PRECISION AGRICULTURE: MEASURING WITHIN-FIELD COTTON YIELD VARIABILITY.

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Introduction

Precision Agriculture (PA) involves the management of sites or regions within a field based on local requirements rather than field average requirements. Historical best management practice involves the careful determination of best average treatment for a whole field or farm. Where there is significant variability in the resources to which management is being employed within a field, "best" management must also be varied in order to accommodate local peculiarities. While awareness of within-field variability is not a recent phenomenon, the ability to accurately locate (using DGPS) and revisit sites in a field, for the purpose of conducting useful quantitative measurements or treatments is only a recent development. On-picker real-time yield monitors provide the opportunity to accurately measure cottonseed yield each second during picking. When this yield information is linked to a geographic location a yield map may be produced giving the grower or agronomist quantitative data for use in evaluating the degree of variability in a field.

In 1997, the CRC for Sustainable Cotton Production with funding support from the CRDC (CRDC project # US36c / CRC#5.2.1), initiated a project aimed at characterizing the spatial variability of cotton yield and investigating yield-influencing factors which may be managed in a PA farming system. This work follows a full statement of the potential of precision agriculture for the cotton industry presented by McBratney and Whelan (1985) who concluded that obtaining yield estimates is the first step to achieving the goal of precision management.

This paper presents some of the preliminary research findings and discusses the relative accuracy that may be expected from various yield measurement and yield estimation systems.

Obtaining information on yield variation within-fields

Accurate yield estimates within-field for cotton have traditionally been based on some form of relatively laborious boll-count or by careful segregation of a field into "module" sections during picking. Since the potential benefits which may be realized from the adoption of precision agriculture techniques, are based on the presence of yield variability and the subsequent measurement of the effect on yield of differential site specific remedial action, the ability to obtain a geo-referenced yield estimate or measurement is essential. There are

Thermal imagery

The simple basis of thermal plant mapping is that a plant loses the ability to transpire and remain cool when stressed. Reduced transpiration may come as a result of disease or insect stress however it is most commonly a result of water stress. As the soil root-zone dries out, so the ability of the plant to extract water is reduced. When water becomes limiting, plant stomata close and less water evaporates from the plant surface. This reduces the local evaporative cooling effect. A thermal sensor with a narrow field of view may then be "scanned" across the crop surface and the adjacent transects of emitted heat data compiled to generate a canopy temperature map. This map may reflect local soil water holding capacity or weed presence.

Results: Yield variability within fields in Australia 1997-98

Yield estimate accuracy

Yield monitors

Before any information can be trusted, its integrity must first be determined. During the 1997 and 1998 picking seasons a series of experiments were conducted aimed at evaluating the accuracy of picker yield monitors. These Australian results along with some international test results are displayed in Table 1.

Table 1 Summary of results from yield monitor accuracy tests.

Researcher (location)	Sensor type (light array)	Picker type	Average sample area (ha)	RMSE %	Accuracy in bales /Ha (% error by 8 bales/ha)
Boydell (Aust.)	Zycom	JD9965	0.5	2.5	+/- 0.2
Boydell (Aust.)	Zycom	CASE2055	0.12	15.7	+/- 1.2
Durrance[1](Ga,USA)	Zycom	JD9965	0.75	11.4	+/- 0.9
Durrance (Ga,USA	Micro-trak	JD9965	0.75	7	+/- 0.5
Wallace[1](Ms. USA)	Zycom	CASE 1-row	0.0003	12	+/- 0.9
Average	(light array)	All types		9.7	+/- 0.77

1. Calibration data from Durance 1997(University of Georgia) and Wallace 1997(Mississippi State Extension Service) was obtained via personal correspondence and is yet to be published.

Current results suggest that light array picker yield monitors are capable of predicting yield to within approximately 7% of the true value. It appears from field-testing that the most significant sources of errors are sensor failure and incorrect sensor calibration. Sensor failure is most often a result of the light array getting dirty and continuing to log inaccurate data without being cleaned. Careful operation of the system should minimize these errors since sensors are equipped with both a "blocked sensor" warning, and a function which allows the operator to verify array integrity prior to entering the crop giving him/her time to correct any problems. The second source of error, inadequate calibration, is a problem common to all yield monitoring (indeed all farm flow rate measurements) and is generally a function of logistics. In order to calibrate a yield monitoring system one must accurately weigh a mass of cotton for comparison with yield monitor estimates and for use in the calculation of a calibration coefficient (which is basically a ratio or counts per kg). The calculated calibration coefficient is possibly field and variety specific since only a count of locs delivered each second is made and not an estimation of their size. As a result of these variables, new calibration coefficients should be applied each time a significant change in variety or field condition is encountered. While a blocked sensor results in the addition of a largely un-removable error, the effect of a poor calibration is far less significant due to the fact that in this case, the error or "bias" may be removed once the "true" yield is revealed. Post processing of yield is based on the fact that there is a "linear" relationship between the sensor count variable and the true yield. Any error in estimating true yield is applied equally to each yield estimate which means that if post-picking records indicate estimates to be on average 7% high, the subtraction of 7% from each estimate should bring all estimates back in line. (An example of a cotton yield map is included as Figure 3.)

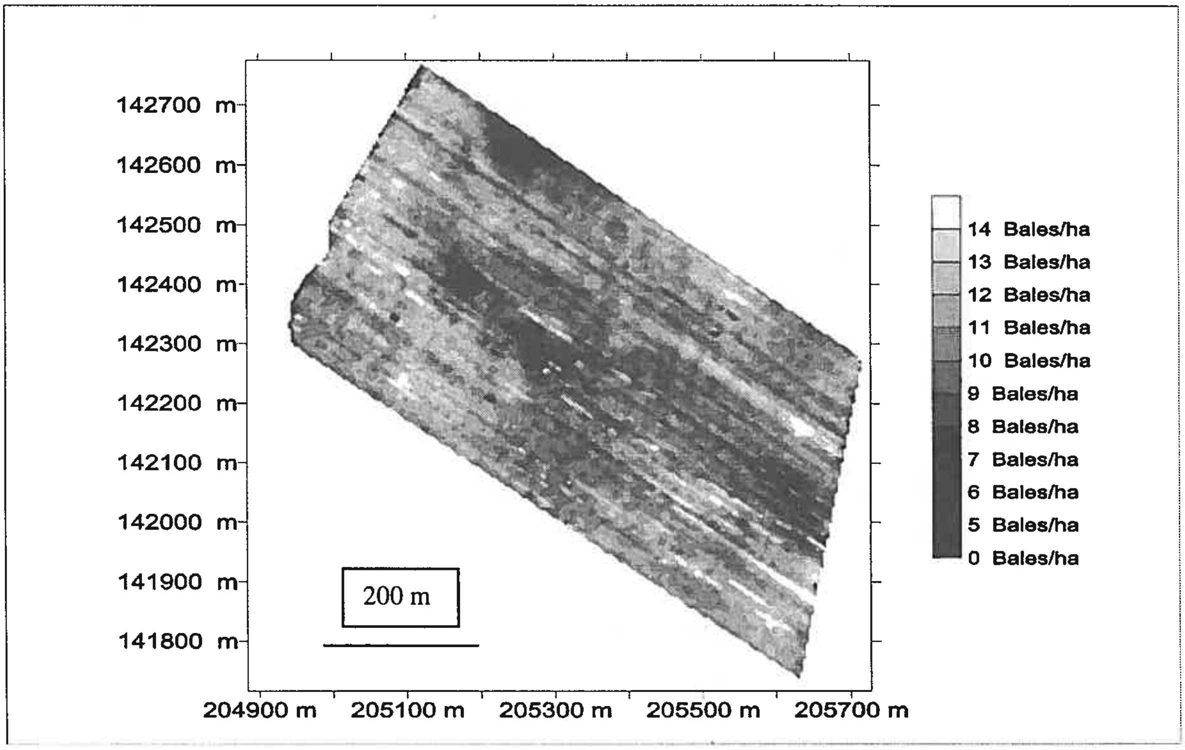

Figure 3 Cotton yield map for Field 28 "Norwood" 1998. Map generated from 78,000 yield monitor measurements.

The yield map in Figure 3 illustrates typical within-field variability patterns. Collected from the Gwydir valley near Moree, with a Zycom real-time cotton yield monitor, the darker regions (<6 bales/ha) appeared to correlate strongly with lighter coloured soil and heavy laser leveling cut actions. The lighter colours indicate high yields (>11 bales/ha) and generally corresponded to the dark soil where there was more often than not a fill action was performed during leveling. This yield correlation with soil colour appears to be similarly correlated with soil properties and management actions and was common across the fields mapped in 1998. Additional features of interest in this map are the presence of stripes running parallel to the top and bottom of the map borders. These correspond to the crop rows and subsequently the picking pattern. Lighter runs indicate higher yield and the colour differences illustrates between row yield differences. Black spots in the map indicate small regions (<40m^2) of catastrophic yield loss the cause of which is unknown but may be a result of such factors as establishment failure, local insect infestations, disease or lightening strikes.

Remote sensing

At the time this paper was submitted very little independent research had been conducted to determine the true accuracy of remotely sensed yield estimates. It is expected that more information on the quality of satellite based yield estimates will be available for presentation at the Australian Cotton Conference in August (1998).

Yield variability

Using the data from yield maps

While ultimately yield maps may be used as the "report card" for agronomists. Their initial employment should probably be to characterize variability in an attempt to evaluate the local potential for benefits from site-specific management. In order to perform this evaluation some consideration must be given to the question, "what sort of variability warrants precision management?" To this end it is worthwhile to look at within-field yield results from the 1997 and 1998 picking seasons and to compare the information that may be derived from various analysis using of traditional statistics and, as an alternative, some spatial statistics.

Traditional statistics as a measure of variability

Traditional statistics may be used to look at quantitatively how much variability is present in a typical cotton field. The results presented in Table 2 include two parameters; the mean yield, and the coefficient of variation (CV) of the yield. The average CV of 29.68 with an average yield of 7.08 bales/ha indicates that on average, for the fields investigated, 65% of the yields fell between 5 and 9.2 bales to the hectare. This is a typical spread of 2.1 bales to the hectare around the mean. In terms of opportunity this equates to plus or minus approximately A$1200[1] which appears to be a considerable one. The problem with traditional statistics however is that it fails to take into account location. While this variability appears to be very significant, if the highest and lowest yields are found in thousands of very small adjacent regions (e.g. melon-hole gilgai) it will be far less attractive as a management opportunity than if the variability were arranged into several distinctly different, but internally homogeneous, large regions. In order to get a measure of this "structure" one must implement spatial statistics.

[1] Based on a June 1988 cotton price or 600 Australian dollars per bale

Table 2 Traditional statistical analysis of within-field cotton yield variability as measured by real-time cotton yield monitors.

Valley	Field	Mean Yield	Coefficient of variation	Field area (ha)
Gwydir	ft10	8	22.68	22.68
Gwydir	ft11	7	30.97	30.97
Gwydir	fn28	9.93	33.29	33.29
Gwydir	fn6	7.1	34	34
Gwydir	fn7	7.6	28.9	28.9
Gwydir	fn8	8.9	23.3	23.3
Gwydir	fn9	10	33.9	33.9
Gwydir	fn22	6.3	28	28
Gwydir	fn26	9	43	43
Gwydir	fn25	9	33	33
Gwydir	fn14	8.2	21	21
Gwydir	fn3	5	38	38
Gwydir	Ala	5.7	23	23
Namoi	fto82	8.7	28.5	28.5
Menindee	ftn1	6.66	23.79	23.79
Average		7.08	29.68	29.68

Spatial statistics: To characterize and understand the extent of opportunity.

Generally, within a field, the yield at two points which are 5 m apart are more likely to be similar than would the yield from points which are 500 m apart. Spatial statistics retains location information when computing variability and may be used to give an indication as to how much variability to expect between sites over a given separation distance (range).

Table 3 Summary of results from spatial analysis of within-field variability data collected with real-time cotton yield monitors.

Valley	Field	Range (m)	Structure 67%	Structure 95% (bales/ha)
Gwydir	9	10	2.61	5.23
Gwydir	8	16	1.32	2.65
Gwydir	7	30	1.55	3.10
Gwydir	6	67	1.61	3.22
Gwydir	3	49	1.12	2.24
Gwydir	26	23	2.37	4.73
Gwydir	22	33	0.84	1.67
Gwydir	10	39	0.95	1.91
Gwydir	14	35	1.05	2.10
Gwydir	All1	39	0.85	1.71
Gwydir	t10	111	1.18	2.37
Gwydir	t11	217	1.73	3.46
Gwydir	n28	46	2.19	4.38
Namoi	t82	16	1.41	2.83
Menindee	Tf1	5	1.18	2.37
Average		49	1.47	2.93