

## **Opportunities for improving the management of sugarcane production through the adoption of precision agriculture – An Australian perspective**

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### **Abstract**

Precision Agriculture (PA) is an all-encompassing term given to a suite of technologies which promote improved management of agricultural production through recognition that the potential productivity of agricultural land can vary considerably, even over very short distances (a few m). The key technologies involved are yield monitors, the global positioning system (GPS) and geographical information systems.

This paper provides an overview of PA, in terms of the philosophy driving its current adoption by other industries, reviews the results of two seasons of sugarcane yield mapping in the Herbert River district of Australia and, drawing on recent research on the application of PA to winegrape production, identifies opportunities for improving the management of sugarcane production through the adoption of a more precise approach. It is concluded that sugarcane production is ideally suited to the adoption of PA, but that for this to be successful, significant changes to current (Australian) practices may be required, especially with respect to harvest management.

### **Résumé**

Le terme Agriculture de Précision (AdP) englobe tout un ensemble de techniques destinées à améliorer la gestion de la production agricole. L'AdP est fondée sur une reconnaissance des variations considérables que peut connaître la productivité potentielle des terres agricoles, même sur de très courtes distances (quelques mètres). Les techniques-clés de l'AdP sont les moniteurs de rendement, les systèmes de positionnement géographique (SPG) et les systèmes d'information géographique.

Cet article présente une vue d'ensemble de l'AdP en identifiant les raisons de son adoption dans d'autres secteurs. L'article résume aussi des résultats de cartographie de rendement de canne à sucre obtenus pendant deux saisons dans la région de la Rivière Herbert (Australie); et, à la lumière de recherches récentes sur l'utilisation de l'AdP dans la production du raisin de cuve, identifie des pistes pour améliorer la gestion de la production de la canne à sucre par l'adoption d'une approche plus précise. Nous en concluons que la production de la canne à sucre s'avère un candidat idéal à l'adoption de l'AdP. En revanche, afin que cela réussisse, il faudra peut-être apporter des modifications significatives aux pratiques courantes (en Australie), tout particulièrement en ce qui a trait à la gestion des récoltes.

**Keywords: Yield Mapping, Spatial Variability, Process Control, Targeted Management, EM38 Soil Survey**

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<sup>2</sup> Ray Quabba died suddenly, and much too young, in late 1999. Amongst many ideas that Ray had, both for his own farm and the Australian sugar industry as a whole, was the vision of a production system in tune with the land supporting it. He saw PA as a tool to assist in achieving this, was an early adopter of yield mapping technology, and an eager participant in the early research on the application of PA to sugarcane production – much of which is described in this paper. He is included as a co-author of this paper with the permission and support of his wife.

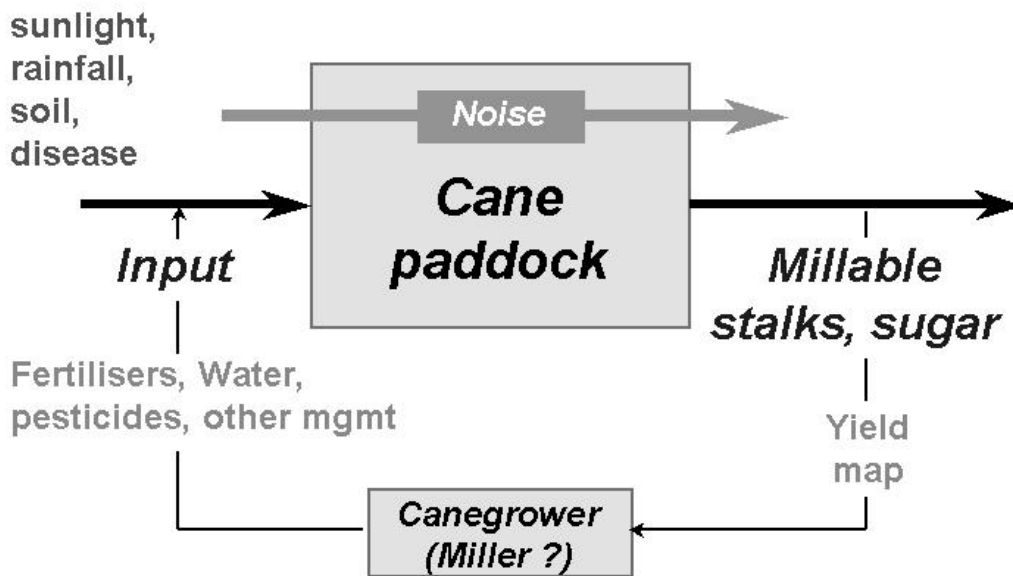
## Introduction

Precision agriculture (PA) is neither new nor complicated (Rawlins, 1997); it has been practiced in the dairy industry for many years, with cows producing a full bucket of milk being given a full scoop of grain at milking, and those producing half a bucket only getting half a scoop. In Australia, as in the USA, the initial interest in PA has been in the grains industries; several Australian farmers have now been yield mapping for 8 years (Cook and Bramley, 2001) and over 1000 headers with yield monitors fitted have been sold in Australia. Indeed, were it not for the simultaneous collapse of the world sugar price and some very wet low yielding years at the end of the last millennium, it is possible that the Australian sugar industry might, by now, be seeing widespread use of yield mapping (Cox *et al.*, 1996; Harris and Cox, 1997) and other PA technologies (see Bramley *et al.*, 1997 and the references therein for a review) - and there might not be much demand for this symposium ! As it is, the industry is at much the same stage as it was over 4 years ago when a similar symposium was held in Townsville (Bramley *et al.*, 1997, 1998). However, canegrowers do now have the benefit of being able to learn from a broader range of experiences of other industries (eg. cotton, wine) in addition to those of the early adopters growing cereals. This paper aims to provide a brief overview of PA and, drawing from recent research, including two seasons of cane yield mapping in the Herbert River district of Australia (Bramley, 1999), seeks to illustrate the potential of PA for improving the management of sugarcane production.

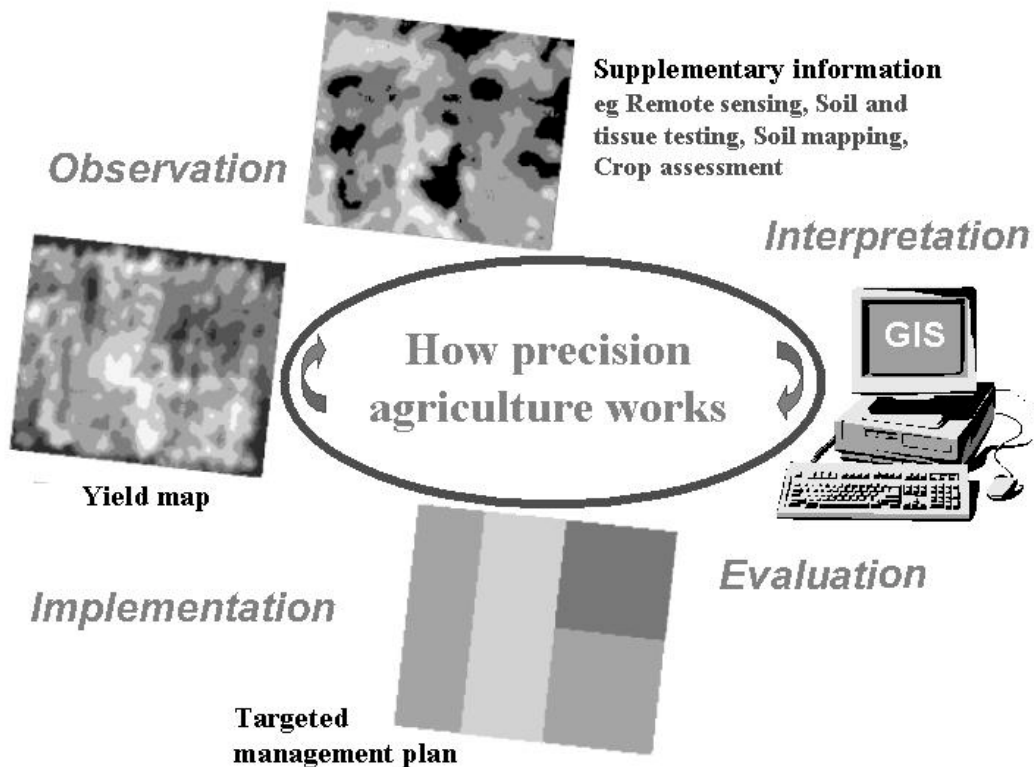
## Precision Agriculture, Process Control and Targeted Management

The philosophy behind PA and the tools on which it depends have been discussed widely elsewhere (eg Bramley *et al.*, 1997 and references therein; Cook and Bramley, 1998). In summary, it is recognised that land, and therefore its potential productivity, is inherently variable to the extent that the input-output relationships driving the production system (Figure 1) can vary, often over distances of only a few m (Cook and Bramley, 2000; McBratney and Pringle, 1999). By better understanding these relationships, and through the use of tools such as yield monitors and remote sensing (eg Lamb, 2000), which enable farmers to see within-paddock variation, management strategies may be implemented in which the inputs to the production system are closely matched to the desired and/or expected outputs (Figure 2). In other words, through the adoption of PA, a grower increases the likelihood of a beneficial outcome by better targeting of inputs (Cook and Bramley, 1998). Note that whilst 'inputs' are often taken to infer fertilisers, they also include irrigation water, pesticides and significantly, the timing of operations such as harvesting. In the case of sugarcane production, they could also include the use of chemical ripeners, or of dual row or high density planting as opposed to single rows at 'standard' intervals.

Figure 2 illustrates an example from the wine industry in which a 7.3 ha block of Cabernet Sauvignon in the Coonawarra region of South Australia was harvested over 3 years (1999-2001) with a mechanical grape harvester fitted with a yield monitor and differentially corrected GPS (dGPS). The pattern of yield variation was found to be sufficiently consistent over the 3 years to warrant production of a composite yield map and this was interpreted with the assistance of supplementary information – in this case, the results of a survey of bulk electrical soil conductivity using an electromagnetic (EM38) sensor, which Bramley *et al.* (2000) demonstrated to be a surrogate for soil depth variation in the *terra rossa* soils of the Coonawarra. This information promoted the development of a targeted harvesting strategy in which fruit from different parts of the block were separated into different bins for separate fermentation. Cox *et al.* (1997) and Cox (1997) describe a somewhat similar situation with respect to the targeted application of gypsum to a 100 ha sugarcane paddock in the Burdekin



**Figure 1.** Sugarcane production as a partially controllable input-output process. Whilst some things cannot be controlled (eg the incidence of sunlight) resulting in some *noise* in the system, many of the inputs may be controlled, and with the feedback information provided by the yield map, these may be controlled differentially and with greater certainty of achieving desired outcomes than is possible at present under a uniform system of management.



**Figure 2.** The process of precision agriculture.

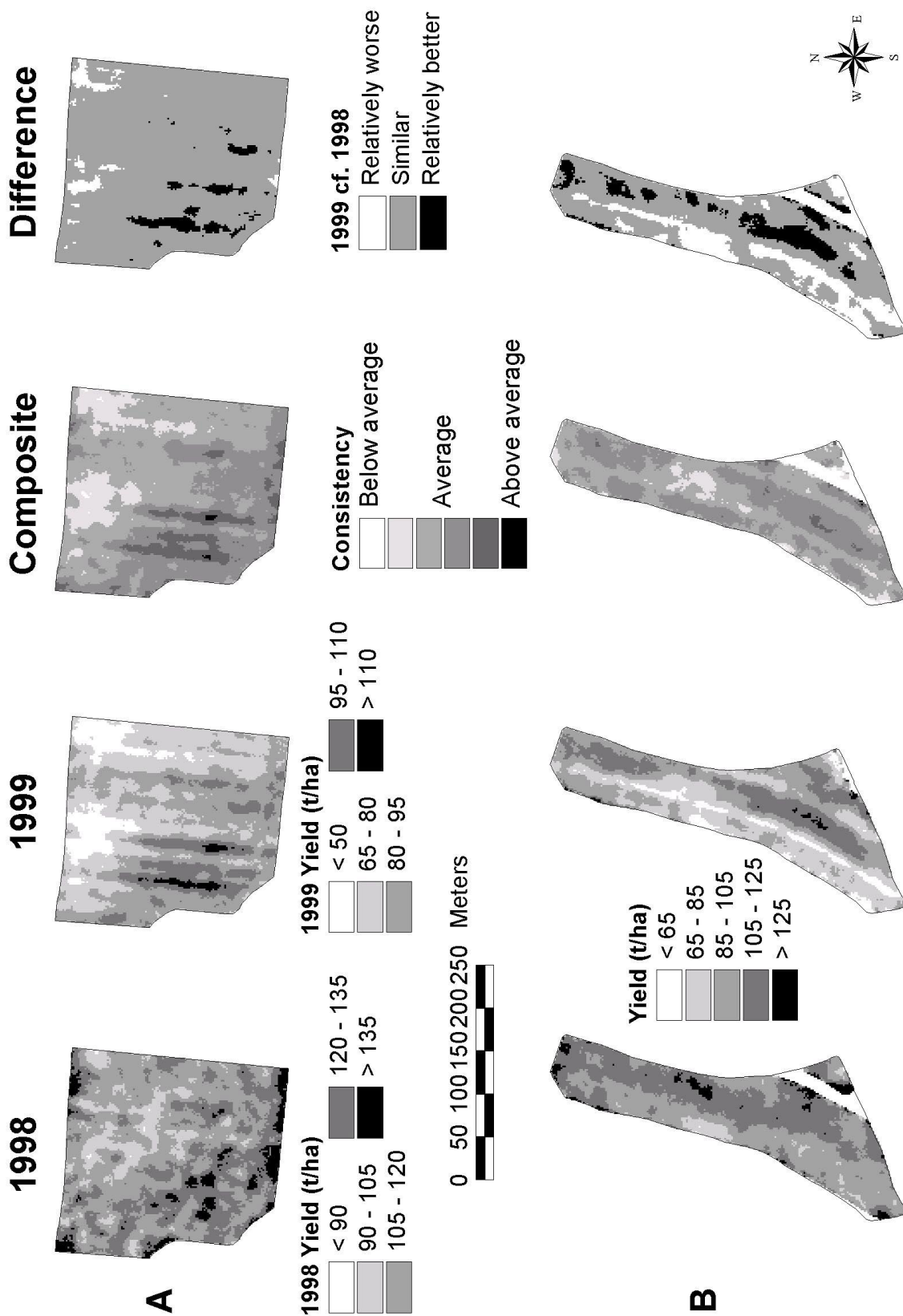
that was variably affected by soil sodicity. Note that the process of PA is cyclical (Figure 2), and so the efficacy of a targeted management strategy may be evaluated and, if need be, refined in future years on the basis of subsequent yield maps and/or additional supplementary information. Thus, PA lends itself to incremental, as opposed to immediate adoption; clearly, having at least *some* information about the production system is better than having none. Note also that conventional wisdom accumulated in the broadacre grains industries suggests that about 5 years of yield data may be needed for the identification of *management zones* warranting differential treatment, although the availability of historical remotely sensed imagery may assist in shortening this period (Dr RJ Corner, Curtin University of Technology, Perth – pers. comm.).

The implementation of a PA approach to agricultural production is analogous to the idea of *process control* as employed in manufacturing industry. Cook (1997) noted that one of the fundamentals of business management is that continuous improvement is necessary to maintain competitiveness in an international market. Muchow *et al.* (2000) made a similar observation, as did Kaydos (1991) who suggested that permanent product improvement only occurs when the production process is itself changed. Thus, PA provides a suite of tools that may assist in improving the production process and, as a consequence, the product; they promote the capacity for growers to acquire detailed geo-referenced information about crop performance and to start using this to tailor production according to expectations and desired goals in terms of yield, quality and the environment.

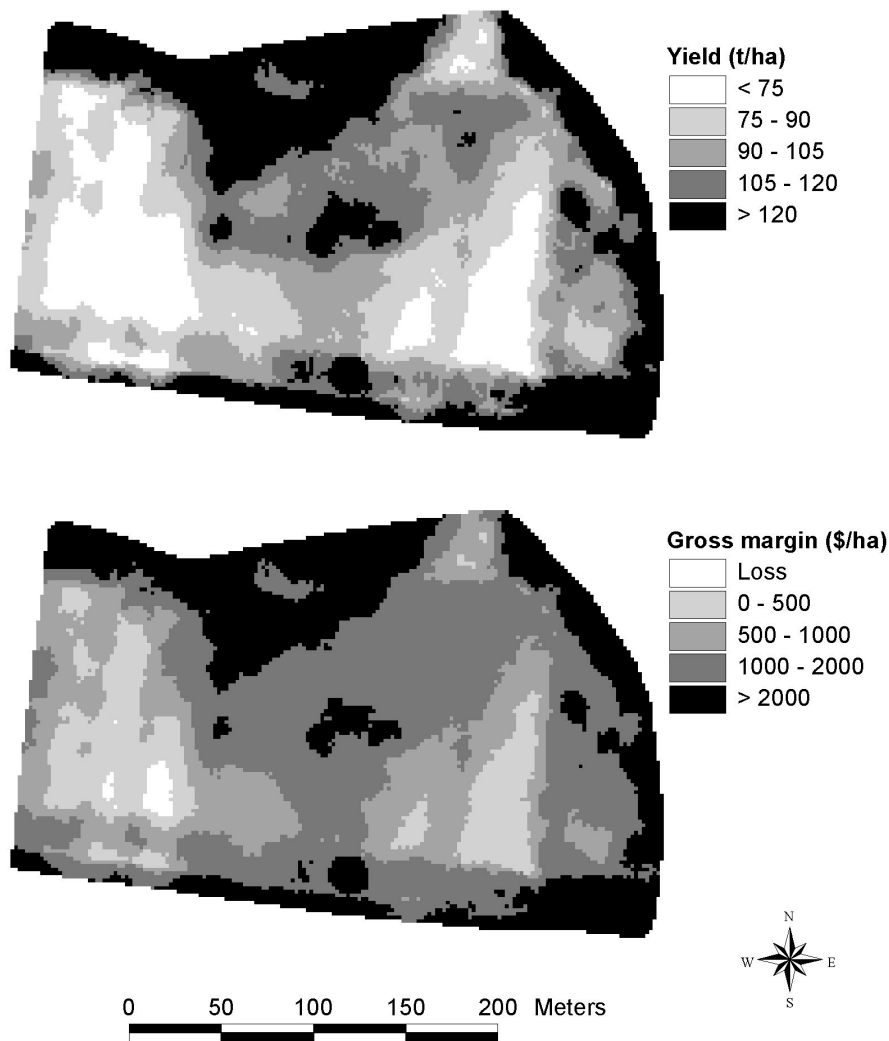
### **Experiences with sugarcane yield mapping**

During the 1998 and 1999 crushing seasons, sugarcane on the Quabba-Russo farms in the Herbert River district was harvested using a Cameco harvester fitted with a dGPS and a prototype cane yield monitor (Cox *et al.*, 1997) supplied by the National Centre for Engineering in Agriculture (University of Southern Queensland) and Pivot Agriculture. Data were collected on a ruggedized laptop computer which was installed in the harvester cab (Bramley, 1999). Teething troubles notwithstanding, use of the yield monitoring system had no impact on harvester operation and to all intents and purposes, harvesting proceeded as normal.

Figures 3 and 4 illustrate yield variation in three blocks which were growing either 1<sup>st</sup> or 3<sup>rd</sup> ratoon cane in 1998. Given the high density of data obtained from the sugarcane yield monitor, which recorded yield and position at 1 second intervals as it moved along rows only 1.5 m apart, it was considered that interpolation of a yield surface using simple moving averages was unlikely to be inferior to a more sophisticated interpolation methodology such as kriging. The latter has been used, for example, in grape yield mapping (eg Figure 5) which involves less frequent data logging and row spacings that are typically 3 m (ie twice the cane row spacing). Subsequent analysis demonstrated a moving average approach to be satisfactory. However, in order to account for the difference between the row spacing and the variation in the distance travelled by the harvester in 1 second (typically 2.5-3.5 m), we decided to base the search window used for calculation of the moving average on a fixed radius rather than a fixed number of observations. Through trial and error, we found a search radius of 8 m to give results that were appropriate in terms of map resolution and grower estimates of the minimum area within a cane block for which the potential use of variable rate fertiliser equipment might be considered. Thus, any given pixel in the yield surface represents the mean of the recorded yield values obtained within a circle of 16 m diameter centred on



**Figure 3.** Yield variation in two Herbert River sugarcane blocks in 1998 and 1999. Yields in 1999 (4<sup>th</sup> ratoon) were substantially down on those in 1998 (3<sup>rd</sup> ratoon) following a very wet season; for block A, the mean yields were 118 and 82 t/ha in 1998 and 1999 respectively, whilst in block B, they were 106 and 90 t/ha. However, analysis of the patterns of variation (see text for explanation) suggests that these were broadly consistent over the two years in block A, but quite dissimilar in block B. The analysis nevertheless supports the view that several years of data will be needed for management zones to be identified with confidence.



**Figure 4.** Yield and gross margin achieved in a block of 1<sup>st</sup> ratoon sugarcane in 1998.

that pixel. This is equivalent to averaging over approximately 10 rows. The results were projected onto 2 m grids (ie each pixel = 4 m<sup>2</sup>).

In Figure 3, data are presented for both 1998 and 1999 together with an analysis of the degree of consistency of the pattern of spatial variation (see below), whilst Figure 4 indicates the effect of yield variation in 1998 on the gross margin achieved by a uniformly managed crop of 1<sup>st</sup> ratoon cane. As can be seen, yield variation may be expensive, with much of the block providing unsatisfactory returns (some even operates at a loss) compared to more profitable areas only a few m away. This observation, together with the finding that the range of variation in cane yield (coefficients of variation (CV) of the order of 30-45 %) is similar to that for a range of other crops for which yield monitoring equipment is now commercially available (eg Pringle *et al.*, 2000), supports the view that PA has the potential to offer canegrowers a means of improving production. Another way of looking at this is that, if a block of sugarcane gives a mean yield of 100 t/ha with a CV of 35%, assuming that yield is

normally distributed within the block, it can be expected to vary from 30 to 170 t/ha. Clearly, with such a range of variation, uniform management strategies are unlikely to be even close to optimal over significant proportions of sugarcane blocks. Note, however, that CVs make no distinction between spatial variation and variation due to other factors (noise, measurement error etc...) which is why Pringle *et al.* (2000) have proposed an *opportunity index* as a basis for assessing the merits of adopting PA on a block by block basis.

Of course, the merits of trying to tailor management to areas of different productivity is dependent to a large extent on the temporal stability of the pattern of spatial variation. Notwithstanding the conventional wisdom that 5 or more years of yield data may be needed for the delineation of so-called *management zones*, Figure 3 presents an analysis of the consistency of spatial variation in yield obtained in 1998 and 1999 similar to that used to determine that the winegrape yield variation shown in Figures 2 and 5 was constant in time. In this analysis, yield data for each year were normalised ( $\mu = 0, \sigma = 1$ ) and used to produce “composite” and difference maps (Figure 3). Analysis of the variance ratio between these maps shows that the degree of consistency between the two years is significant ( $p < 0.001$ ) in the case of block A, but that there is no significant ( $p > 0.05$ ) similarity between the two years in the case of block B. Given that 1999 was a very poor year, with yields markedly reduced as a consequence of very wet growing and crushing seasons, this result reinforces the fact that a grower would be unwise to begin devising and implementing targeted management on the basis of only two years of data.

The effects of the wet growing conditions are seen in the yield maps for both blocks A and B (Figure 3) in terms of the “stripiness” apparent in the 1999 maps. These strips correspond to the separation of the block into a number of beds separated by furrows, a drainage management strategy that was widely used in the Herbert River district in the days before laser-guided land levelling. Indeed, many of these furrows remain, whilst some have been filled in as a consequence of laser levelling. Low yields aligned with these furrows presumably indicate the effects of extended periods of water-logging either side of them, whilst higher yields were achieved on the slightly higher ground in the central portion of the block (Figure 3). Note also that the generally lower yields along the western side of block B were ascribed to the combined effects of the shading of afternoon sun due to the steep hillside abutting the block to the north and west, and the delivery of surface water from this hillside onto the block. The lowest yielding area on the western side of the block which shows up clearly in the 1998 map, corresponds to an area that had been extensively “dug over” for the removal of large stones and boulders, causing significant disturbance of topsoil and exposure of subsoil.

### **Lessons to be learned from other industries and opportunities for sugarcane production**

Precision agriculture is not just about yield mapping; other tools such as remote sensing (from satellites and/or aircraft; eg. Lamb, 2000), EM38 soil survey (Bramley *et al.*, 2000; Evans, 1998; Williams and Baker, 1982), and digital elevation models are also important sources of information about paddock variability that can assist in understanding variable crop performance.

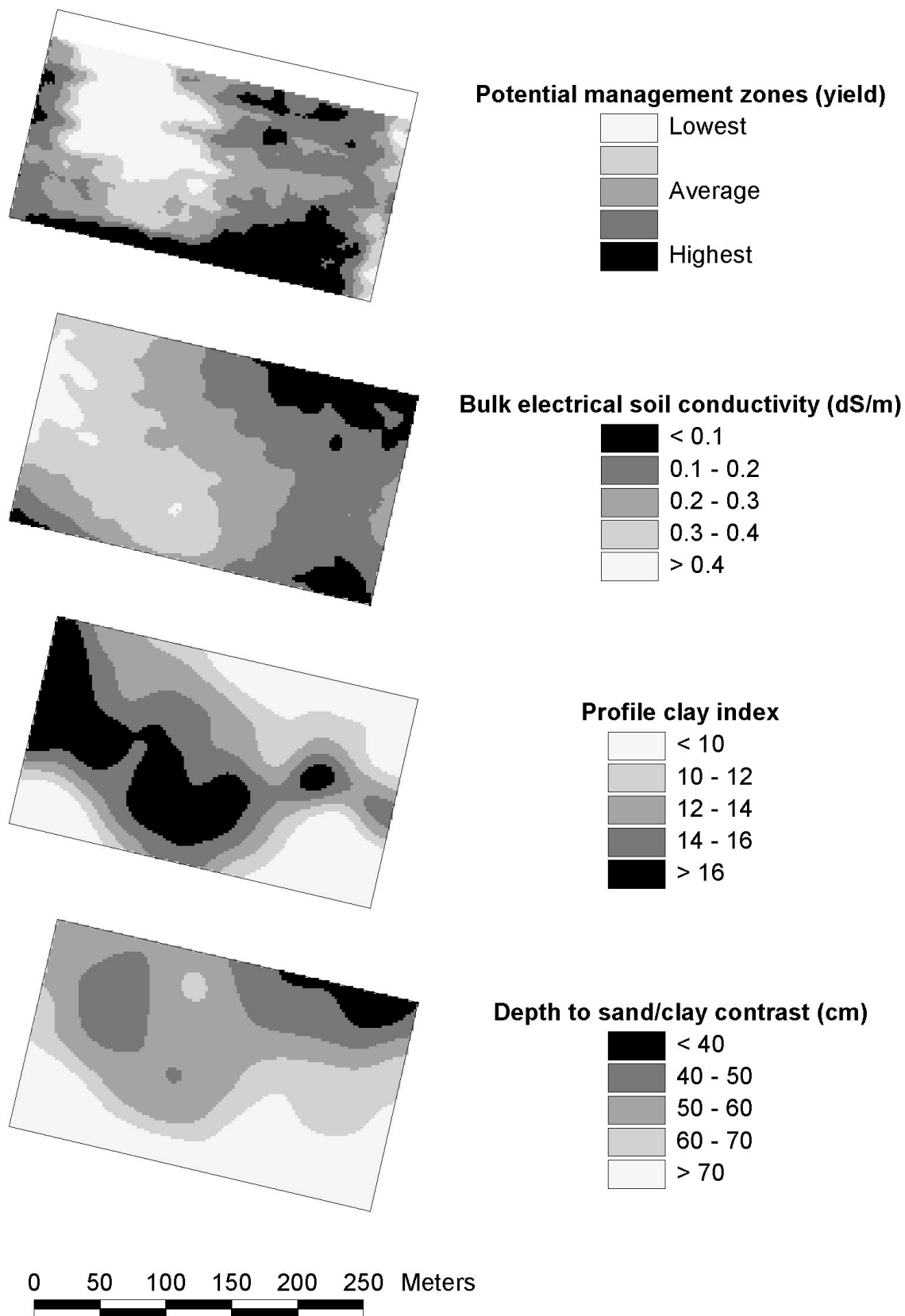
Figure 5 illustrates an example from the wine industry in which yield variation of Ruby Cabernet in a 4.5 ha vineyard was explained in terms of the effects of winter and spring waterlogging in those parts of the block where a poorly-drained clay subsoil occurs close to the surface. In this case, a survey of bulk electrical soil conductivity at high spatial resolution

(continuous on-the-go measurement down every second row) using an EM38 sensor coupled to dGPS provided detailed information about soil variation, which could be correlated with lower-resolution measurement of the amount and position of clay in the profile (Bramley *et al.*, 2000; Bramley, 2001). As indicated above, EM38 was similarly useful in another viticultural example from Coonawarra in providing surrogate information about soil depth. It is also useful for identification of salinity hazards (Williams and Baker, 1982). Bramley (2001) provides a review of progress in the application of PA to winegrape production.

Opportunities for improving nutrient management in sugarcane production have previously been identified by Wood *et al.* (1997a,b) and Schroeder *et al.* (1998) with a view to increased between- and within-region differentiation of fertiliser recommendations. The availability of electronic controller boxes for fertiliser spreaders now means that fertiliser management can be tailored within single paddocks. However, Cook and Bramley (2000) and Bramley and Cook (2000) have highlighted the need for caution in using regionally-derived fertiliser recommendations in a PA context and demonstrated the fallibility of soil test information with two examples from the wheatbelt of Western Australia. On the other hand, a grower has to start somewhere. Thus, Cook (1997), Cook and Bramley (1998) and Bramley and Cook (2000) have proposed the use of *on-farm experimentation* as a means of both fine tuning fertiliser recommendations and generating a site-specific basis for soil test interpretation. In this approach, a simple but highly replicated experiment would be used by a grower to identify variable response to an input such as fertiliser within a block. Bramley (1999) outlined a simple approach that might be suitable for sugarcane production. Site-specific fine tuning of fertiliser management or assessment of the suitability of dual or high density planting are two potential applications of such an approach.

As Figure 4 suggests, under uniform management, some parts of paddocks may operate at a loss. Note that the map shown in Figure 4 was produced at a time when the world sugar price was about US12c/lb; it subsequently fell to around US5c/lb before recovering to its present level of about US9c/lb. Clearly, as the sugar price goes down, the probability of uniform management resulting in areas of negative gross margin within sugarcane blocks goes up. Conversely, when prices are high, targeted management of the inputs to production could result in growers achieving some very significant net returns. In light of recent price fluctuations, one might suggest that the relatively late interest being shown in precision agriculture by the sugar industry amounts to a missed opportunity. Having said that, experience in industries in which adoption of PA has commenced suggests that, in the first instance, yield mapping leads to more questions than answers. It does, however, provide a powerful tool for assisting in understanding the factors limiting yield and can act as a stimulus for growers to try to better understand the production system they are managing.

Muchow *et al.* (1998, 2000) have drawn attention to the possibility of markedly increasing the net production of sugar in a district, or by the whole industry, by better matching the timing of harvest to the time at which commercial cane sugar (ccs) recovery is maximised in particular regions within milling districts. Philosophically, this is no different to a PA approach to harvesting which might also result in a grower cutting cane in different parts of paddocks at different times during the harvest round. Even the current cane supply arrangements lend themselves to this approach since it is common for single blocks to be harvested in more than one stage during the harvest season; clearly, grower income is maximised by delivering cane to the mill when ccs is optimal. This raises the question of whether the sugar industry is interested in implementing a system of supply-chain management in which, over time, millers and growers will learn where ccs is highest (even at the sub-block scale) at particular times in



**Figure 5.** Variation in yield of Ruby Cabernet winegrapes over two years (1999 and 2000) in a 4.5 ha vineyard in Sunraysia, north west Victoria, and its relationship with soil variation. Bulk electrical conductivity was measured using an EM38 sensor; the profile clay index was estimated as the mean clay content in the 5-15 and 55-65 cm depth increments in 130 soil cores which were also used as the basis for identification of the position of the texture contrast between the sandy A horizon and clayey subsoil.

the season and manage the cane supply to the mill accordingly. As Figure 2 indicates, similar opportunities for targeted harvesting exist in the wine industry and Bramley (2001) has highlighted an example in which knowledge of the variation shown in Figure 5 improved the ability of a grapegrower to optimise the time of fruit delivery to a winery (ie the time of harvest). A similar approach could be used to manage the risk of elevated levels of impurities in sugar and to consign cane from particular locations for production of sugar meeting specific quality specifications. In a research sense, this sort of idea has been used to study the impact and use of variable nitrogen fertiliser management by canegrowers at the regional scale (Keating *et al.*, 1999). It is for this reason that the millers are identified in Figure 1 as players in a PA-based sugarcane production system. Clearly, such innovation will depend on whether there is sufficient motivation within the industry to modify the current cane supply arrangements. Praat *et al.* (2001) give an example of the interaction between PA and supply chain management in the New Zealand apple industry. Other aspects of PA that may be attractive to canegrowers involve machine guidance, GPS-based laser levelling, weed management and the intuitive benefits to the environment that accrue through better matching inputs (Figure 1) to expected outputs. These issues have been discussed in some detail by Cox (1997) and Bramley *et al.* (1998).

### **Strategies for adoption**

Strategies for adoption, and in particular, impediments to the adoption of PA by the sugar industry were canvassed by McMahon and Bramley (1997) and Bramley *et al.* (1998). Here it is sufficient to re-enforce the idea that PA lends itself to incremental adoption (Figure 2). Thus, in addition to providing the basis for an improved sugarcane production system, could also provide the basis for education and learning about the production system which McMahon and Bramley (1997) identified as being necessary for successful adoption. Cook and Bramley (2001) drew a somewhat similar conclusion in a discussion of impediments to the adoption of PA by broadacre grains growers. One of the most significant has been the resistance of consultants and many agronomic researchers to start thinking spatially; as the analysis of the utility of soil test-derived fertiliser recommendations (Cook and Bramley 2000; Bramley and Cook, 2000) highlights, for some consultants and researchers, a move towards PA will involve acceptance that much of what they have done in the past may have neither delivered the expected benefits to farmers, nor even had much chance of doing so. On the other hand, it must be understood that PA does not guarantee beneficial outcomes. It will, however, through the provision of better information about crop performance, increase the likelihood of a given management decision delivering a beneficial outcome (Cook and Bramley, 1998).

### **Conclusions**

Precision agriculture is happening in other agricultural industries and it *will* happen in the sugar industries of the world ! This paper has described some preliminary research into sugarcane yield mapping and has demonstrated how other industries are making use of the technologies embodied in PA. Thus, it is not so much a question of “why ?” or “how ?”; rather, the question to be addressed by canegrowers is “when ?”. Whilst widespread adoption might promote, and even necessitate, significant change within the industry, the fact that PA lends itself to incremental adoption means that such change will be manageable. Having at least some information is better than having none, and it would therefore be appropriate for the sugar industry to begin the adoption process sooner rather than later. Of necessity, this

will have to be accompanied by a supporting participative research program involving both growers and researchers.

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