#.NET using Framework 3.5 with the data stored in an SQL Server 2008 database.

The use of an industry standard database to store all spatial data allows integration with various GIS platforms that may be used in the industry (MapInfo, ArcInfo, Manifold).

The application will run on all modern Windows operating systems that support .NET framework.

AgDat has been developed as three main modules: the Base Mapping module, the Harvest Management module, and the Data Recording module.

The Base Mapping module is an application that allows users to record information about large numbers of farms, paddocks and crops through a map interface.

This module provides managed data editing (including data integrity checking), cartographic labelling and batch printing of farm maps. The data that is generated forms the basis for most other functionality.

The AgDat Data Recording module has 3 different interfaces, all of which are simply ways of entering the same data as they are driven by the common configuration of the data contexts. The interfaces are:

- ***AgDat Desktop*** – a fully functional .NET run on a laptop or tablet PC. This application is designed for the high performance end-user such as Productivity staff and advisors.
- ***AgDat Web*** – a web mapping interface primarily designed to be used by growers that allows the user to view and edit data that has been recorded previously, as well as record new data. This interface and functionality of the web application is similar to the Desktop version but is considered simpler to use and only requires minimal specialized software to be loaded onto the end-users computer.
- ***AgDat Remote*** – a very simple interface that allows operators to record activities whilst they are in the paddock performing the activity in question. Data recorded by the operator on what is being done, the GPS location of the vehicle as well as sensor data used to indicate the status of the vehicle are collected automatically and sent to the AgDat Interpolator. The Interpolator then calculates the area that the activity covered in a similar fashion to the harvest module. Once the area has been calculated, both the contextual and spatial data is sent to the AgDat data recording modules where users can view, edit the information or analyse the data against other relevant datasets.

The Data Recording modules allows organisations to configure data "contexts", which can then be used to provide a data entry form for users. These contexts configured include:

1. Farm nutrient inputs;
2. Farm chemical applications;
3. Surveys such as disease or pest survey;
4. Tests such as soil, leaf or water analyses; and
5. Productivity data.

All of the data is recorded spatially (against the land that it refers to) so that it can be accessed through time regardless of what the paddock layout or name is in the future. Further, all data can be retrieved for any area through spatial queries using the spatial representation of the land of interest.

Figure 15 is a snapshot of the nutrient application recording screen as developed for the grower web application.

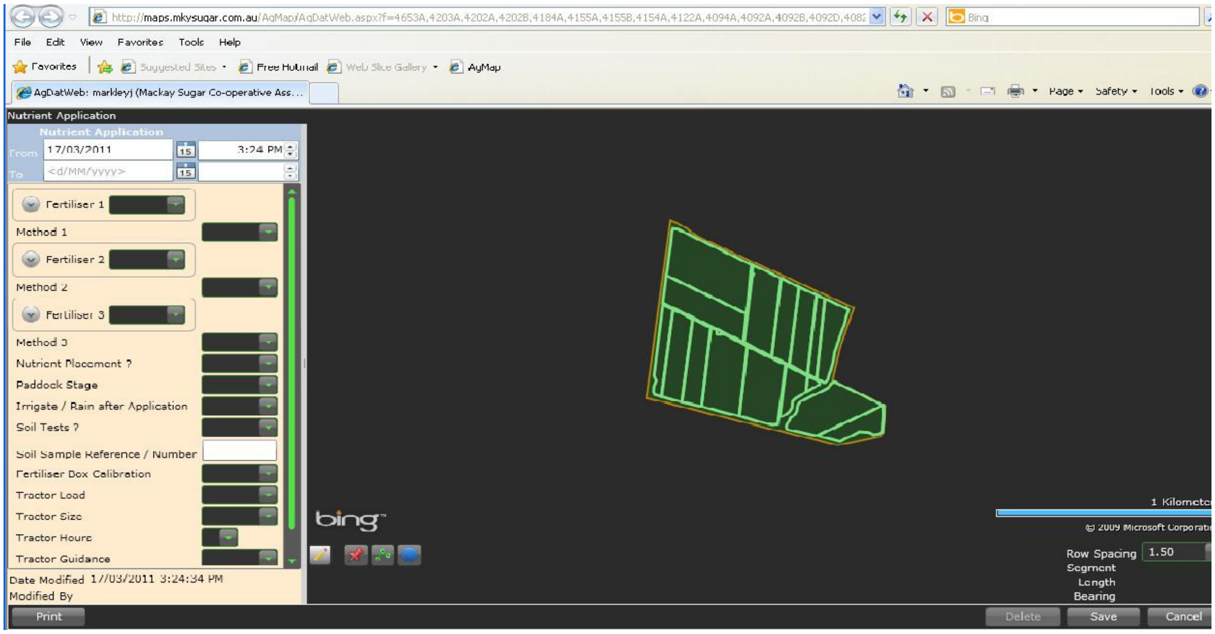

Figure 15 – AgDat Web Nutrient Application Recording Screen

A user can record information regarding farming activities and use the productivity analysis function to analyse production against the mapped land attributes and spatially recorded inputs. This will allow grower and harvester contractors to gain rapid access to all information that may be relevant to an investigation of inputs used in the production of cane (or other crops) in an auditable system that can prove the location from where the that product was sourced.

Figure 16 is a screen shot of AgDat detailing the productivity data as determined by NIR and GPS analysis. These details include the tonnes of cane and sugar per hectare as well as the tonnes per hectare of fibre, dirt and impurities in the cane supplied as well as NIR derived data.

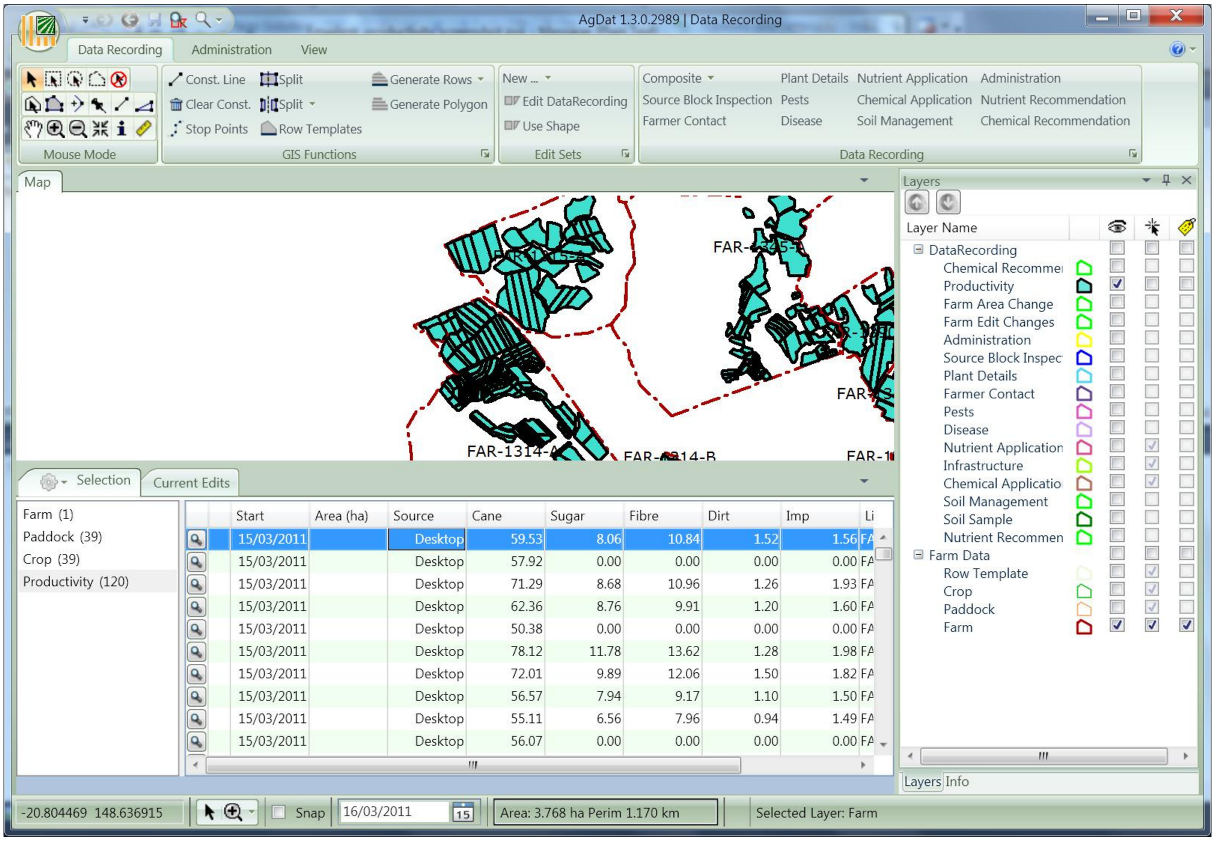

Figure 16 – AgDat Productivity Screen

It must be noted that AgDat has been developed over several years and only specialised components, namely the linkage between NIR data and harvested area as well as the importing of NIR and other productivity data into the AgDat data recording contexts have been developed within this project framework.

Information Feedback along the value chain

The feedback of information to growers and harvesters encompasses the use of farm management tools such as AgDat coupled with NIR measurements for nutrient, cane quality and cane payment information.

Nutrients

Growers in the Invicta area were been informed about the NIR project through a number of meetings held in December 2006. Two articles on Precision agriculture were also published in the Ayr Advocate "Burdekin Grower" lift out. In all a total of five meetings were held around the Invicta district to explain NIR and its uses. A meeting to explain the project and NIR technology was also held with all the cane growers representatives on the 16th October. At this meeting Lisa McDonald and Steve Staunton gave presentations about the project and NIR technology.

A survey by MSL was conducted on 7th August 2008 to determine growers and harvesters responses to farm nutrient management practices and the possibility of measuring nutrients in cane via NIR technology. Table 12 indicates the outcomes of the survey.

Table 12 MSL Grower and Harvester survey results

Question	Results
Do you currently measure soil and/or leaf nutrients?	82% Yes
If nutrient information was available through NIR measurements, would you use them to alter farming practices?	82% Yes
Do you believe that cane yield can be maintained, or improved, at lower rates of nutrient applications?	55% Yes
Have environmental concerns altered your nutrient application practices?	45% Yes
Did you know that the NIR is capable of determining nutrient levels in prepared cane?	36% Yes
What is your knowledge of the SRDC project CSR038? (No knowledge 1 to A good understanding 6)	Avg 2.3
What is your understanding of NIR technology? (No knowledge 1 to A good understanding 6)	Avg 2.8
How do you rate the NIR data presentation currently on the Mackay Sugar website? (Not satisfied 1 to Very satisfied 6)	Avg 3.6
How would you rate the importance of the availability of relevant NIR nutrient information in farm management practices? (Not important 1 to Very important 6)	Avg 5.0

Eighty two percent (82%) of the respondents were already measuring soil or leaf nutrients for use in nutrient or fertiliser management. There was a positive response to using NIR nutrient information if it was available (82%) even though there was little knowledge that NIR was capable of nutrient measurements (36%). Only 55% of the respondents thought that lower nutrient rates could be applied but still maintain, or improve, cane yields. Perhaps surprisingly, only 45% of respondents noted environmental concerns as a trigger for changing nutrient application practices.

Not surprisingly there was little knowledge of the project or NIR technology (average rankings of 2.3 & 2.8 respectively (1 being no knowledge and 6 being good understanding). Respondents were reasonably happy with the current MSL web site presentation of NIR data (average ranking of 3.6). The importance of available NIR nutrient data to farm management practices was ranked highly (average ranking of 5).

Unfortunately the projects aim of linking nutrient measurements in prepared cane to crop yield response was much more difficult to achieve as mentioned in the discussion above. Hence no clear message could be coupled with the availability of the NIR nutrient information that would provide growers with a recipe for improving yield whilst minimising fertiliser application.

Cane Payment

During 2007 CSR modified its SQL Server based canepay system so as to hold all NIR captured data against rake information. An Excel based application was then developed to allow in-house analysis of the NIR data. Much of this data has been summarised and provided to Canegrowers groups. Due to NIR data not being deemed acceptable for payment by CSR, CSR has elected to not further develop Web based applications for distributing NIR data to growers or harvesters.

Should NIR data become appropriate for payment, CSR will enhance Web based applications such that information is more readily available via the Web.

For the 2005 season, Mackay Sugar and its growers agreed to implement a new cane payment system. As described in MSA003 and the attached ASSCT paper (Attachment 8), the aim of the new system was to better align the business drivers between the mill and its growers and as a result improve business decision making. The technical basis of the new cane payment system included a fixed sharing of the revenue from sugar cane between the mill and growers. Further, the new system replaced the CCS formula with a new estimate of recoverable sugar (PRS) and introduced NIR for payment analyses. The total cane payment included payments made for sugar (based on PRS), molasses and fibre revenue components. Significant mill and grower consultation processes led to the agreement to implement the new system in 2005.

Mackay Sugar displays payment information to growers on their website to allow them to see what areas of farm management may have impacted on their cane payment. The four components used in the calculation of PRS (pol in cane, fibre in cane, impurities in cane and dirt in cane) are displayed individually for each rake supplied. The table then shows the calculated incoming pol and the associated factory loss estimates which produce the PRS result for each rake.

To further assist growers see what drives their sugar component of cane payment the growers and MSL daily averages are displayed along with units of difference. This is visually displayed on a histogram showing the PRS values for all deliveries for that day as well as the MSL average and the growers average.

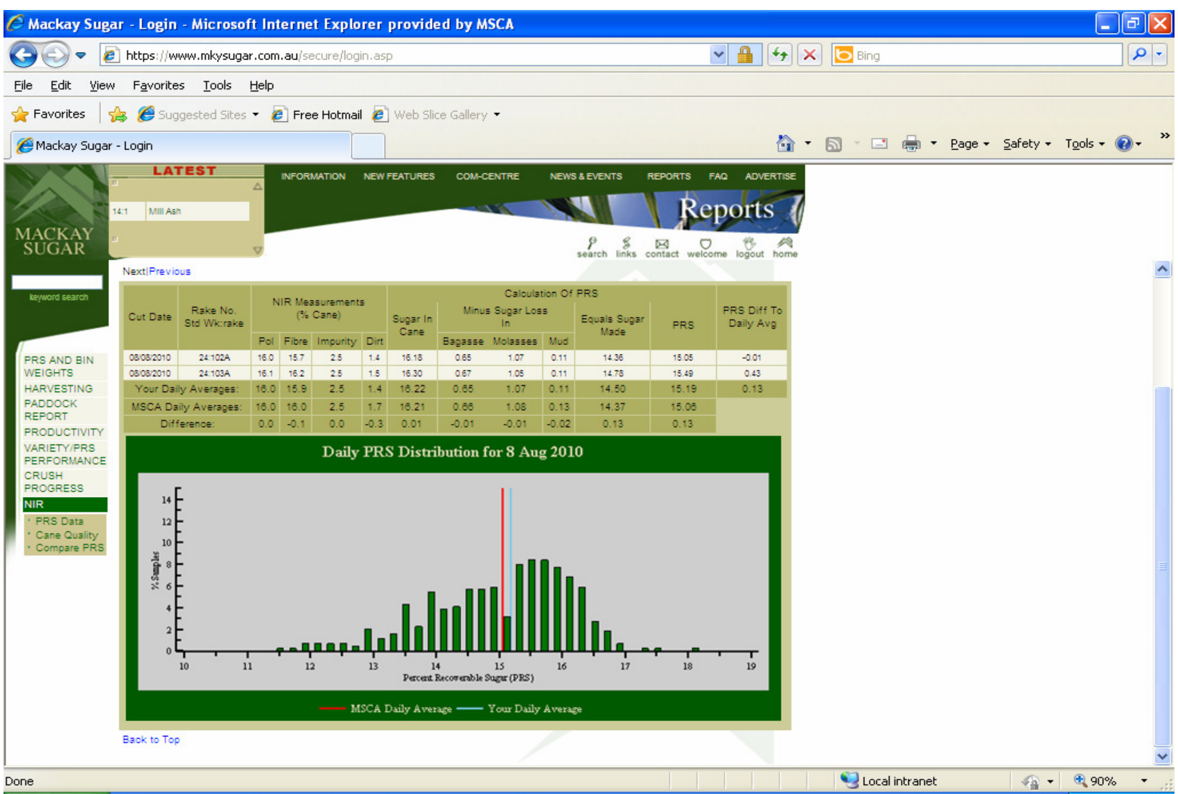

Figure 17 – MSL Web based Cane Payment (Sugar Component - PRS)

During the project the information to growers was extended to show season to date values for PRS of the farm, MSL and the zone that the farm belonged to.

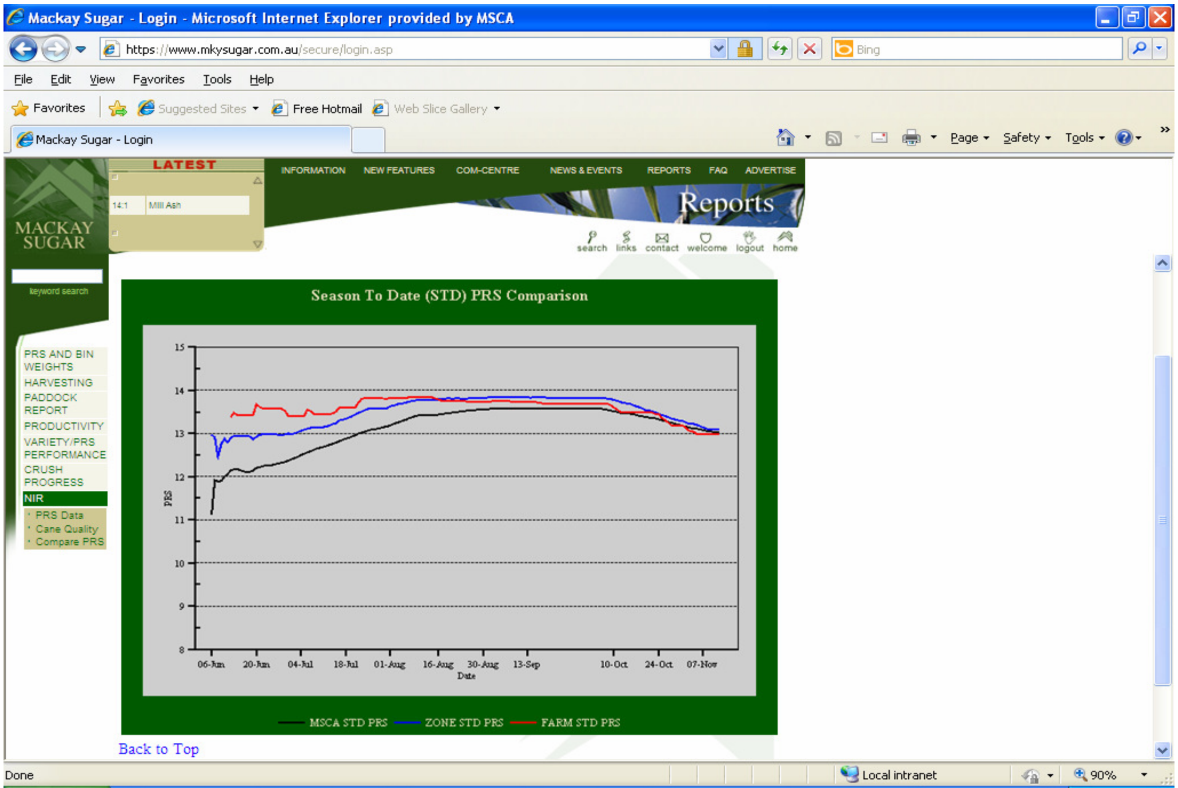

Figure 18 – MSL Web display seasonal trends for PRS

Cane Quality

Mackay Sugar has developed a process whereby some NIR information in relation to cane dirt levels and extraneous matter is available on the grower web site (SRDC project MSA003). This data shows dirt (Dirt = NIR total Ash – 0.45) and extraneous matter levels in for individual harvesters. This enables harvester operators and growers to view the dirt and extraneous matter levels for their rakes supplied on any given day. A comparison against the Mackay Sugar average is also supplied. This is intended to act as a driver to improve cane quality supplied and has been generally well received by growers and harvester operators.

Whilst in the past NIR derived cane quality data has been used predominately for display purposes only it is the intent of Mackay Sugar to commence a penalty/reward scheme trial during the 2011 season with the likelihood of full implementation for the 2012 cane harvest season.

NIR measurements for Mill Operations.

MSL during the life of this project developed three operational strategies based on NIR measurements. All of these strategies involve the clarification area performance. Wet weather during the 2010 season impacted significantly on the MSL factory operations and in particular Marian Mill. The graph below shows the sudden increase in dirt levels within the prepared cane during the season and the magnitude of this compared to previous years.

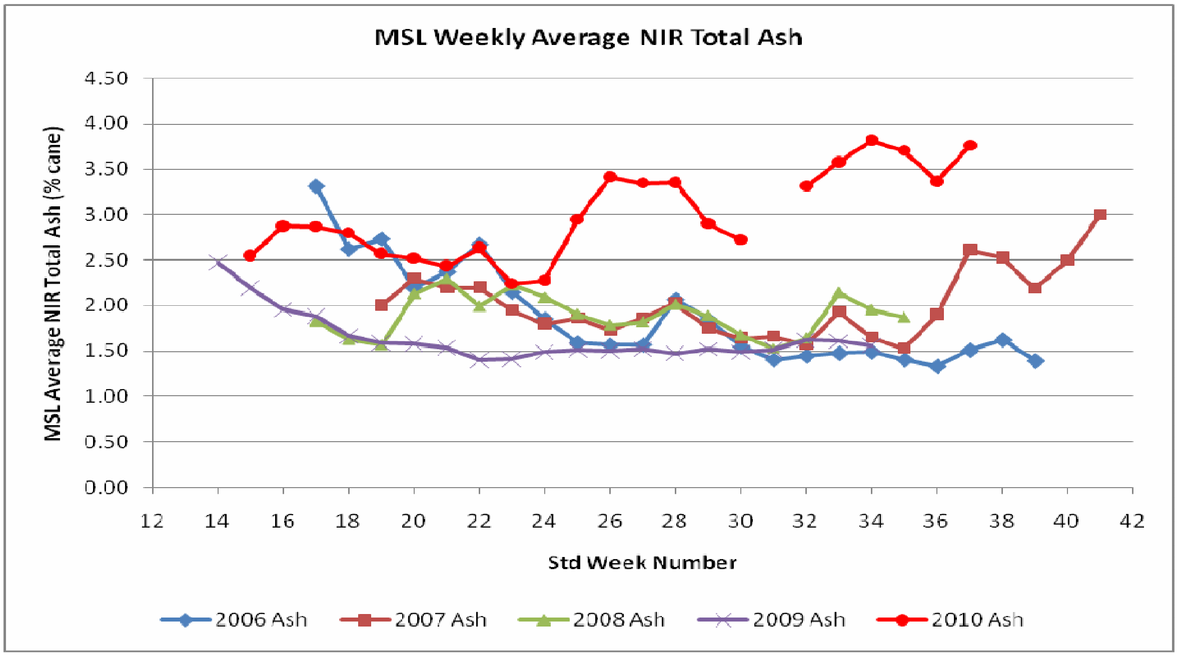

Figure 19 – MSL Historical Weekly Average NIR Total Ash

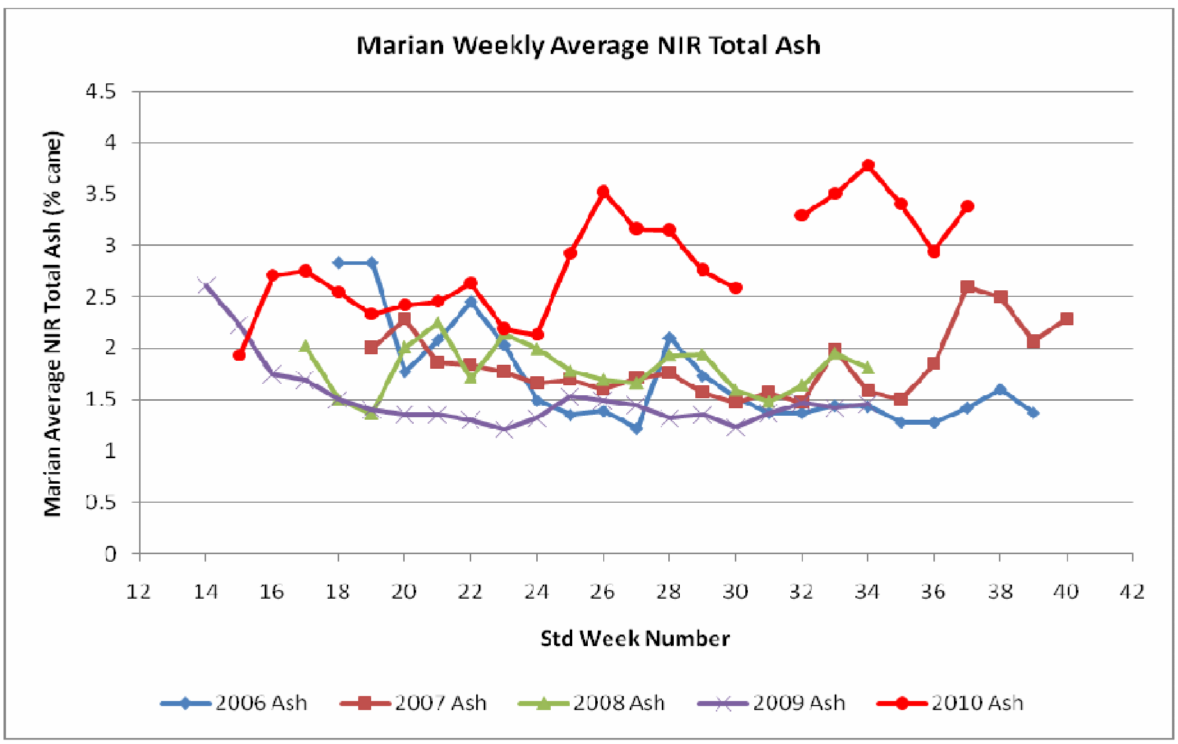

Figure 20 – Marian Mill Weekly Average NIR Total Ash

Juice Phosphate Control

The levels of phosphate in juice are critical to the performance of the clarifiers in that a minimum level of phosphate is required for adequate settling performance of normal soils. Dirt levels in 2010 were significantly higher than previous years due to wet weather prior to the start and during the crushing season (Figures 19 & 20).

As well as this there are extended periods of poor settling clay type soils which severely reduce the performance of the clarification and filter stages leading to reduced crushing rates. A system was implemented at Marian Mill that utilized the NIR juice phosphate prediction to adjust a dosing rate of phosphoric acid to primary juice. A controller adjusted the quantity of phosphoric acid added based on a setpoint and a smoothed value of the phosphate in juice from whichever milling train was running at the time. If both trains were running then NIR signal would be taken from the B train unit. Both NIR unit phosphate in juice readings were adjusted for bias differences using control charts as described in the validation discussion below and these offsets were manually adjusted periodically in the control system.

The NIR juice phosphate values were validated by analyzing one juice sample per day for comparison with the NIR values and charting the differences as groups of three (3) in control charts. The average control chart provides the indication of the bias to apply to the NIR readings. The NIR Phosphate in Juice equation is still a developmental equation meaning that it provides indicative values with a large error associated with it but it was seen as adequate for the purpose of control of acid addition.

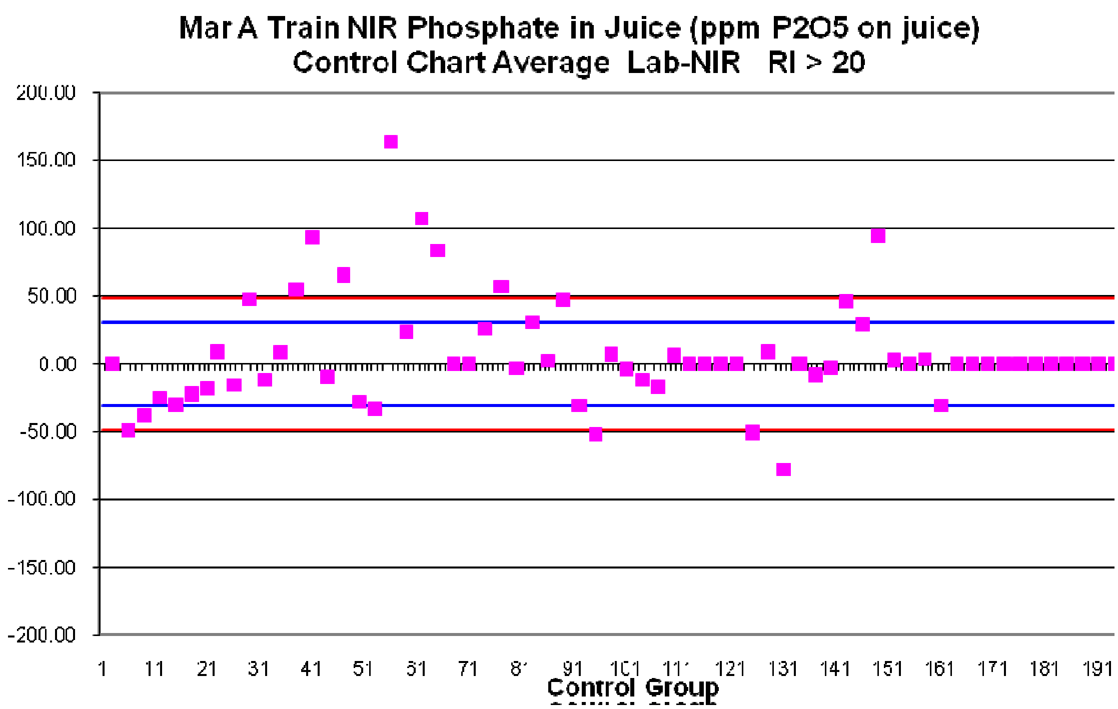

Figure 21 – NIR Phosphate in Juice Average Control Chart (Marian A)

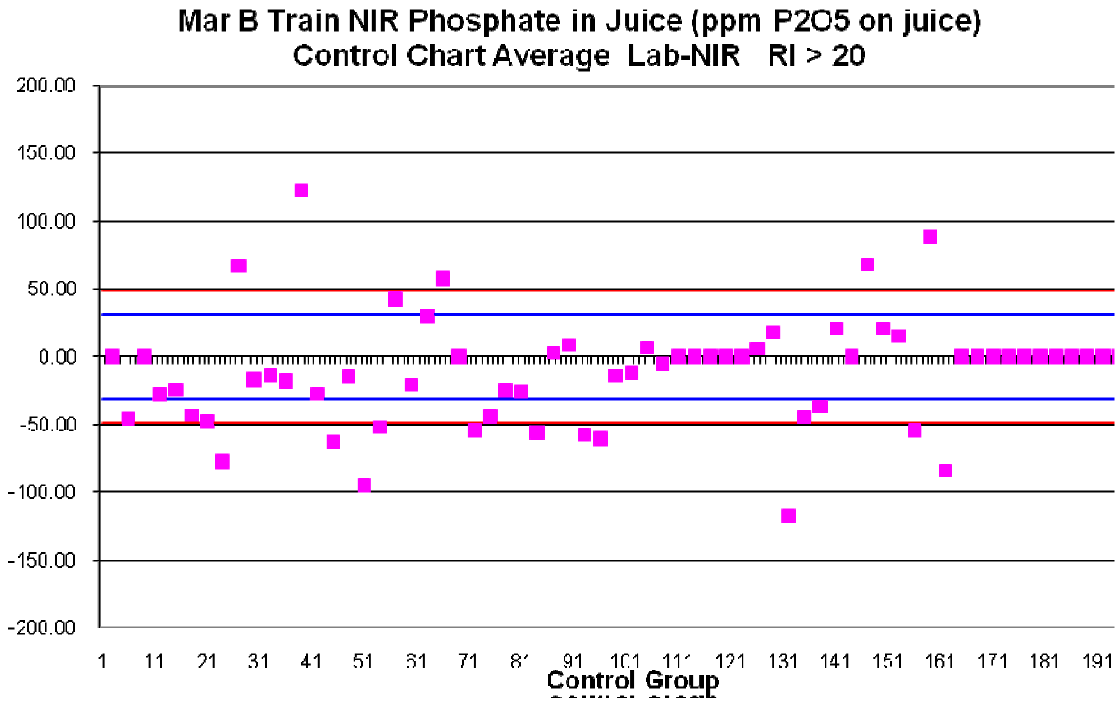

Figure 22 – NIR Phosphate in Juice Average Control Chart (Marian B)

Marian Clarifier Flocculent Addition

As mentioned above the mud loadings in 2010 at Marian were significantly above the previous year's loadings (Figure 20). Marian encountered considerable clarification problems with periods of very high mud loadings and with periods of processing clay soils.

In an attempt to improve the clarification process the NIR total ash values were used to indicate dirt loadings in the incoming cane samples. Using these measurements the clarifier flocculent addition rates, for both clarifiers, a change to the current control logic was installed whereby the flocculent rate ratios would be automatically adjusted from current setpoint settings. The flocculent control system would have a set ratio from the clarifier feed flow measurement when the NIR total ash levels were below a trigger value. Once the NIR total ash values increased above the trigger value the flocculent addition ratio setpoint would increase with increasing NIR total ash levels. A maximum flocculent addition ratio was set to prevent too much flocculent being added.

Ash Alarms - Pleystowe and Racecourse

Dirt content in cane has been an issue for a number of years at both Pleystowe and Racecourse. Pleystowe particularly was prone to receiving clay soils which reduced factory production rates due to poor clarification performance. Pleystowe displayed the NIR variables on their Citect operator interface and the values for NIR total ash were seen to be useful in identifying which rakes of cane were responsible for causing clarification problems. These growers would then be visited by Field Officers to determine what improvements could be made in reducing soil content of the harvested cane. Figure 23 below represents a 10 hour period of ash data from Pleystowe. The chart shows the trigger level. The gap in data was due to a mill stop for high mud levels so the 5 minute moving average (MA 5 min) indicates when sufficient levels of mud are entering the juice circuit to cause problems.

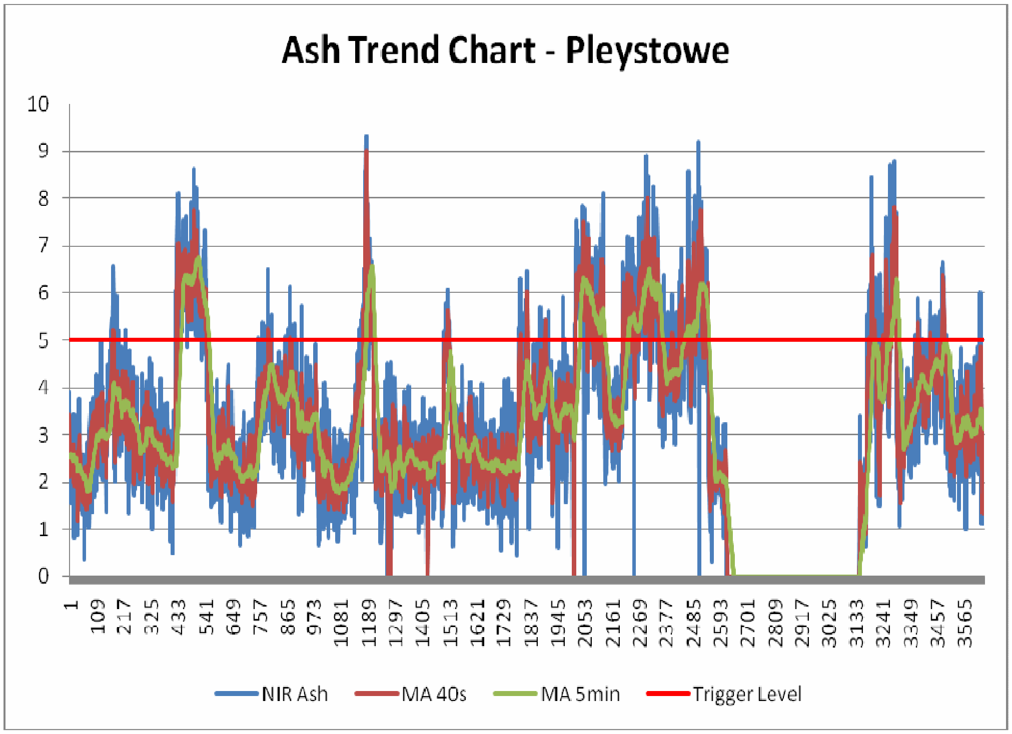

Figure 23 – NIR Total Ash trend for Pleystowe

Racecourse operators were relying on the juice analysts to convey to them the NIR total ash % cane levels and notify them if there are high levels (ie. > 5%). The operators have anecdotally related the cane total ash values to changes in mud levels in the clarifier. In 2009 the control system equipment was installed at Racecourse to allow trending of the NIR total ash values in real time (Figure 24) for the clarification/filter operator.

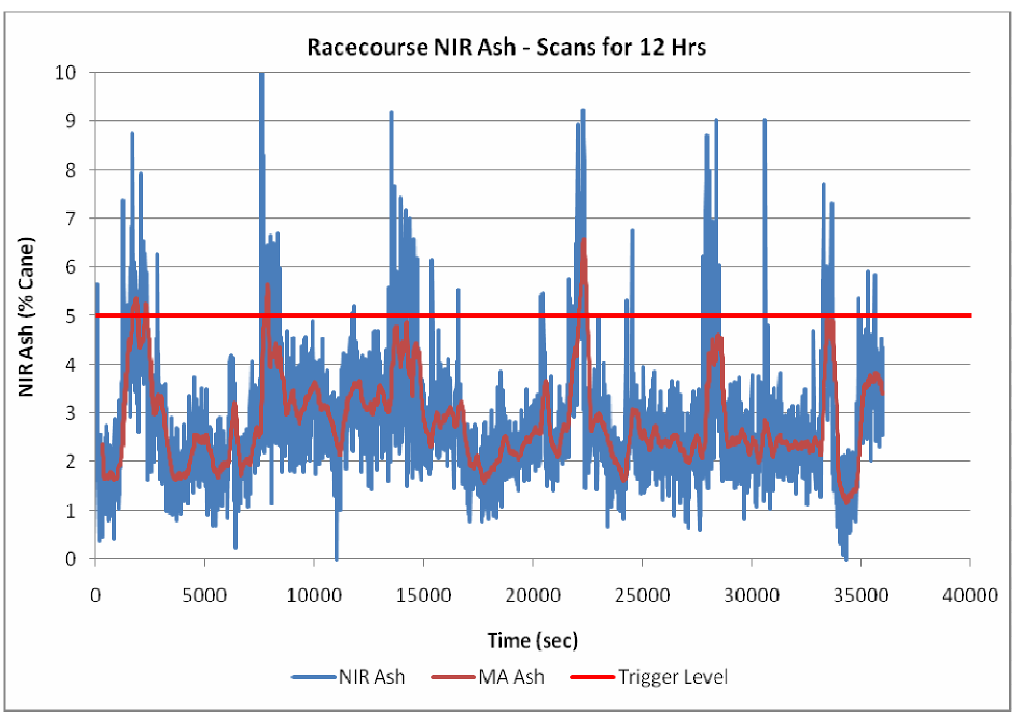

Figure 24 – NIR Total Ash trend for Racecourse

The NIR data required smoothing and an alarm at the clarification stage is triggered when the 5 minute moving average NIR total ash value is above 5% (adjustable). This provides a signal that indicates a significant quantity of ash has entered the juice circuit rather than a small quantity from a small but high ash sample. The large juice circuit volumes and tank mixing dilutes the effect of small high ash rakes on the clarifier. An alarm for milling train operators with a shorter moving average period (40 sec) was also installed to warn of high ash cane that may affect milling and boiler operations.

Intellectual Property and Confidentiality:

The current NIR calibrations are owned by BSES Ltd and available through the FOSS CAS NIR System. The new calibrations will generate some IP but will require a lot more work before they are commercially viable. The new calibrations would be available free of charge to anyone in the industry who was interested in using/developing them further until they are considered suitable commercial use.

It is acknowledged that the AgDat development has pre-existing Intellectual Property owned by Agtrix Pty. Ltd. and is provided under a non-exclusive, non-transferable licence to use and not for sale or lease to other parties unless under agreement from Agtrix Pty.Ltd.

Environmental and Social Impacts:

The Mackay Whitsunday region represents approximately 1/3 of Queensland's sugar cane production area. Within the region, sugar cane is the dominant primary intensive agriculture land use, while only making up about 18% of the catchment area (167100ha), represents close to 96% of the regions intensive cropping agricultural land use. The grower shareholders of Mackay Sugar account for greater than 65% of the regions sugar cane growing area.

Water quality monitoring undertaken in the region prior to 2008 confirmed that in those fresh water catchments, estuaries and the Great Barrier Reef, areas within close proximity to sugar cane production, elevated amounts of nutrients and chemicals were found.

In 2008 the Mackay Whitsunday Natural Resource Management Group (now known as Reef Catchments Mackay Whitsunday Inc.) published the Water Quality Improvement Plan (WQIP), (Drewry, J., Higham, W., Mitchell, C. 2008) for the Mackay Whitsunday region. The WQIP specified the current resource condition (as at 2008) of 33 sub-catchments, the identified resource condition targets and timeframes (2014 and 2050) as well as the year of reference for the level of classification.

A pivotal stage in the WQIP process was the development of the ABCD framework. The ABCD framework was designed to highlight and facilitate communication about the different levels or standards of management practice (as opposed to resource condition) within the cane industry for different water quality parameters (i.e. sediment, nutrients and chemicals). The classification provides a definition and a scale of improvement from dated (D) to current (C), best practice (B), through to new or innovative practices known as aspirational (A).

The framework has been designed so that as the associated improved land management practices are implemented it will have a positive impact on all aspects of farming from production, efficiency, economics as well as the desired improvements in water quality.
The use of NIR derived plant nutrient data is listed as an A class practice under the ABCD framework. The inclusion of this as an A class practice is as direct consequence of the NIR calibration and analysis work from this project. While acknowledging the fact that the project could not reach any firm conclusions in regard the use if NIR derived nutrient data it is the intension of researchers to use NIR data to firstly produce a nutrient removal map across several sites and secondly develop recommendations as to the level of nutrient replacement as a result of the nutrient removal.

Also within the A class practice description is the need to keep farming activity records using an electronic spatial database (Agdat). The use of spatial record keeping and the ability to analyse those records(farm inputs) against farm outputs (productivity) is considered to provide valuable data to growers and extension staff. The use of this data can then be used to make more informed decisions especially in regard to the placement and rate at which chemicals and nutrients are applied.

It is important to remember that A class is an innovative practice that requires further validation before recommending widespread adoption. The NIR derived nutrient removal maps and subsequent recommendations will require more validation work before this can be used for widespread adoption. However, the development of Agdat as a data recording and reporting tool has reached maturity and is currently undergoing widespread adoption amongst growers, extension staff and independent agronomists.

Expected Outcomes:

The outcomes from the project together with a listing of the outcome components and their status is shown in Table 13

Project Outcome	Outcome components	Status	Comment
Increase knowledge and awareness of 25 growers in Mackay on the relationship between NIR nutrient measurement and infield nutrient management practices. This group of growers using data to assess the suitability of modifying practices based on the relationship between NIR nutrient measurement and infield nutrient management practices.	Establish strip trials	Complete	
	Harvest and analyse strip trials results.	Complete	
	Sample prepared cane and analyse for nutrients.	Complete	
	Establish and modify NIR nutrient calibrations from the results of prepared cane analysis.	Complete	Added as an additional outcome.
	Analyse harvest data to establish relationship between NIR nutrients and in-field management practices.	Incomplete	Incomplete in field historical dataset. Inconclusive evidence to establish relationships.
	Establish a link between NIR data and the cane source (Electronic consignment)	Complete	Added as an additional outcome.
	Establish a program to record the history of farm management practices (Agdat) and to analyse productivity results.	Complete	Added as additional outcome.
	Increase knowledge and awareness regarding NIR data to 25 growers.	Incomplete	Inconclusive evidence to establish relationships.
Economic and operational benefits from improved mill operation from use of new calibrations	Establish operational improvements in milling operations using NIR data.	Complete	
	Establish economic benefits from introduction of the operational improvements.	Incomplete	Difficult to establish the economic benefits – would require further research.
Increase knowledge and awareness by harvester operators of the relationship between relevant NIR data and harvesting practices.	Establish a information dataset advising growers and harvester operators of their daily dirt loads.	Complete	
	Establish a cane quality scheme	In progress	Assessment undertaken during project. Trial for 2011 season Full implementation 2012 season

Table 13 - Expected project outcomes

Future Research Needs:

- Quite clearly the failure to establish a conclusive link between derived nutrient data and in-field nutrient management was a disappointment of the project. As stated in the report body, one of the main reasons behind this was the lack of historical data relating to in-field management practices. With the introduction of Agdat to the growing community and extension staff, this knowledge gap can start to be closed. Upon the creation of this dataset the linkages between management practice data and derived NIR data could and should be further researched in order better assess the suitability of NIR data in the decision making process regarding nutrient and chemical application and/or soil health.

- The NIR nutrient equations still require further development and lots more samples to improve the prediction ability of the equations. This focus should really be an industry wide focus utilising all of the current NIR users and enable capture of variability in the data set. The impediment to this process is the cost for large numbers of nutrient analyses.
- With increased focus on the clarification process with continued wet weather seasons the phosphate in juice equation for NIR may well become a more valuable tool in processing difficult to clarify juices. Knowledge in this area may well extend back to the plant growing conditions or identification of soil types to assist with pro-active processing changes to handle these difficult juices.

Recommendations:

The principal recommendation of the project participants is to continue with the progress made in the use of NIR derived data and the software developments and include:

- Introduction of a cane quality scheme using NIR derived data with the emphasis not only on cane quality but also harvester speed and harvester efficiency.
- The replacement of the current paper based and manual consignment system that has a high level of inaccuracy with an automated electronic consignment application.
- Adoption of AgDat as an Australian industry standard application for recording and reporting of spatial farm management practices, harvesting and productivity data.
- NIR nutrient equation development should be continued with an industry wide focus on obtaining and paying for the analyses of the samples.
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List of Publications:

Markley, J.A., *et al* (2009) The development of electronic consignment bin recording.
Proc. Aust. Soc. Sugar Cane Technol. 31: 568-579

BSES bulletin

References

MSA003 – A Co-operative Systems Model for the Mackay Regional Sugar Industry

CSE001 – Improved environmental outcomes and profitability through innovative management of nitrogen.

Attachments

Attachment 1 NIR Value Chains Sugarcane Review.doc

Attachment 2_Soil types field experiments 2007-08.pdf

Attachment 3 Dr Peter Stone report

Attachment 4_CSIRO_Report on field experiments 2007-08.doc

Attachment 5 CSIRO_RegressionTreeAnalysis.doc

Attachment 6 CSIRO_RegressionTreeAnalysis 2009_10.doc

Attachment 7 ASSCT paper – electronic consignment

Attachment 8 ASSCT paper – MSL Cane payment

Appendices

Appendix A – Soil test results for field experiments 2007-08

Appendix B – Leaf test results for field experiments 2007-08

Appendix C – NIR Calibration Statistics

Appendix A – Soil test results for field experiments 2007/08

Experiment 1 Soil Tests

Trial #	Plot #	Soil Tests - Before nutrient application										
		pH	OC	NO3-N	S04-S	P (c)	P (BSES)	K meq	K %CEC	Ca meq	Ca %CEC	Mg meq
Very Low Fert	1	5.70	2.27	30	20	30	35	0.19	0.05	7.03	0.59	4.33
Low Fert	2	5.80	1.17	23	13	26	31	0.15	0.04	3.18	0.62	1.60
Standard Fert	3	5.60	1.05	20	12	21	30	0.17	0.05	4.13	0.75	1.65

Trial #	Plot #	Soil Tests - Before nutrient application										
		Mg %CEC	Na meq	Na %CEC	Cl	EC	Cu	Zn	Mn	Fe	B	CEC	Ca/Mg
Very Low Fert	1	0.36	0.33	0.03	19	0.15	1.30	3.00	0.30	7.30	0.12	11.93	1.63
Low Fert	2	0.31	0.09	0.02	23	0.12	1.30	1.50	0.26	48.10	0.13	5.09	1.98
Standard Fert	3	0.35	0.10	0.03	19	0.13	1.30	1.50	0.27	35.00	0.11	6.11	1.75

Experiment 2 Soil Tests

Trial #	Plot #	Soil Tests - Before nutrient application										
		pH	OC	NO3-N	S04-S	P (c)	P (BSES)	K meq	K %CEC	Ca meq	Ca %CEC	Mg meq
Nil P	1	5.20	1.04	10	5	113	157	0.18	0.04	3.15	0.71	1.07
Plus S	2	5.30	0.91	16	7	210	243	0.15	0.04	3.19	0.73	0.99
Nil K	3	5.40	0.80	13	6	24	27	0.17	0.04	3.90	0.76	0.97
Plus P	4	4.50	0.86	23	3	30	63	0.19	0.09	1.53	0.70	0.42
Nil S	5	4.80	0.70	11	4	31	43	0.14	0.05	1.97	0.70	0.66
Plus K	6	4.90	0.80	12	5	21	30	0.13	0.05	1.86	0.65	0.63

Trial #	Plot #	Soil Tests - Before nutrient application											
		Mg %CEC	Na meq	Na %CEC	Cl	EC	Cu	Zn	Mn	Fe	B	CEC	Ca/Mg
Nil P	1	0.24	0.03	0.01	15	0.04	0.00	0.00	0.00	0.00	0.00	4.42	2.95
Plus S	2	0.23	0.03	0.01	19	0.05	0.00	0.00	0.00	0.00	0.00	4.37	3.22
Nil K	3	0.24	0.03	0.01	18	0.05	0.00	0.00	0.00	0.00	0.00	4.23	3.12
Plus P	4	0.19	0.03	0.02	21	0.07	0.00	0.00	0.00	0.00	0.00	2.17	3.66
Nil S	5	0.23	0.04	0.02	14	0.04	0.00	0.00	0.00	0.00	0.00	2.81	2.98
Plus K	6	0.22	0.04	0.02	13	0.04	0.00	0.00	0.00	0.00	0.00	2.54	2.76

Appendix B – Leaf test results for field experiments 2007/08

Experiment 1 Leaf Tests

Trial #	Plot #	Leaf Tests - After nutrient application								
		Chloride %	Nitrate Nitrogen mg/kg	Nitrogen (Kjeldahl) %	Calcium %	Magnesium %	Phosphorus %	Potassium %	Sodium %	Sulfur %
Very Low Fert	1			1.60	0.33	0.21	0.29	1.10		0.14
Low Fert	2	0.24	50	1.60	0.26	0.19	0.27	1.10	0.03	0.14
Standard Fert	3	0.26	50	1.70	0.27	0.20	0.26	1.10	0.03	0.15
High Fert	4	0.24	50	1.90	0.42	0.26	0.24	1.10	0.09	0.17

Trial #	Plot #	Leaf Tests - After nutrient application							
		Boron mg/kg	Copper mg/kg	Iron mg/kg	Manganese mg/kg	Zinc mg/kg	N:S Ratio	N:P Ratio	N:K Ratio
Very Low Fert	1		7.20	73	86	19.00	11.4	5.5	1.5
Low Fert	2	5.70	8.90	65	63	18.00	11.0	5.9	1.5
Standard Fert	3	6.70	9.20	83	65	21.00	11.0	6.5	1.5
High Fert	4	7.10	7.40	99	130	19.00	11.0	7.9	1.7

Experiment 2 Leaf Tests

Trial #	Plot #	Leaf Tests - After nutrient application								
		Chloride %	Nitrate Nitrogen mg/kg	Nitrogen (Kjeldahl) %	Calcium %	Magnesium %	Phosphorus %	Potassium %	Sodium %	Sulfur %
Nil P	1	0.28	50	1.70	0.25	0.22	0.27	1.30	0.04	0.17
Plus S	2	0.30	50	2.00	0.28	0.23	0.26	1.40	0.02	0.16
Nil K	3	0.50	50	1.70	0.26	0.21	0.21	1.40	0.03	0.17
Plus P	4			1.88	0.33	0.26	0.25	1.38	0.05	0.19
Nil S	5	0.30	50	1.80	0.29	0.23	0.26	1.40	0.04	0.17
Plus K	6			1.88	0.33	0.26	0.25	1.38	0.05	0.19

Trial #	Plot #	Leaf Tests - After nutrient application							
		Boron mg/kg	Copper mg/kg	Iron mg/kg	Manganese mg/kg	Zinc mg/kg	N:S Ratio	N:P Ratio	N:K Ratio
Nil P	1	4.60	7.80	83	150	20.00	10.0	6.3	1.3
Plus S	2	5.10	8.10	83	150	22.00	13.0	7.7	1.4
Nil K	3	4.40	7.40	64	220	19.00	10.0	8.1	1.2
Plus P	4		5.60	54	156	21.40	9.7	7.4	1.4
Nil S	5	5.40	8.10	78	160	21.00	11.0	6.9	1.3
Plus K	6		5.60	54	156	21.40	9.7	7.4	1.4

Appendix C – NIR Nutrient Calibrations Statistics

Table C.1 – Type 1 NIR Calibration Statistics

Global Type 1	Calibration Statistics									
Constituent	Equation Name	SEC	R^2	Mean	Std. Dev.	Effective Range	N	% Outliers	Error Control Limit	No of terms
Cane Sulphate (SO4 % DryMatter)	Fib_S	0.032	0.94	0.19	0.123	0.02 - 0.39	150	4.4%	0.038	12
Cane Phosphate (PO4 % DryMatter)	Fib_P	0.020	0.95	0.11	0.020	0.02 - 0.33	83	6.7%	0.024	8
Cane Calcium (% DryMatter)	Fib_Ca	0.016	0.93	0.08	0.060	0.02 - 0.55	180	8.1%	0.019	12
Cane Potassium (% DryMatter)	Fib_K	0.040	0.94	0.26	0.164	0.07 - 0.64	86	3.3%	0.048	8
Cane Magnesium (% DryMatter)	Fib_Mg	0.013	0.91	0.07	0.041	0.02 - 0.19	85	4.4%	0.016	8
Cane Sodium (% DryMatter)	Fib_Na	0.003	0.64	0.01	0.005	0.004 - 0.043	68	23.3%	0.004	8
Cane Iron (% DryMatter)	Fib_Fe	0.021	0.84	0.07	0.054	0.02 - 0.27	64	8.5%	0.025	8
Cane Aluminium (% DryMatter)	Fib_Al	0.030	0.75	0.07	0.060	0.02 - 0.26	70	0%	0.036	8
Cane Manganese (% DryMatter)	Fib_Mn	0.001	0.79	0.005	0.003	0.002 - 0.017	70	0%	0.001	8
Cane Nitrogen (N % Dry Matter)	TotalN	0.037	0.71	0.23	0.069	0.07 - 0.48	444	11.7%	0.044	12
Cane Carbon (C % Dry Matter)	TotalC	0.820	0.87	40.99	2.320	34.3 - 47.4	432	11.5%	0.984	12

Table C.2 – Type 2 NIR Calibration Statistics

Global Type 2	Calibration Statistics									
Constituent	Equation Name	SEC	R^2	Mean	Std. Dev.	Effective Range	N	% Outliers	Error Control Limit	No of terms
Cane Sulphate (SO4 % DryMatter)	Fib_S	0.035	0.83	0.17	0.083	0.02 - 0.37	260	8.7%	0.042	12
Cane Phosphate (PO4 % DryMatter)	Fib_P	0.035	0.89	0.20	0.099	0.02 - 0.42	228	9.5%	0.042	12
Cane Calcium (% DryMatter)	Fib_Ca	0.015	0.92	0.08	0.051	0.04 - 0.55	236	6.0%	0.018	12
Cane Potassium (% DryMatter)	Fib_K	0.059	0.86	0.37	0.161	0.08 - 1.06	222	12.2%	0.071	12
Cane Magnesium (% DryMatter)	Fib_Mg	0.011	0.88	0.09	0.031	0.02 - 0.17	230	8.3%	0.013	12
Cane Sodium (% DryMatter)	Fib_Na	0.004	0.63	0.01	0.007	0.002 - 0.05	172	16.0%	0.005	12
Cane Iron (% DryMatter)	Fib_Fe	0.026	0.83	0.08	0.062	0.008 - 0.42	142	11.1%	0.031	12
Cane Aluminium (% DryMatter)	Fib_Al	0.048	0.77	0.10	0.100	0.01 - 0.70	146	9.3%	0.058	12
Cane Manganese (% DryMatter)	Fib_Mn	0.002	0.73	0.010	0.005	0.002 - 0.027	189	8.7%	0.002	12
Cane Nitrogen (N % Dry Matter)	TotalN	0.028	0.76	0.20	0.056	0.056 - 0.392	251	11.8%	0.034	12
Cane Carbon (C % Dry Matter)	TotalC	0.680	0.91	42.15	2.240	35.9 - 47.4	230	10.6%	0.816	12