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Preface: Use of Precision Agriculture by the Australian grains industry

The contributions to this special edition of the *Crop & Pasture Science* report recent research undertaken as part of a national R&D initiative on Precision Agriculture (PA) established by the Grains Research and Development Corporation (GRDC). The Corporation is a statutory authority established to plan and invest in R&D for the Australian grains industry. Its primary objective is to support effective competition by Australian grain growers in global grain markets, through enhanced profitability and sustainability. Its Precision Agriculture Initiative (code: SIP09) operated as a national R&D program over the period 2002–03 to 2007–08, with projects in each of the three major grains regions (west, south and north).

Precision Agriculture (PA) is also known as Site-Specific Crop Management (SSCM), Information Rich Agriculture (IRA) and by other similar terms. It includes a suite of technologies and methods that are increasingly based on the use of global positioning systems (GPS) to provide a geo-referenced location for soil, farm or landscape data, and for accurate positioning of farm vehicles and implements. This allows different types of data from the same locations to be collated, analysed and mapped, and for different agronomic decisions to be implemented at the precise location where they are required. In commercial practice in Australia, PA may include the use of vehicle guidance to reduce overlap in application of fertiliser or pesticides, controlled traffic farming (CTF or tramlining) to reduce the area subject to wheeling and soil compaction, accurate location of equipment for inter-row sowing or use of shielded sprayers in row crops, yield monitoring and mapping, variable rate application of fertiliser or pesticides, and the collection and mapping of soil and other digital data (e.g. elevation) and its combination with satellite imagery.

The ability to combine soil, satellite and yield data has enabled the establishment of within-paddock management zones where different crops, varieties or agronomic management can be applied to match more accurately the productive potential of each area. Digital maps provide an accurate record of yield across seasons and crops, and the Gross Margin being achieved from different parts of a farm or paddock can be calculated. PA, therefore, has the potential to underpin a new level of more profitable and environmentally sustainable decision-making by farmers, through better management of the spatial variability found across many paddocks and farms. PA has also provided some less-intended benefits, such as reduced operator fatigue and the ability to continue cropping operations at night.

There are different views about what exactly in included in the term ‘Precision Agriculture’, but in this special edition we include all those aspects listed above. Reviews such as McBratney *et al*. (2005), Jochinke *et al*. (2006), and Robertson *et al*. (2008) provide summaries of how PA is being applied in Australia, with special reference to the Australian grains industry.

Until the early part of the twentieth century it was quite common for farmers to be able to apply site-specific management, based on their own knowledge built up over the years of within-paddock variation. But mechanisation changed all that. There have been huge gains in productivity and profit as a result of the mechanisation of cropping, and without it broadacre cropping might not exist today. But it has also meant that large areas are now treated as uniform when in fact they are not.

As Australian grain growers have devised better ways to grow crops more efficiently and to manage erosion, nutrition, disease, weeds and pests, and seasonal variability in timing and amount of rainfall, spatial variability has become a more important determinant of profit and sustainability. This variability in space may reflect differences in soil type and depth, elevation, compaction or salinity or other restriction to root growth, weed or disease burden, or just the effects of past management. Whatever the causes, there are now many examples where growers have been able to map and manage this spatial variability and thereby to lift profit by $10 to 50/ha.

The basic tools needed for PA, i.e. GPS positioning and guidance, biomass maps and yield monitors, and variable rate applicators, have been available in Australia for over a decade. Despite the potential for significant cost savings and improved crop returns, and although more and more grain growers are starting to use some components of PA such as vehicle guidance, the full adoption of PA as defined above remains very low.

There are several reasons. Getting the different parts of a PA system to work together can be difficult, especially if those parts come from different manufacturers. The investment needed to buy and set up for full PA is quite high (although decreasing), and growers are not yet confident of getting a return on their money. For many growers, variability in crop yield across the farm or within individual paddocks is not their first priority, either because this variability is naturally low, or because better agronomic management, marketing or other factors remain more important in driving yield and profit. In some paddocks the potential management zones (those of high or low yield and profit) seem to change position from year to year according to the season or crop type; this makes it difficult to predict with confidence what zones should be used in the coming season for differential management. A final and very important reason is that to turn PA ***data*** into useful ***knowledge***, and to interpret it in a way that enables growers to make better ***decisions***, requires a high degree of skill and experience, and so far there are not enough people trained in PA to support Australian grain growers in this way.

Against this background, the GRDC PA initiative was established in 2002–03, with the aims of further developing PA methods for use by Australian growers, evaluating and demonstrating those methods in different cropping regions and systems, and providing education and training information about the practical use of PA. It comprised a range of projects where growers and researchers worked closely together to make the

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promise of PA a reality. The initiative considered four broad stages in grain growers using PA:

- **Stage 1** is recognising that significant variability in yield and profit is occurring within a paddock or across the farm, and determining whether the yield zones are stable or unstable between years (seasons) and different crops. This stage is generally achieved from growers' own knowledge of paddocks, and from biomass (NDVI), yield, quality (e.g. protein) or gross margin maps based on processed data from satellites or the header.
- **Stage 2** is about identifying the underlying causes of yield variability. These could include soil depth, soil type (water holding capacity, nutrients), elevation, acidity, sub-surface salinity or compaction, presence of soil pests and diseases, or the influence of past management (old fencelines, windrows, previous crop type). This stage requires the comparison of biomass or yield/quality zone maps with other mapped data for the paddock, for example from soil tests, electromagnetic induction (EM) or gammaradiometric survey, disease testing, aerial photographs, or contour data, followed by field inspection and tests to ensure the correct causal factors have been determined. Where there are several likely causes, it is important to get a sense of their relative impact on yield and profit. By the end of this stage, growers should know what the main underlying causes are of yield variability, and whether it is practical to do anything about them, either by direct amelioration (e.g. ripping, correcting nutrient deficiency, liming) or by changing management (e.g. use of a tolerant crop, reducing fertiliser inputs on non-responsive areas and/or increasing them where there is a good yield response).
- **Stage 3** is about asking "is it worth managing the spatial variability?" In other words, knowing the scale of variation in profit (stage 1) and the underlying causes and possible solutions (stage 2), is it worth doing anything about it? In this stage grower/adviser experience and crop models can be used to help assess the likely impact on yield under different seasonal conditions and between different crops. By combining the results with financial analysis, growers can work out whether it is economically sensible to tackle spatial variability using PA, and if so what its relative priority should be in the farm or cropping budget.
- **Stage 4** is where PA can be "rolled out" within a cropping district. Having gained experience by going through stages 1–3 on several paddocks or farms within the district, growers, advisers, farm consultants or extension officers should be able to go to a new paddock or farm and quickly identify, with some confidence, the likely underlying causes of yield variation, and provide advice on whether and how that variation can be managed to improve overall yield and return.

It is unlikely that PA will be a panacea or 'silver bullet' for all grain growers, and the best PA techniques to use and how best to apply them are likely to vary across districts, farms, and perhaps even paddocks. In some situations PA may have little to offer for the reasons listed earlier, and the area cropped and level of yield variability between potential management zones, for example, are likely to influence the size and speed of financial return from an investment in PA. But for many growers, once the basics of the cropping program are working well and management is being varied according to season and available soil water, then PA may offer an additional step to lift profit and sustainability. The experiences gained across the different SIP09 projects, and the tools being developed to help growers decide whether (and when) PA may be valuable for them, will help in making decisions about, and applying, the different components of PA.

The following papers provide a summary of just some of the results of the PA initiative, others have already been published or will be over coming months. Results have also been provided in forms that promote their adoption by growers and farm advisers, including workshops, field days and training programs. The GRDC has released a PA Manual in CD format that provides a detailed description of equipment and methods and how they can be used in practice for different purposes, including a practical guide to EM mapping and of how to conduct on farm trials using PA. Grower groups, including the Southern Precision Agriculture Association, the Australian Centre for Precision Agriculture and other research groups, and some farm advisers, are also active in further development, demonstration, and training in PA.

This special edition starts with a paper by **Robertson, Carberry and Brennan** that aims to quantify the economic benefits of adoption of PA technology on six case study farms from the Australian wheatbelt. These cover a range of agro-climatic regions, cropping systems, farm sizes, soil types and production levels. The farmers had been involved in PA from 2 to 10 years, and the analysis concentrates on variable rate application of fertiliser, but also considers benefits from guidance and reduced traffic. Capital investment in PA equipment ranged from $55 000 to $189 000 per farm and there was a similar range in the estimated annual benefits. This paper also outlines some of the factors that determine whether an investment in PA is likely to be financially sound.

The next paper, by **Whelan, Taylor and Hassall**, examines the importance of grain quality as well as quantity. Wheat grain protein concentration (GPC) and wheat grain yield (GY) were monitored on-harvester for three seasons across 27 paddocks using two independent, on-the-go sensing systems. The spatial pattern in variability of these two measures was shown to display spatial coherence from which inferences regarding the relative availability of soil nitrogen and moisture are suggested. The results point to the suitability of on-the-go grain sensors combined with other PA data to enable more-sophisticated agronomic and environmentally targetted nitrogen-use.

Mayfield and Trengove report results when post emergent nitrogen fertiliser was applied at a variable rate using an on-the-go sensor compared with a constant rate using the same total amount of fertiliser. The commercial 'N-Sensor' used scans crops and automatically regulates the rate of nitrogen fertiliser spread according to the reflectance of the crop. Normally it applies more fertiliser to the paler green areas and less to the darker green areas, but can also be reversed to apply more nitrogen to darker green areas, for example, to increase grain protein content or where a response to nitrogen in paler green areas is not likely to be economic due to other crop constraints. Although the production benefits reported here were small, this type of sensor is in common use in Europe for both production and environmental sustainability goals.

The financial results based on grain yield and quality reported by Whelan *et al*. and by Mayfield and Trengove can be compared with the broader results of Robertson *et al.* It seems clear that PA can provide a significant improvement to profit under some, but not all, circumstances; sometimes the benefit is minimal and the investment in PA may not be justified. As input costs, particularly for fertiliser, increase, this equation will change, but growers will still need to consider the area of crop that PA can be applied to, the degree of spatial variability present (the proportional response to inputs in different management zones), and the new decisions that PA may allow (such as segregated harvesting based on grain quality).

Heap and McKay examine another factor where PA could assist growers' decisions, in this case the management of soil-borne diseases. Their field experiments in southern Australia examined the spatial distribution of soil-borne disease inoculum within paddocks using DNA-based soil assays. Paddocks were divided into zones using a range of combinations of digital data layers, and inoculum levels differed between zones in up to almost two-thirds of cases. The relationship is not straightforward and varied with different disease organisms and different data layers used to define the zones, but the authors suggest several ways in which PA data could be used to help reduce the risk to profit from soil-borne diseases.

The paper by **Lawes, Oliver and Robertson** considers another major variable that grain growers must take into account – season. It is well known that all management zones in some paddocks, and some zones in other paddocks, are generally stable in their relative yield (i.e. they are nearly always high-, medium- or low-yielding relative to other zones or to the paddock mean), for other paddocks or zones the spatial variation of yield is influenced by season and is often temporally unstable. Parts of a paddock may yield well relative to the remainder in one season and poorly in another, suggesting that different parts of a paddock vary in their response to the type of season. These authors have evaluated the capacity of two analytical techniques to capture this variation, and discuss how this additional information could be used to define management zones for a coming crop.

Next are papers from researchers at the Victorian Department of Primary Industries that report the results obtained from detailed investigation of a site near Birchip in the Victorian Mallee. At this farm, the relative yield zone (high, medium, and low) within paddocks may change position with different seasons and crops. By analysing and modeling a range of soil and agronomic data, the researchers have attempted to unravel the reasons for this, with the aim of developing capacity to predict likely future yield and hence to identify and map the management zones for a coming cropping season.

Fisher, Abuzar, Rab, Best and Chandra examine whether several years of historical satellite normalised difference vegetation index (NDVI) data combined with estimates of average paddock yield for each of those same years can be used to estimate future yield and delineate management zones. In their results, the estimated yield varied by less than 20% of actual yield for almost two-thirds of the paddock, although for 10% of the area the yield estimate had an error of 40% or more.

The paper by **Robinson** and colleagues examines the value of different soil attributes in delineating yield zones, concluding that EM38h, EM38v and γ-ray total count data were significantly correlated with yield for all seasons, while the terrain derivatives: relative elevation, slope and elevation, were associated with yield for one season, and terrain derivatives: aspect, and profile and planimetric curvature, were not associated with yield.

Armstrong and colleagues examined a wider range of soil, properties, including subsoil constraints, for their effects on relative yield of different crops in different seasons. There was a strong relationship between crop growth and the use of soil water and nitrate across the management zones with most water use by the crop occurring in the pre-anthesis/flowering period, but the nature of this relationship appeared to vary with year and/or crop type. They suggest that in a dry year, relative yield zones may be driven by the amount of plant available water in the upper 0.6 m of soil, while in wetter seasons the effects of subsoil constraints and nitrogen availability also affect yield.

Rab, Fisher, Armstrong, Abuzar, Robinson and Chandra examine the variability in Plant-Available Water (PAW) and associated soil properties across the same paddock, and conclude that variation in soil water content is likely to explain a large amount of the within paddock spatial variability in yields. However, their results suggest that using any single soil property is inadequate to describe the location of high or low yielding zones because different properties become more or less important under different seasonal conditions.

This theme is taken further by **Anwar *et al.*** who simulate yields over 119 years of climatic data. The APSIM crop model produced consistent responses to the observed data from the paddock experiment in 2004 and 2005 where a high and stable yielding zone produced the highest dry matter as well as grain yield, while a low and variable zone recorded the lowest grain yield. But when results were taken from the whole 119 years of climate data, the highest median wheat yield value was obtained with high N fertiliser application on the zone ranked low but variable using 2004–05 data, while the lowest was obtained on the high but variable zone. This analysis highlights the risk of using a limited range of seasons of different weather conditions and agronomy to make strategic decisions about paddock management zones unless the underlying causal factors are understood and can be matched with pre-season rainfall, plant available water at sowing and forecast rainfall probabilities.

PA could also be used to help make decisions at a much broader scale than within individual paddocks. Whole farm mapping of yield and soils data could be (and in a few cases is being) used to make decisions about where expensive inputs can be used to best effect, to improve profit and environmental sustainability at the whole-enterprise or whole-farm scale. PA data and methods could also be applied at a landscape or catchment scale, for example to help decisions about land use or about alternative options to meet targets for salt export or biodiversity conservation. **Lawes and Dodd** describe how PA technologies and other methods can be used to identify poorly-performing cropped patches on three farms using historical yield maps, and to assess the ecological value associated with their potential re-vegetation. They also investigate how the size and location of these patches changed with varying definitions of poor performance. It seems likely that PA methods will be used in this way much more in the future, especially if the potential impacts of climate change can be incorporated into the analyses.

The results presented and discussed in this special edition demonstrate that PA can not be used in a "one size fits all" approach. There are likely to be regions, farms, and paddocks, where the level of yield variability is too low to justify the adoption of variable rate application (VRA) methods, and where the main gains from PA will be in guidance and reduced fatigue, in decisions based on past collated data showing yield and gross margin performance, and in adjusting inputs to match likely seasonal conditions. In other areas, some yield zones are relatively stable between years and crops. Here, and where seasonal condition can be reasonably judged from pre-sowing rainfall and/or plant available water, management zones can be defined for the coming season with some confidence and inputs varied between them accordingly. In yet other situations, yield zones are known to 'flip-flop' between seasons and crops. Here, it will be necessary to understand the causal factors and how their influence varies according to season and crop type before management zones can be established and the full range of PA methods applied.

The work of the Precision Agriculture R&D Initiative, part of which is reported in this special edition, contributes to the GRDC goal to develop optimal farm management practices that, when used to grow superior high-yielding varieties, will lead to increased productivity from sustainable grain production systems. Better farming practices contribute to increased productivity by enabling grain growers to obtain the maximum return from their inputs, while at the same time minimising losses and off-site effects. Improved management resulting from this research is being combined with new knowledge from other GRDC R&D initiatives that enables growers to also identify soil constraints and nutritional requirements to vary fertiliser and other inputs across the farm or paddock according to estimated crop demand. Agronomic packages that incorporate these R&D results are tailored to suit each region, and tested and further developed under local conditions by grower groups.

Other GRDC investments support education, training and other capacity-building activities that facilitate on-farm practice change and allow the grains industry to make the best use of new technologies developed from the research initiatives. The Corporation is funding several follow-up projects to develop PA education and training materials aimed at growers and farm advisers/consultants and to deliver and further refine them in collaboration with grower groups. These materials, and others suitable for use in tertiary education courses, will be made widely available for use by others in their own education and training programs in PA. The GRDC is also supporting further work to expand the range of PA methods and to test and demonstrate their use in practice.

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