"NEW CHALLENGES FROM PRECISION AGRICULTURE"

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Precision agriculture (PA) research for cotton in Australia began in 1997 and has followed a clear path aimed at discovering key information for the Industry. The potential benefit of PA management techniques within a particular field over the current "field average" management techniques is directly linked to the amount of spatial variability present, therefore a key question was "how much variability is typical in Australian cotton fields". The second question follows from the first and is "if I have variability in my cotton field, how may I manage it so as to achieve economic and environmental benefits for myself and my community"? The answers to these questions have been the goal of two research projects conducted by the University of Sydney with cooperation and funding from the Cotton Research and Development Corporation and the Australian Cotton CRC. The results are detailed in two parts of this paper. The first section "Measuring variability" discusses methods of measuring yield variability and presents results of research into the accuracy of on-picker yield monitors. The second section discusses "managing variability" and looks at a method of determining how to better manage nitrogen within a variable field.

PART I: MEASURING VARIABILITY

PA in grain crops is more advanced than it is the cotton industry largely due to the fact that while there have been reliable and accurate on-combine yield mapping systems in the grains industry since 1994, the equivalent for cotton has only recently become available. These monitors have been used by producers to measure the variability on their own farms and in most cases have revealed yield variability that has inspired management effort. Attempts at measuring the variability in cotton yield which can be used to verify if PA management may help in a particular field have focussed on picker yield mapping systems and on remotely sensed (satellite images) yield estimates.

Proximal yield sensing (Yield monitors on pickers)

Research into the accuracy and reliability of cotton yield monitors began in 1997 coincident with the first stage of field testing by manufacturers. The focus of testing was to ascertain both the accuracy and reliability of these sensors when operating in the field. The correct spatial resolution to effectively engage precision agricultural management techniques is still unknown. However, as one investigates smaller and smaller potential management areas it is important that the confidence placed in information gathered and calibrated at the large scale (field) translates into estimates of similar quality which may thus be treated with similar confidence at a smaller scale (small regions within the field). Results of various tests are detailed in figure 1. From these it can be seen that individual measurements are slightly erratic and typically have errors of ~10-11% however averaging of the measurements in areas of ~6m x 6m of larger will bring the error down to ~3% and your confidence in the data up to

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reasonable levels. At this scale, you would get at least 270 yield measurements per hectare. Excellent for mapping variability.

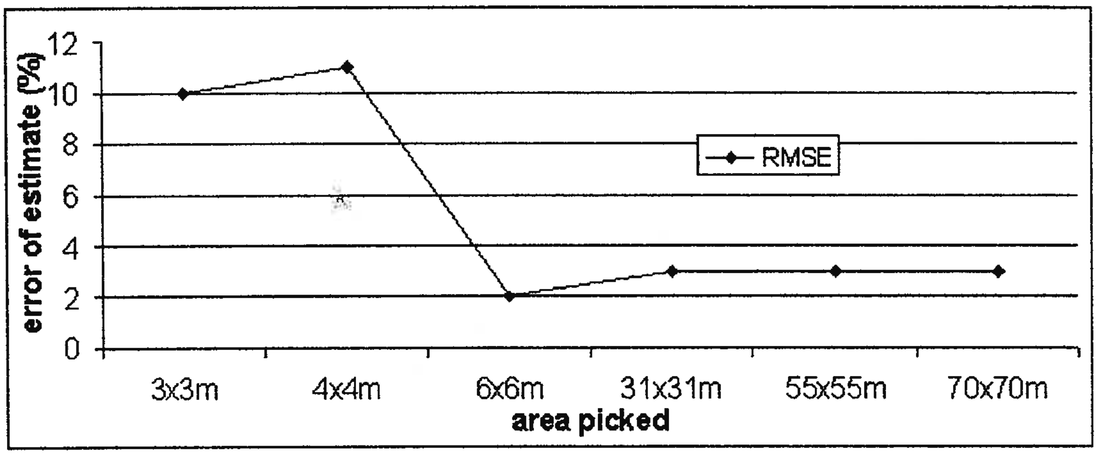


Figure 1 Error of measurements from yield monitors after averaging all estimates within a given area

An obvious use of yield maps may be to do on farm trials and in particular to do variety trials. The effect that varieties had on accuracy was evaluated and is detailed in figure 2. The results indicate that varieties with the same yield may actually be estimated as being as much as 20% better or worse if a variety specific calibration is not made. The calibration is a straight % change and for this reason, mapping within a variety is still relatively precise, but cannot be compared between varieties. The correct calibration can be manually entered at a later date to each variety to correct this error however and is therefore not a critical failing in the sensor.

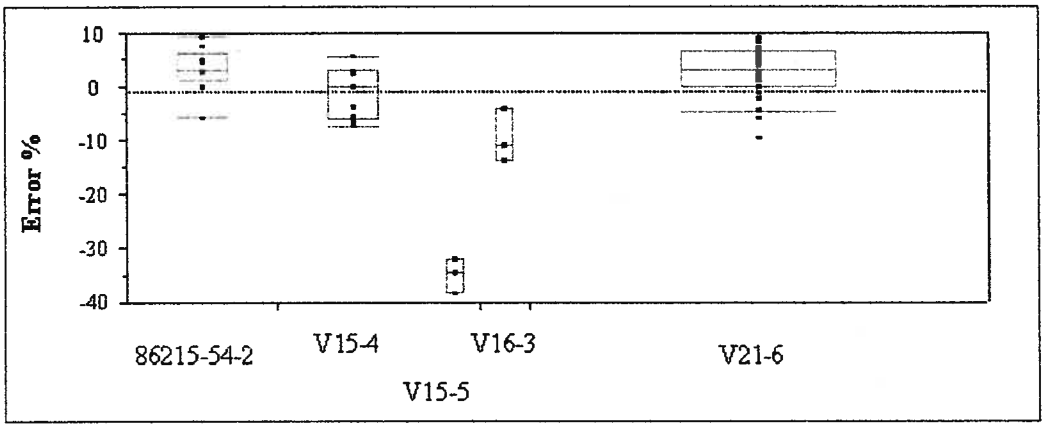


Figure 2 The influence of varieties on the quality of a single calibration on the Zycom cotton yield monitor. (Error is expressed as a percentage, measured vs estimated yield)

In terms of reliability, the greatest problem with yield monitors in cotton pickers has been their ability to sty clean and subsequently, the amount of maintenance required to keep them clean. The first models available in 1997 required manual cleaning (climb out of the picker and remove sensors and wipe them with a clean cloth) as much as every 20 minutes and as a result were totally impractical for field use. The monitors reviewed in the 1999/2000 season however typically lasted a full day without cleaning and often as much as a week. Additionally they have self check functions which warn the operator when the sensors are dirty. When these warnings are raised, the data is compromised and the sensor should be either turned off till cleaning or cleaned immediately. Good calibration and proper maintenance of a cotton yield monitor will result is the production of excellent yield maps.

Yield estimates from remote sensing

In 1998 a satellite based yield estimate map was released at the cotton conference called "Farsite". The accuracy of these estimates has been compared to yield maps created using cotton pickers and a similar Landsat (satellite) based yield estimation was developed. The model to make the yield estimates was based on the within field estimates not whole field yield data that was used to make "Farsite". These were taken from data for the 1997-99 seasons and are illustrated in figure 3(a). Data from the recent 2000 pick were compared to the yield estimates and typically the correlation was very high. The similarity between estimates from the satellite and those measured at picking with the monitor is shown in the graph in figure 3(b). A straight 45° line would men that the estimates were perfect and spread from the line indicates that the precision is off. In this case the relative variability within the fields was typically precise to ±~1 bale/ha. The overall field average however for the 2000 pick was however estimated to be ~2bales less than it turned out to be.

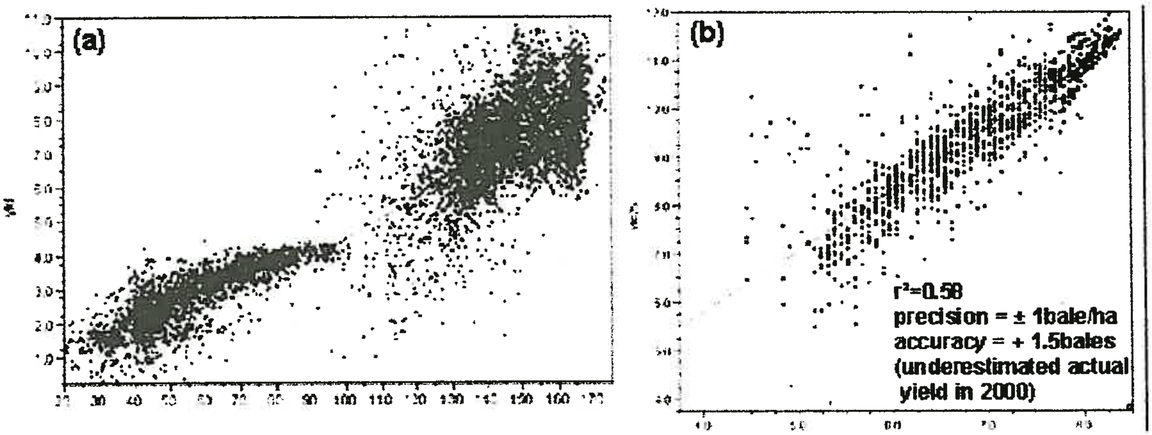


Figure 3 The model to transform Landsat satellite images into yield estimates was derived from the response (a) where yield is on the "y" axis and landsat numbers are on the "x" axis. The Graph on the right is the yield estimate on the "x" axis and the actual yield on the "y" axis. Results from the 1999/00 season indicate that the estimates are very good at predicting relative yield (precision of ± 1 bale) but underestimated the actual yield by ~2 bales/ha.

Figure 4 is a map representation of the similarity between Landsat yield estimates on the left (a) and a yield monitor map on the right (b). It is evident that the general yield variability is very closely matched (± ~1bale) between yield mapping methods. The yield estimate map however averaged ~2 bales/ha less than the correct yield monitor meaning that it would require re-calibration after harvest. Biggest errors in the landsat estimates relative to picker yield maps occur where something agronomically catastrophic has occurred since the image was captured (eg. Hail storm or late season insect escape). Add to this the fact that landsat yield estimates are 25m x 25m

($625m^2$) while picker estimates are ~6m x 6m ($36m^2$) and as such will only give you ~1/17th of the information on variability that a picker monitor will.

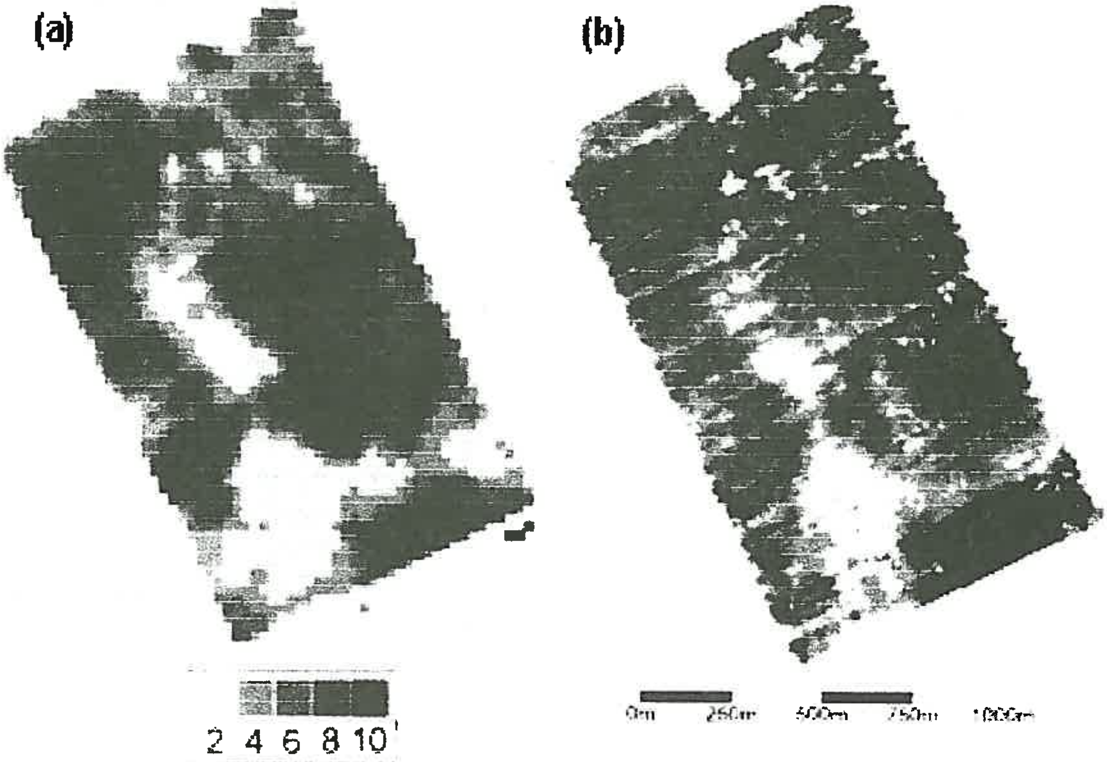


Figure 4 Landsat (satellite) yield estimate on the left and the actual measured yield on the right. Landsat estimates are more spatially coarse (25m x 25m) than the yield monitor data (>10m x 10m) and is less accurate but is available for every field in Australia and for past seasons via the ACRES archive.

Typical variability

Through all of these experiments the amount of variability in cotton yield within fields has been characterised for most growing regions in Australia. Tests reveal that the average field will yield ~7 bales/ha but may have regions yielding ~2bales/ha more or less for every 9 ha of the field. This variability is derived from data collected from the darling downs, border rivers, Gwydir, lower Namoi, upper Namoi, Bourke and Lake Tandau growing regions. No region tested was without variability. In the Gwydir and lower Namoi where testing was most concentrated it appeared that there was slightly more variability present in fields to the east of Moree (Gwydir) and east of Wee Waa in the lower Namoi. For the upper Namoi, variability increases the more northern you travel. In 90% of fields investigated, the variability present was >2bales/ha and indicated management opportunity.

Variability over time: 1988-1998 (predicability).

Figure 5 illustrates a study where 11 years of Landsat yield estimate data was compared to see how predictable yield is from year to year. If the yield is consistently higher in one part of the field relative to another (year-in year-out), the multiple years of yield estimates may be useful to identify these regions and delineate potential management zones. These may be used to treat the best yielding areas differently to the poorer yielding areas. Analysis found that although you could make regions from all years of data, the yield patterns in a dryland (non-irrigated) year were distinctly different to the irrigated years. The most predictable management zones can be made if you use only good years to make a potential irrigated management plan and only dry years to make dryland management years. Typically it takes ~3-5 years of yield estimates to make a stable potential management zone map. The 11 years of yield estimates with average and standard deviation (s.d. or typical variability) in yield are illustrated to the left of figure 5 with the potential management zones illustrated to the right.

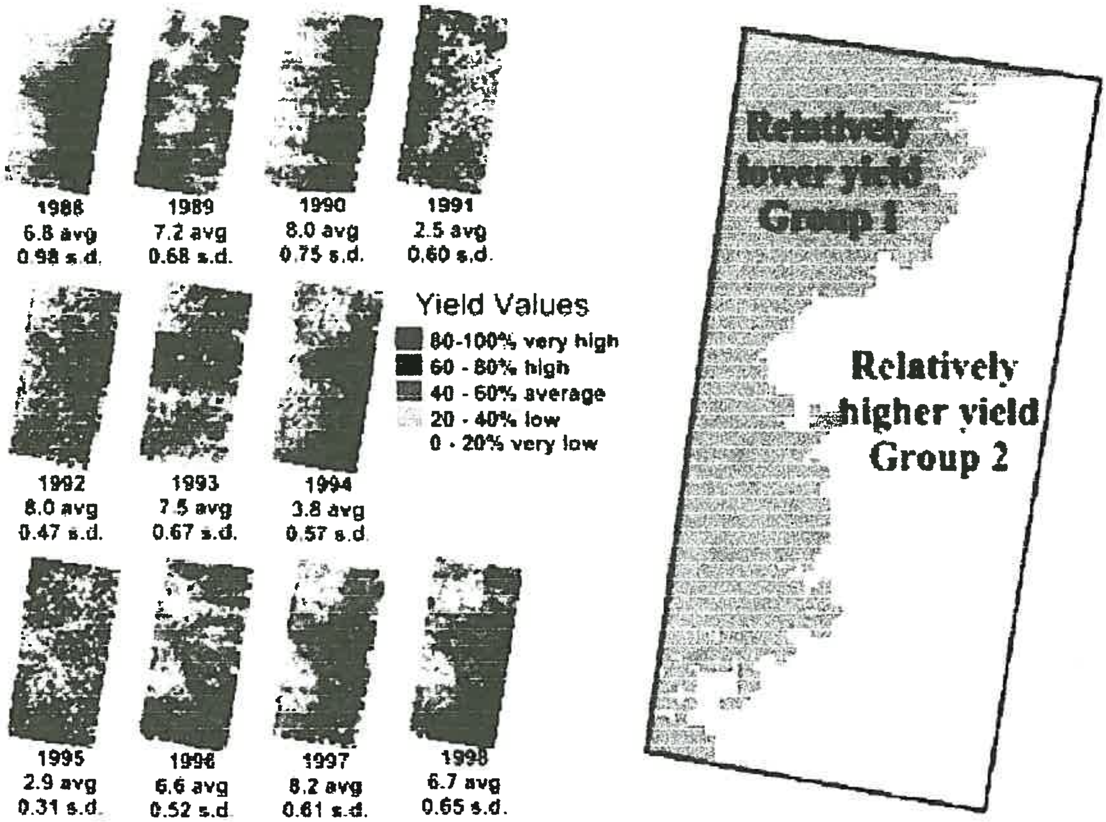


Figure 5 Historical yield data suggests that multiple years of yield estimates may be useful to identify regions in a field which is consistently higher or lower yielding that other regions. This information may be used to direct investigations and possibly to define potential management zones.

PART II: MANAGING VARIABILITY

In order to gain an advantage from quantifying yield variability within a field, a system then has to be implemented which uses this information to bring about either economic or environmental benefits or preferably both. For the Australian cotton industry an obvious place to start is with the application of nitrogen fertiliser. Nitrogen fertiliser rates are high (up to 200kg Ha^{-1}) and the potential for leaching of excess nitrates in the soil at the end of the cotton season is great. Additionally, customising fertiliser rates according to local requirement will reduce fertiliser costs as rates can then be reduced to consistently lower yielding regions within the field. To accomplish this with respect to fertiliser application, research has focused on two strategies. A 'nutrient budget' approach, which relies on intensive pre-sowing soil testing to replenish nutrients to essential levels. Obviously intensive soil sampling is not economically viable, but with the development of a field soil sensor mounted on machinery or through advancements in remote sensing technologies, predictions of pre-sowing nitrate levels will be accessible much more cheaply. In this scenario, the nitrate values could then be input into the NutriLOGIC component of CottonLOGIC to make site-specific nitrogen recommendations. An alternate approach has been to identify a series of homogeneous units within a field by combining a number of spatial data sources such as yield maps, soil maps and remotely sensed images. These homogeneous units are referred to as 'management zones', which basically represent regions of equal yield potential within a field. Fertiliser rates are then determined according to the expected yield of each zone.

Methods

Both these strategies were examined for irrigated cotton in Australia during the 1999/2000 growing season. Two sites were selected based on the variability in their yield map for the 1998/99 season. Field 28 on Auscott Midkin in the Gwydir Valley and field 5 on Oakville in the Namoi Valley. The trial areas in both cases were 100 hectares; this encompassed the whole field at Oakville and part of a 240-hectare field at Auscott. In addition to the yield map, a detailed electromagnetic (EM) survey was conducted using a mobile sensing system (Triantafilis and McBratney, 1998). This survey allows a prediction to be made on the soil texture and mineralogy variation present in the field, both of which influences yield. Using the yield map and the EM maps and also a Far Site image for field 5, 'management zones' were identified for each field using the statistical classification technique called hard clustering. This technique applies an algorithm to divide the data into cohesive groups for which the average value of each input data layer can be obtained for each zone. The number of management zones was thus decided by ensuring that all zones had at least a one-bale difference in average yield. Fertiliser rates were then determined for each zone after consultation with the farm agronomists (Figure 6).

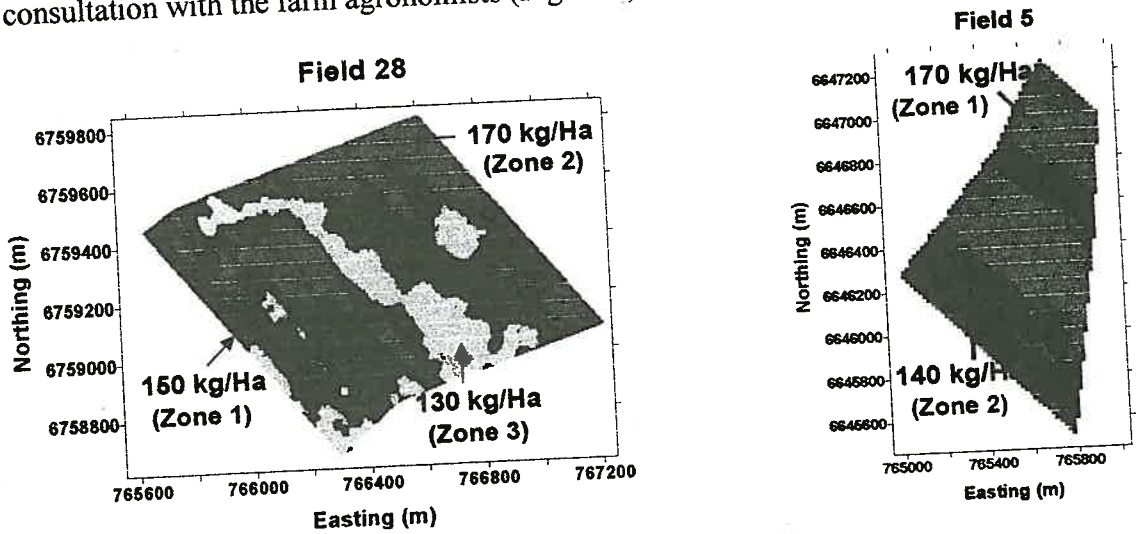


Figure 5 Management Zone fertiliser maps

To test the nutrient budget approach, six weeks prior to fertilisation 100 soil samples were collected from each field, with the percentage number of samples in each zone corresponding to the percentage area each zone occupied in the field. These samples were analysed for soil nitrate with the result input into the NutriLOGIC program to obtain an estimate of local fertiliser requirement. A map for the entire field was then generated by interpolating these 100 estimates using the VESPER program (Minasny et al., 1999) and is illustrated in figure 7.

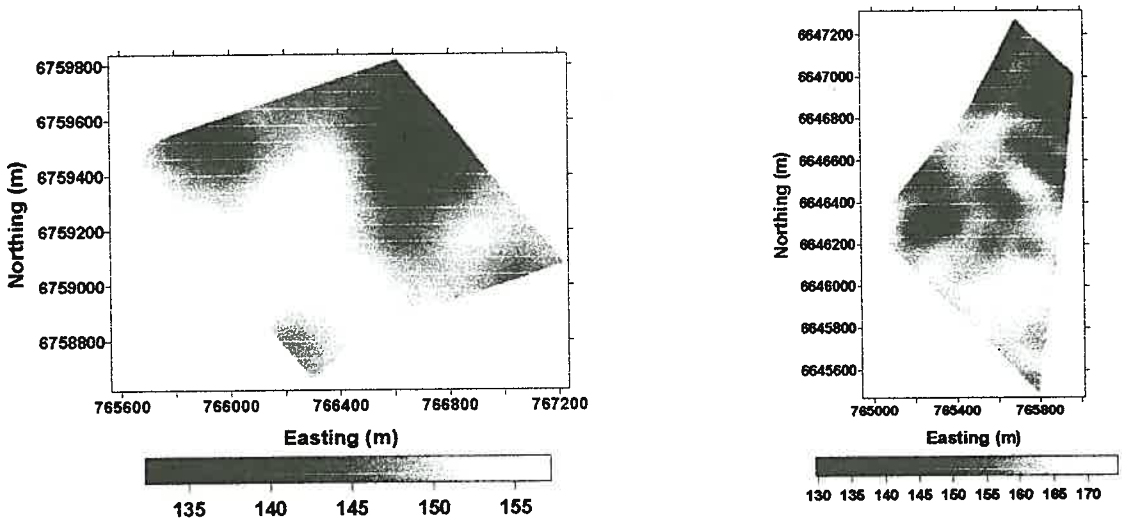
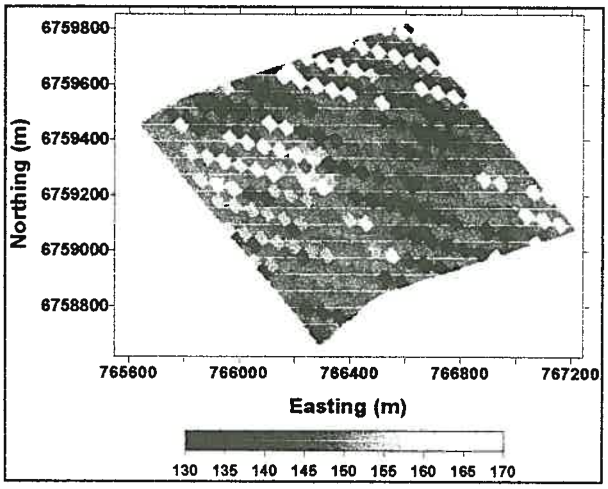


Figure 5 Fertiliser maps generated from soil sampling (N kg/Ha)

These treatments were then compared to the uniform application each field was to receive under normal circumstances, determined by the average NutriLOGIC recommendation at Auscott and the historical rate at Oakville. Including the uniform application map, this meant there was three separate application maps for each field, which were then numbered *A*, *B* and *C*. To compare the fertiliser treatments a 36 x 50 metre grid (approximately 560 plots) was placed over each field and the plots numbered one to three consecutively for the entire field. A single fertiliser application map was then generated by taking the value in the *A* map at the identical location to all the one numbered plots. Secondly the values corresponding in location in the *B* map to all the 2 numbered plots and similarly for the *C* map and all the 3 numbered plots (Figure 8). Fertiliser was then applied as anhydrous ammonia using a Vision System™ controller hooked into a DICKY-John™ Land Manager, which output the fertiliser on-the-go according to the generated map. During harvest both fields were yield monitored and the three treatments plots were then separated and the yields compared.



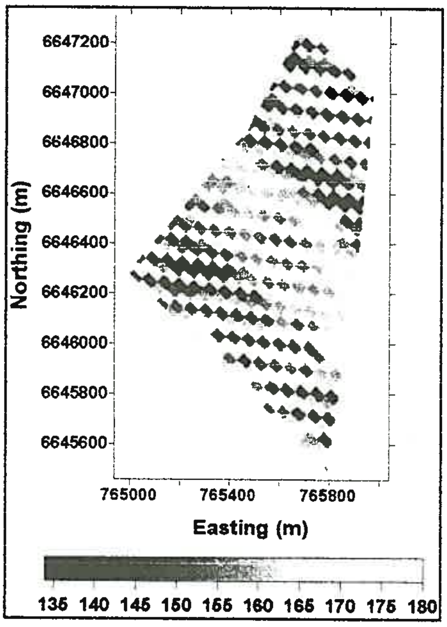


Figure 5 Amount of nitrogen fertiliser applied (kg/Ha)

Results

For each fertiliser treatment and management zone the average yield and fertiliser rate applied in kilograms per hectare and the amount of lint produced per kilogram of fertiliser is presented in tables 1 and 2. A direct comparison of the two variable-rate strategies against the uniform strategy gave no difference in yield between any of the treatments at both sites. Furthermore comparing the treatments within each management zone also gave no difference between the yields. However, this is not unexpected if the traditional fertiliser application rate is sufficiently or exceedingly high so that it is not limiting yield on any part of the field. As can be seen from the results from both fields, applying lower average fertiliser rates using a variable-rate approach did not reduce cotton yield. In fact for field 28 there was a negative response to fertiliser application down to the lowest rate (130 kg/Ha), while there was no response to fertiliser in field 5. This resulted in greater nitrogen efficiency at both sites.

Table 1: Comparison of treatments for Field 28

	ZONE 1	ZONE 2	ZONE 3	All Field
NutriLOGIC Uniform	2077[A] 150[B]	1807 150	2394 150	2072 150
	13.9kg Lint/ kg N	12 kg Lint/ kg N	16kg Lint/ kg N	13.8kg Lint/ kg N
NutriLOGIC Variable-rate	2076 149	1810 147	2404 148	2072 148
	13.9kg Lint/ kg N	12.3kg Lint/ kg N	16.2kg Lint/ kg N	14kg Lint/ kg N
Zone Rate	2071 149	1797 166	2406 134	2068 150
	13.9kg Lint/ kg N	10.8kg Lint/ kg N	18kg Lint/ kg N	13.8kg Lint/ kg N

A – average lint yield in kg/Ha for selected treatment
B – average fertiliser rate in kg/ha applied to selected zone for each treatment

Table 2: Comparison of treatments for Field 5

	ZONE 1	ZONE 2	All Field
Historical Uniform	1493 180	1452 180	1471 180
	8.3kg Lint/ kg N	8.1 kg Lint/ kg N	8.2 kg Lint/ kg N
NutriLOGIC Variable-rate	1486 159	1451 156	1466 157
	9.3kg Lint/ kg N	9.3kg Lint/ kg N	9.3kg Lint/ kg N
Zone Rate	1491 144	1458 167	1473 157
	10.4kg Lint/ kg N	8.7kg Lint/ kg N	9.4kg Lint/ kg N

The success of dividing the field into a series of management zones based on an estimated yield potential was very successful for field 28. Large yield differences occurred between the zones indicating that each zone does have different fertiliser requirements and thus should be managed accordingly. To adopt a zone-based strategy more than one season of data will ultimately be required to confirm these relationships are occurring temporally. This may have been the reason for the smaller difference in the yield at site 5. Once a field has been delineated into similar zones and fertiliser requirements relevant to a distinct zone have been determined, then the economic and environmental benefits from the variable-rate fertiliser application should be forthcoming.

FUTURE RESEARCH AND EXTENSION OF CURRENT RESEARCH

Precision weed management:

Following on from the two existing research programs into measurement of variability in cotton yield and management of this variability will be a new three-year Australian Cotton CRC project with Grant Roberts. Including a PhD studentship, this project aims to develop precision weed management techniques.

Software:

Research to date has identified a deficiency in the current software packages used on farm to organise and implement PA management techniques. Subsequently, operators incorporating PA into their management program will need to purchase software. The University of Sydney is currently comparing a number of software packages (including, AGRIS Aglink, Redhen Farm HMS, Kemira LORIS, SST toolbox, Farmworks, Pinpoint, PAM2000 and Hortfarm) with the aim to release a review of them to the Australian cotton industry by December 2000.

Precision Agriculture In the Australian Cotton industry Book:

The discussion paper "The Potential for Site-Specific Management of Cotton Farms" prepared by Brett Whelan and Alex McBratney for the Australian Cotton industry is being updated and a revised edition will be available early in 2001. Copies may be requested by sending an e-mail to: Cotton_PA@acss.usyd.edu.au including your contact details and mailing address.

Conclusions:

This research indicates that there is significant variability in yield (± ~2 bales/9ha) within most Australian cotton fields. This indicates potential for application of PA management techniques. There are now two methods of obtaining yield maps for determining the opportunity that may be derived in an individual field from PA. The first, proximal yield monitors (on-picker), appear to be capable of producing yield estimates to areas as small as 6m x 6m with an accuracy of ±3% so long as they are calibrated correctly. The second, satellite based Landsat yield estimates, are capable of delivering yield estimates which show the relative yield variability however are less successful at identifying actual yield (average errors of ~2bales/ha compared to field average). These estimates are for areas as small as 25m x 25m.

A suitable start-up approach to PA management appears to be "Zone Management", where areas of consistently higher or lower yield are identified in a field and managed differently. These zones are best created using yield maps along with soil measurements such as EM readings and traditional soil tests. These zones offer a significant improvement to uniform field management and should ultimately lead to improved economic return and a minimisation of unwanted environmental impact.

Further research is needed into PA management techniques with good opportunity for rapid results from efforts to implement site-specific weed management and a more thorough understanding of zone management and data handling to achieve this at the farm level.

References

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