

PRECISION AGRICULTURE:

Where are we Now and Where to Next???

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Precision agriculture (PA) as a crop management philosophy was first hypothesised in the early 1990's as a way of utilising the development of technology such as the Global Positioning System (GPS) and variable-rate crop applicators to produce crops in a more sustainable fashion. Historically, fields have been managed as homogeneous units, receiving equal amounts of crop production inputs. The rationale behind precision agriculture, or site-specific crop management, is that by identifying within-field variability in crop and soil attributes (e.g. cotton yield, soil nitrogen levels) and their origin, it then becomes possible to optimise crop production inputs such as pesticides and fertilisers on a point-by-point basis. Implicitly, this lowers the potential for the over- and under-application of these crop production inputs, thus increasing profitability for the grower whilst simultaneously reducing the probability of adverse environmental impacts such as groundwater or surface water contamination from the over application of agrochemicals. While progress in developing a fully integrated PA system has been slow over the past decade, research from a number of industries worldwide has highlighted there will be many benefits to be gained from adopting such a system. Secondly, further technological advances in airborne imagery collection, on-the-go sensor development and computer processing techniques means there is an unprecedented number of tools available to aid in crop management. Furthermore over the last decade it has emerged that each country and crop will have its own unique requirements within the larger framework of PA.

Where are we Now?

Research funded by the CRDC and CRC into adapting PA techniques to Australian cotton farming systems began at The University of Sydney in 1997. Over the last five years our

results have confirmed that there are many benefits to be gained from adoption of this technology.

Quantifying Yield and Soil Variability.

Our initial focus was to examine the accuracy and the reliability of the technology associated with estimating within field cotton yield. This began with an investigation into picker-mounted cotton yield monitors. After three years of testing and improvement of the yield monitors by the manufacturers the following conclusions were reached. The error from a single picker-mounted yield estimate is relatively large (~10%) for small sample sizes (~5kg), diminishing to 3 per cent as the sample size increases to 16kg. However, this error can be maintained at or below 3 per cent by using a two-dimensional block to represent yield created by averaging a number of neighbouring yield estimates. The ideal size would be dependent upon the cotton yield but typically 5 x 5 metres would be suitable for most Australian irrigated cotton fields. At this scale, you would get at least 270 yield measurements per hectare, excellent for mapping variability. Yield monitor reliability was found to be very good with the only problems caused by sensor performance failures attributed to the build up of dust or grime on the sensor eye. Improvements have been made by the manufacturers over past two years to minimise these problems.

An alternative source for estimating within-field yield variability that was also examined was the use of remote sensing. Using Landsat-7 TM satellite data (25 metre or 0.006ha resolution) it was possible to predict reliable and relatively accurate yield estimates to \pm one bale per hectare to one standard deviation. A comparative study between the picker-mounted yield monitor and satellite data indicated a greater range of the variability was explained by the picker-mounted data interpolated at the same resolution (0-14 bales) as compared (4 - 9 bales) to the satellite data.

Satisfied that this technology gave accurate data it was used in conjunction with traditional sampling techniques to quantify the degree of spatial variability of important variables within and between cotton fields. Our research has highlighted that this variation is indeed substantial and can occur over very short distances. Large variations in soil nutrient levels are common within single fields, which subsequently were reflected in cotton yields. Table 1 shows the pre-sowing variation of four important soil nutrients within five irrigated cotton fields determined by a soil sampling density of one per hectare within each field. The coefficient of variation (C_v) given in this table is a measure of relative dispersion and is simply the standard deviation of all samples divided by the overall mean of all samples. When the C_v is small, it says that a particular nutrient is occurring over a very small range of values, something you would expect if applying both nitrogen and phosphorus fertilisers in uniform quantities.

However, the values obtained for each of these fields are considered very large and indicate the supply of nutrients to the cotton plant is vastly different within different parts of the field. Similarly, the high variation reported for exchangeable sodium, which relates to the soil's ability to maintain good structure suggests that some areas of the field will be more prone to structural degradation than others. Further analysis showed the spatial variability of these properties is highly correlated with crop yield within each field.

Table 1: Coefficient of Variation (%) of Selected Soil Properties within 5 Irrigated Cotton Fields⁺

Location and Field Size	Nitrate	Phosphorus	Potassium	Exchangeable Sodium %
Collarenebri 140 hectares	47	66	21	38
Telleraga 80 hectares	41	70	23	70
Ashley 75 hectares	42	119	22	42
Ashley 100 hectares	44	88	22	36
Narrabri 100 hectares	46	18	15	33

⁺ Sampling density equaled one per hectare.

The impact these and other factors is having on cotton yield was highlighted by a study assessing yield variability across three of the major cotton growing valleys conducted in 1999/2000. Using remotely sensed yield estimates from Landsat-7 TM data, calibrated using picker-mounted yield monitors, it was possible to quantify the degree of yield variability in 273 cotton fields encompassing 27 000 hectares across the Gwydir, Upper and Lower Namoi Valleys. The results of this study are presented in Table 2. In all three valleys analysis indicated the average cotton yield of just over 6 bales per hectare was likely to vary by ± 1.6 bales per hectare over a *range* of only 270 metres. The *range* indicates the maximum distance at which you expect to find a relationship in yield at two different points. Therefore, you would expect to find this yield difference occurring within just a 9-hectare area of the field. These results are similar across each of the three valleys investigated. When we consider this variation over an entire field it is not surprising that yield maps for an average size cotton field can show up to an 8 bale per hectare difference between the lowest and the highest yielding parts of the yield. Another study (Boydell et al., 2000) of 11 years of consecutive cotton of three neighbouring fields in the western Gwydir valley indicated that although the magnitude

of variability is large for single fields over numerous seasons, the range at which this variability occurs is reasonably stable.

Table 2: The average cotton yield variability and the range over which it is occurring within 3 valleys for the 1999/2000 season.

Valley	Average Yield (bales/ha)	Lowest Yield (bales/ha)	Highest Yield (bales/ha)	Range of variability (m)
Gwydir	7.12	5.23	9.01	295
Lower Namoi	6.66	4.98	8.33	285
Upper Namoi	5.04	3.57	6.52	217
All	6.33	4.63	8.03	267

Managing Variability.

Having identified significant variability in both cotton yield and soil properties within single fields, attempts were made to manage this variability, with a particular focus on nitrogen management. Our research in this area has shown that at this point of time, management can be improved by dividing a field into a series of 'management zones' based on their yield potential. Each 'zone' represents areas of the field that can be expected to produce comparable yields due to similarities in factors such as soil properties. This usually results in between two and four different zones for the average size field. From this each zone receives a specific rate of fertiliser or other input based on the expected yield of that zone. Nitrogen rate trials conducted on a number of fields using this 'zone' strategy has shown that the overall application of nitrogen could be reduced by up to 15 per cent without diminishing yields. Not only does this result in monetary benefits to the producer but also improves the sustainability of these systems by preventing the excess release of unused fertiliser into the environment.

Meaningful management zones can be determined from a number of sources such as multi-spectral data collected from satellites or aeroplanes, picker-mounted yield monitors, digital elevation models (DEMs) and soil-sensing techniques like electromagnetic induction (EM). They can be created using only a single data layer or from the combination of any number of these sources. An example was described in the previous proceedings (Boydell et al., 2000) of using 11 years of remotely sensed yield estimates. This showed that the yield

patterns are reasonably consistent from year-to-year, and that stable yield patterns could be predicted from two to four years' of yield estimates data. An equally simplistic approach that provides the grower with a starting point to begin a simple zone management strategy is the use bare soil colour maps. As agricultural field boundaries are seldom designed to follow soil type, a major cause of yield variation is due to differences in soil type within fields. For example, Figure 1 illustrates two yield maps for the 2000 and the 2001 season. In spite of there being approximately a two bale per hectare difference in the average yield for the field between the two seasons, the high and low yielding areas are in similar parts of the field. Further investigation of this field showed that yield was related to soil type. Beginning in the top right-hand corner of the field is a coarser-textured soil that meanders diagonally through the field. This pattern is evident on the yield maps. Figure 2 shows the management zones derived for this field using soil colour to distinguish between soil types. Subsequent soil testing of each zone highlighted different properties in terms of plant available nutrients and the soil water-holding capacity. In the higher yielding areas there was much higher levels of phosphorus, while nitrogen levels were significantly lower prior to fertilisation as a consequence of the higher yields from the season before. Benefits would be forthcoming from applying different levels of both nitrogen and phosphorus to each zone within the field. The application of the fertiliser itself is very easy using variable-rate technology that uses GPS to adjust the rate based on location from a pre-made map.

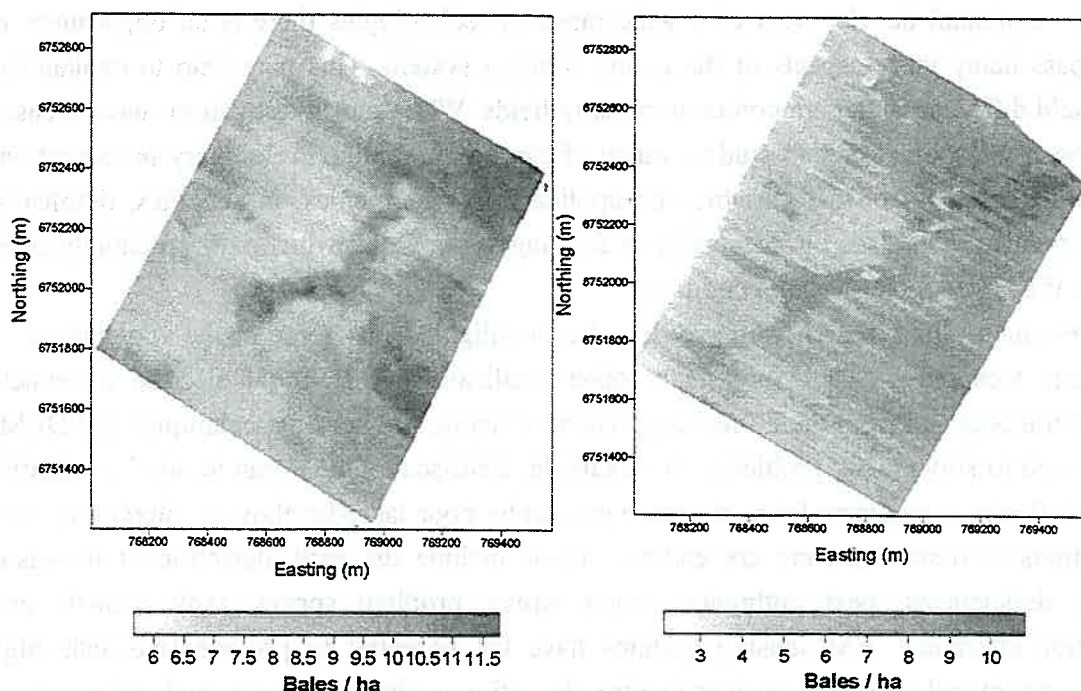


Figure 1: Yield maps from 2000 (left) and 2001 highlighting the temporal stability of yielding patterns within cotton fields.

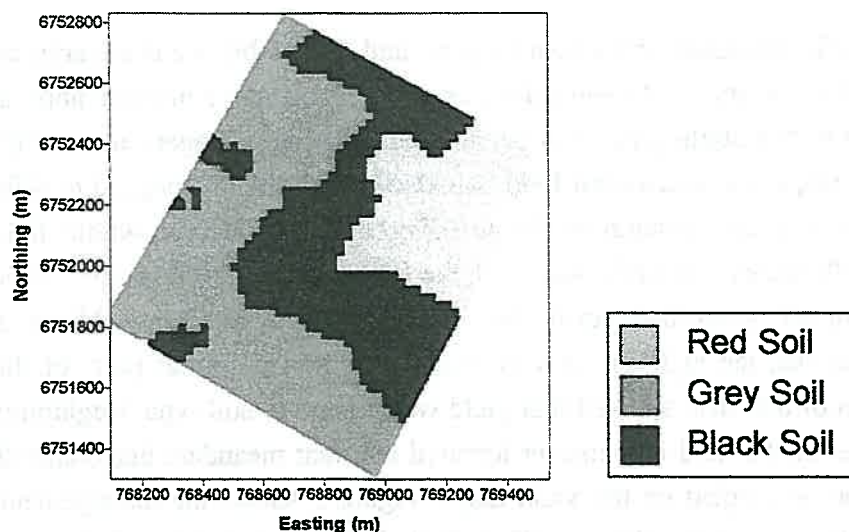


Figure 2: Management zone map for input application based on soil colour.

Where to Next?

The study results have shown there is significant within-field yield variability and that the technology to measure it is adequate, even for small areas or sample sizes. Secondly, that yield patterns are relatively stable and can be predicted using a number of different sources. With the continual development of a wide range of technologies there is an opportunity to encompass many more aspects of the cotton farming system. This may help to explain the large yield differences that are common in many fields. While our investigations have focused on nitrogen the scope exists to study a range of agronomic inputs. Preliminary investigations have begun overseas on the variable-rate application of herbicides, insecticides, defoliants, growth regulators and seed to a number of farming systems, all which will potentially offer benefits if adapted to Australian conditions.

Furthermore, the research we have done has highlighted just some of the applications of using this technology. There are many other applications that could also be examined. Information obtained from yield mapping, remote sensing, soil sensing techniques and DEMs can be used to solve many problems. For example, field-scale DEMs can be used to identify localised flooding problems from irrigation caused by poor laser-leveling or 'slumping'. The applications of remote sensing are endless. These include the early detection of in-season nutrient deficiencies, pest outbreaks, water stress, problem sprays, rank growth, and defoliation efficiency. EM sensing systems have the potential to provide fine-scale high quality maps of soil properties such as texture, the cation-exchange capacity and soil moisture. Post-season, a yield map can be utilised for targeted sampling of problems regions within a field to correct localised deficiencies or take non-productive areas out of cotton.

Additionally research needs to use these tools to quantify the degree of temporal variation present in different aspects of cotton farming systems. This variation for agronomic inputs such as nitrogen appears to be of a greater magnitude and harder to deal with than the spatial variation. The incorporation of this into a PA system will improve these recommendations in the future. Our key findings and recommendations will be published in a monograph (Boydell, Stewart, McBratney) which is now in preparation.

Having demonstrated the reality of variation of yields within fields and from season to season, and the potential of economic and environmental benefits from this relatively easily obtainable information, we now need to develop an implementation strategy, involving the Industry Development Officers for the cotton industry. We also need research to tackle some key agronomic questions site-specifically, especially weed control and irrigation management; and the whole area of lint-quality mapping within fields needs to be opened up. The Grains Research and Development Corporation (GRDC) are now beginning a 5-year Strategic Initiative in Precision Agriculture, funded at around \$1.5 m per annum, aimed at research and implementation. We feel the cotton industry, through the CRDC and CRC, needs a similar initiative generally, especially for irrigated cotton, and some formal collaboration with the GRDC program for the dryland crop.

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The first of these is the fact that the number of people who are employed in the service sector has increased significantly in recent years. This is due to a number of factors, including the fact that the service sector is becoming increasingly important in the economy, and the fact that the service sector is becoming increasingly important in the lives of people.

Service Sector

The second of these is the fact that the number of people who are employed in the manufacturing sector has decreased significantly in recent years. This is due to a number of factors, including the fact that the manufacturing sector is becoming increasingly important in the economy, and the fact that the manufacturing sector is becoming increasingly important in the lives of people.

Manufacturing Sector

The third of these is the fact that the number of people who are employed in the agricultural sector has decreased significantly in recent years. This is due to a number of factors, including the fact that the agricultural sector is becoming increasingly important in the economy, and the fact that the agricultural sector is becoming increasingly important in the lives of people.

Agricultural Sector

The fourth of these is the fact that the number of people who are employed in the construction sector has decreased significantly in recent years. This is due to a number of factors, including the fact that the construction sector is becoming increasingly important in the economy, and the fact that the construction sector is becoming increasingly important in the lives of people.

Construction Sector

The fifth of these is the fact that the number of people who are employed in the health sector has decreased significantly in recent years. This is due to a number of factors, including the fact that the health sector is becoming increasingly important in the economy, and the fact that the health sector is becoming increasingly important in the lives of people.

Health Sector

The sixth of these is the fact that the number of people who are employed in the education sector has decreased significantly in recent years. This is due to a number of factors, including the fact that the education sector is becoming increasingly important in the economy, and the fact that the education sector is becoming increasingly important in the lives of people.

Education Sector

The seventh of these is the fact that the number of people who are employed in the social services sector has decreased significantly in recent years. This is due to a number of factors, including the fact that the social services sector is becoming increasingly important in the economy, and the fact that the social services sector is becoming increasingly important in the lives of people.

Social Services Sector

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Public Sector