Managing spatial and seasonal variability within field can improve the profitability of WA grain production

Michael Robertson[1], Bindi Isbister[2], Ian Maling[3], Yvette Oliver[4], Mike Wong[5], Matt Adams[6], Bill Bowden[7] and Peter Tozer[8]

[1] CSIRO Sustainable Ecosystems, www.csiro.au Email michael.robertson@csiro.au
[2] Western Australian Department of Agriculture and Food, www.agric.wa.gov.au Email BJIsbister@agric.wa.gov.au
[3] SilverFox Solutions, Silverfox.net.au Email IMaling@silverfox.net.au
[4] CSIRO Sustainable Ecosystems, www.csiro.au Email Yvette.Oliver@csiro.au
[5] CSIRO Land and Water, www.csiro.au Email Mike.Wong@csiro.au
[6] Western Australian Department of Land Information, www.dli.wa.gov.au Email Matthew.Adams@dli.wa.gov.au
[7] Western Australian Department of Agriculture and Food, www.agric.wa.gov.au Email bbowden@agric.wa.gov.au
[8] Western Australian Department of Agriculture and Food, www.agric.wa.gov.au Email ptozer@agric.wa.gov.au

Abstract

Sensing, interpreting and acting upon within-field spatial variation in crop performance through precision agriculture (PA) techniques stands to benefit farmers economically and environmentally. The increases in crop gross margin required to offset the cost of purchasing and operating PA technology can be calculated to help growers make PA investment decisions. Economic modelling shows potential benefits of <$5/ha to $40/ha for variable rate management. This is supported by on-farm trials showing benefits of $29-$63/ha for zone management in the northern sandplain of WA. The full benefits of zone management can only be realised by developing methods for defining management zones that are consistent in performance, and accounting for crop nutrient requirements within zones by allowing for seasonal effects on yield potential. Various methods can be used to define zones of consistent performance in fields that can be targeted for variable rate fertiliser inputs. In many situations yield variation can be related to variation in soil plant-available water capacity. Predictive systems using geophysical information will enable inexpensive extrapolation of valuable point-based soil characterisation. Constraints to adoption by farmers include lack of training and technical support, equipment incompatibility, perceived riskiness of economic returns, and barriers to use of “hi tech” elements. Future R, D and E should target a wider farmer audience who are aware of spatial variability but are not currently using PA technologies.

Keywords

precision agriculture, soil variation, yield maps, NDVI, EM38, gamma-radiometry, economics

Introduction

A major concept underpinning precision agriculture (PA) is the matching of nutrient supply to the spatial variability of grain yield over a farm, through the use of variable rate technology (VRT). At the most refined level, this form of precision management requires the use of advanced technologies such as global positioning and guidance systems, grain yield monitors and variable rate applicators. Emphasis in PA research to date has been placed on the use of VRT for nutrient management in different areas or zones in fields, hereafter called zone management (McBratney et al. 2005). Limited attention has been made to variable seeding rate, and is probably an under-exploited area. Although the benefits of PA seem obvious, the adoption of spatially-variable fertiliser management is not widespread, both internationally (Daberkow and McBride 2003) and within Australia (Lowenberg 2003). Although PA technology has been available in Australia for more than a decade, it has been estimated that only around 3% of Australian grain growers are using some form of the technology (Price 2004).

We believe that conditions in Western Australia (WA) predispose PA to be advantageous relative to current practice. The large scale of farming operations means that the technology is affordable and increasing input costs are driving growers to improve farm efficiency to remain profitable. In addition, the approach of managing within-field or -farm production variability is well suited because of the consistency of patterns in crop performance, both in space and time, so that zones can be managed reliably from season to season. Finally, there is access to a strong communication network linking PA researchers, PA equipment and software manufacturers, consultants and leading-edge growers.

In this paper we discuss current progress and future prospects in research and development for PA in WA.

Financial considerations of investing in precision agriculture

One of the reasons for low adoption of PA is the understandable reluctance of farmers to invest many thousands of dollars in PA for variable rate technology without knowing if the technology will return a profit. This problem is somewhat accentuated in PA as the early adopters are often moving into PA with systems based on high cost 2cm accurate GPS auto-steer systems with capital costs ca. $60 000. To potential adopters this seems too expensive and they question the application of PA to their farming system. In WA the early adopters often crop large areas (above 3000ha) which means highly accurate auto-steer 2cm systems are a good investment based on 10% savings in inputs from less overlap (Stone 2004). Highly accurate GPS systems are not an essential piece of the equipment for VRT and the cost can range from $800 to $60 000 depending on what accuracy is most appropriate for the operation.

It is difficult for farmers to know if PA is profitable until something is known about the variability on the farm, which can’t be obtained without spending some money on PA equipment. We propose the decision can be tackled backwards by finding out by how much a gross margin needs to improve - using a simple investment analysis. A range of factors affect the investment value of PA including the current farm gross margin, cost of PA equipment, the area and number of years over which the equipment is used and the rate at which benefits from adoption start to occur (Stone 2004, Jennings 2005). The investment analysis uses a ‘discounting’ process that recognises that a dollar received today is worth more than a dollar received next year. Rather than guessing how much benefit PA might provide, this analysis determines how much benefit the new technology needs to provide to make the investment in PA profitable. This value is presented as a ‘break even’ increase in gross margin, enabling the investor to reflect on how achievable could a break-even increase in gross margin be in practice. Table 1 illustrates the impact of variation in the amount invested in PA and area of cropping benefiting from PA on the required gross margin increase. Clearly, the increase in gross margin required depends on the size of the investment and will be lower if the benefits can be spread over a wider area.

Table 1: Increase in gross margin ($/ha) required to cover the cost of investment in PA equipment. Discount rate was 8% and annual operating costs for PA were $1000.

Investment in PA	Area benefiting (ha)	Increase in gross margin ($/ha)
$5000	500	5
	1000	3
	2000	1
	4000	1

$20000	500	11
	1000	6
	2000	3
	4000	1

Typical gross margin increases required to offset the PA technology costs can be calculated for different regions in WA according to statistics of cropped area on farms. Grain growing properties in the northern agricultural areas of WA average 3600 ha, of which about 1700 ha is cropped each year. In the eastern agricultural area, average farm size is about 5000 ha with just over 1700 ha under crop each year. Given these farm sizes, the range of gross margin increases required to break even from investment in PA is less than $5/ha depending on the level of investment and assuming that benefits accrue over the entire cropping program on the farm starting at year 2 after equipment purchase and persist through a 10 year period. Average farm size in the central agricultural area and the mallee and sandplain country of WA is similar at about 2300–2600 ha. About 1000 ha of this land is cropped each year. For these areas, the break-even gross margin will be $3-6/ha depending upon the size of the investment.

Economic benefits of zone management

Given that the required percentage increase in gross margin increase for a particular combination of factors can be calculated, this can be compared with expected gross margin increases from variable rate application of fertilisers to field zones. Profit increases from zone management can come from the achievement of higher yields with higher input where the value of the extra yield outweighs the cost of the extra fertiliser, or where the cost savings in fertiliser input exceed the reduced value of the yield either through the achievement of the same yield but with less fertiliser or a lower yield with less input.

Robertson et al. (2006) examined the relationship between within-field yield variation and economic advantages for zone management, and the impact of variation in size of management zones, costs and prices, and soil fertility status. They found that the biggest gains were to be made in fields with the widest differences in yield potential. This is because yield potential (defined as the yield limited only by water) is the major determinant of crop nutritional requirements. The advantages gained through zone management were seen mostly via higher rates of fertiliser on medium and high yielding zones, and to a lesser extent as lower rates, and thus cost savings, on low yielding zones. Additional benefits would accrue if zone differences in starting soil fertility co-occur with differences in yield potential particularly where high starting fertility occurs on low yielding zones. For the range of cases presented by Robertson et al. (2006) the potential economic benefits to WA growers ranged from <$5/ha to over $40/ha, and are similar to the benefits derived by Brennan et al. (2006) in northern New South Wales and Godwin et al. (2003a) in the United Kingdom. At current typical gross margins at $100-150/ha for much of WA (Department of Agriculture and Food Western Australia 2005), advantages to zone management of as little as $10/ha represent a sizable increase on a baseline gross margin.

While theoretical calculations of the economic benefits of zone management abound, there are few documented cases of on-farm benefits. Table 2 shows on-farm trial results of matching fertiliser inputs to zone potential, where, based on past performance recorded by yield maps, a field was divided into three zones with low, medium or high potential (Webb et al. 2005, Isbister et al. 2006).The advantage of applying low, medium or high rates of fertiliser to zones of low, medium or high potential over the baseline strategy of applying a medium rate to the whole field varied from $29 to $63/ha, within the range of modelled estimates above. In 2002, the optimal practice was to match fertiliser rates to the long-term zone potential. In 2004 on the medium zone it would have been best to apply a high rate rather than a medium rate and so benefits of matching inputs to zone potential were less than if the optimum for that season was applied. In 2005, applying high rates on all zones would have been best, so the advantages of matching fertiliser rates to the long-term zone potential were less than the optimum in all three zones. These results show that the economic benefits of zone management derived from theoretical estimates are not always achievable in commercial practice due to seasonal influences enhancing or diluting the benefits of matching fertiliser to zone potential through the impact on yield potential, as with any nutritional management (Adams et al. 2000, Whelan and McBratney 2000, Brennan et al. 2006). A challenge for PA extension is to get farmers to recognise the value of changing management when they currently have no trouble in recognising different yield potential zones.

Table 2: Wheat grain yield (t/ha) and gross margin ($/ha) per zone in each of three seasons at a farm in the northern sandplain of WA. The percentage area of each zone in Paddock A was 21% low, 28% medium and 51% high and in Paddock B was 20% low, 35% medium and 45% high. Gross margins were determined using input costs, yield and grain quality and premium grain prices for the year. Shaded cells are the maximum gross margin for each zone within a season.

		Paddock A				Paddock B	
		Yield (t/ha)		Gross Margin ($/ha)		Y (t/ha)	GM ($/ha)
Zone	Fertiliser Input	2002	2004	2002	2004	2005	2005
Low	Low	1.5	2.2	105	188	2.8	236
	Medium	1.7	2.0	38	88	3.5	345
	High	1.7	2.2	-26	60	4.2	429
Medium	Low	2.1	2.3	248	209	3.2	311
	Medium	3.6	2.7	303	223	3.6	362
	High	3.7	3.4	238	285	4.5	483
High	Low	2.4	2.4	254	242	3.5	387
	Medium	3.6	3.0	320	275	4.5	549
	High	4.3	3.8	398	357	5.4	661
Advantage of matching input to long-term zone potential vs. medium rate across field				56	63		29

Advantage of optimum input for that season vs. medium rate across field	56	80	110

Even with in-season applications of fertiliser to match evolving seasonal conditions there is residual uncertainty in the yield outcome. Further advances in quantifying the benefits of zone management will require linking knowledge of spatial variability with systems for seasonal climate forecasting.

Methods for definition of zones

One of the ingredients to implementing a successful zone management system is being able to define the location and relative yield potential of zones so that they can be managed with confidence from season-to-season. Management zones that are made up of a large percentage of consistently performing area through time are prime candidates for variable rate technology. A number of methods are available, varying in convenience, technical skills required, cost, and whether they are plant or soil -based. Yield maps are a direct measure of the attribute of interest. However investment in a yield monitor is required and often a number of seasons of yield maps for the same crop species are required before zones can be defined with confidence. Our experience with farmers is that yield maps can sometimes have missing data, seasonal influences that hinder interpretation of underlying yield potential (e.g. patchy weed infestations, frost damage) and can be subject to calibration and positional errors. Hence it is unwise to rely solely on yield maps as a basis for zone definition.

Historical series of mid-season normalised difference vegetation index (NDVI) (Tucker 1979) can be obtained from the Landsat satellite, averaged for seasons of common crop-type (e.g. cereal vs. broadleaf crops) to determine zones of consistently average, below-average, and above-average NDVI (Adams 1999). Table 3 shows results from 13 randomly selected fields from one farm near Kellerberrin in the central wheatbelt of WA. Notable is the high percentage of the fields where greater than two-thirds of the field area had NDVI that was consistent from season-to-season in its rank performance. In these situations of consistent performance of NDVI, it can be used with confidence over a large area of a farm to define management zones (Adams and Maling 2005). The usefulness of this technique relies on a strong positive correlation between NDVI and yield, at least at regional scale in WA (Smith et al.1995). In cloudy climates the availability of clear scenes of NDVI during the winter growing-season may be limited. Occurrence of weed infestations can impose an additional limitation. The historical NDVI record extends back to 1993 and allows an analysis of the consistency of ranking, from season-to-season, of below, above and average zones. We have found that growers readily recognise NDVI and easily relate it to their knowledge of the field. There are two commercial service providers now in WA who use NDVI for the purposes of zone management and targeting soil sampling.

Table 3: Percent area of 13 fields from one farm at Kellerberrin WA where NDVI performance from season to season was consistent, and the percent of each field that fell into low, medium or high NDVI performance.

			% of field on each NDVI zone		
Field	Field size (ha)	% consistent	Low	Medium	High
1	68	79	26	41	33
2	59	88	23	36	41
3	110	77	27	33	40

4	43	81	25	29	46
5	78	75	23	44	33
6	59	61	25	42	33
7	80	66	21	46	33
8	48	71	26	40	34
9	97	76	22	43	35
10	43	51	28	43	29
11	62	65	21	45	34
12	62	69	27	36	37
13	72	72	30	27	43

Soil-based methods rely on a close relationship between soil type and crop performance. Traditional soil mapping to define soil polygons is expensive (e.g. $20,000 for a 3000 ha farm) and rarely undertaken by farmers in WA. However, in contrast to yield maps there is no problem of data acquisition, management and interpretation, with many growers being able to immediately recognise and help interpret the data based on their experience/knowledge of the farm. Considerable value can be added to traditional soil surveys if “soil type” can be related to actual targeted PAWC measurements across the field/farm (Oliver et al 2006). Estimates of plant available water capacity (PAWC) allows us to estimate season and site specific yields, yield gaps, formulate fertiliser requirements and target management attention to problem areas.

Detailed soil mapping using remote or proximal sensing is likely to be more effective than the use of soil type polygons because of (1) possible ambiguity between soil type and functional attributes of soil such as PAWC, (2) weakness in the assumption of uniformity within soil types, and (3) high cost of traditional soil mapping. Wong et al. (2006) and Wong and Asseng (2006) describe an approach using a combination for gamma-ray spectrometry and apparent soil electrical conductivity (EC_a) surveys to estimate PAWC on the WA northern sandplain soil-landscape system, where soils vary from gravels to duplex soils to deep sands (Oliver et al. 2006) with confounding influences of salt affecting PAWC. In our experience it is likely that a combination of EC_a, gamma and elevation will be required, and to relate this to targeted PAWC measurements in each farm will need local calibration. Gamma appears to be much more effective in WA than in many other areas.

Farmers currently make little use of remote or proximal soil sensing. This is partly because there is not the infrastructure and support available to use this technique in the WA wheatbelt. The mining industry has a lot of experience / infrastructure in this field and could be a future service provider for agriculture. However, we expect use of remote/proximal sensing for soil survey will increase as costs are reduced, accessibility increased and development of algorithms that relate the signal to a functional attribute of soil type (such as PAWC) that can in turn be related to yield potential of the site for the season. There is also potential to use simulation models, that relate yield to seasonal conditions and soil attributes, in conjunction with yield maps to back-calculate maps of soil attributes, such as PAWC.

In our experience, farmers do not rely on one single method and use a combination of their own experience of spatial variation in crop performance and more objective methods such as yield maps and NDVI. Table 4 shows that a farmer's own knowledge of spatial patterns in productivity agreed 77% or 57% with a 2 or 3-zone classification, respectively, based on a series of historical yield maps. Using a the historical series of NDVI maps for the field or just a single yield map from 1996, a season in which maximum yield variation was expressed, provided similar levels of agreement, while remote or proximal sensed measures of soil did poorest. The latter two measures also had the highest chance of mis-classification of low as high zones, or high as low zones in the 3-zone system. These results suggest "objective" measures of spatial patterns may not have any more predictive ability than knowledge developed by farmers through observation over many seasons. However, they may add confidence in decision-making, especially where farmer experience is limited and may assist in identification of boundaries between soil types.

Table 4: Percent agreement between zones as defined by 5 historical yield maps and zones as defined by farmer productivity rating, gamma K, EM38, NDVI and a single yield map from 1996. Data are for the case of 2 or 3 zones in a single field at Buntine, WA. Also shown for the 3-zone case is the % of the field where the low zone was classified as high and vice versa ("two classes away").

	Farmer productivity map	Gamma K	EM38	NDVI	Yield map in 1996
2 zones					
% full agreement	77%	62%	37%	82%	80%
3 Zones					
% full agreement	57%	53%	30%	52%	61%
% two classes away	9%	13%	26%	2%	3%

Precision agriculture for diagnostics

While yield maps may highlight regions of fields that are consistently poor performing they offer few insights into the reasons for low yields and hence feasible interventions to manage such areas for increased profit or reduced environmental impacts. However, coupling yield maps with additional soil- or plant-based information may provide such insights that would not be available from inspection of yield maps alone. Most commonly, such additional information takes the form of targeted soil survey to diagnose soil "constraints", however, for the reasons outlined above it is limited in terms of spatial extrapolation and requires assumptions about uniformity of soil attributes within zones. We believe that some of these limitations can be overcome by using mid-season NDVI, taken before canopy closure, as a surrogate for vegetative biomass to identify low-yielding areas within a field associated with either high or low mid-season "biomass". For example, low yielding areas that had high mid-season biomass may have a subsoil constraint that did not allow early biomass production to translate into high yield due to late-season water limitation. Likewise, low yielding areas with low mid-season biomass indicates a persistent constraint on growth that may be a function of poor establishment and/or early growth. Figure 1 illustrates the approach for one season in one field in WA. There are low yielding areas that are associated with either low biomass or high biomass. The low yield and high biomass areas occur on very shallow soils suggesting that low PAWC may be limiting the ability of the crop to translate early growth into yield. These areas may justify reduced inputs or seeding rates to better match the inherently low yield potential of these shallow soils. On the other hand, areas that are low yield and low biomass may indicate surface soil conditions that cause poor establishment and early growth and may be able to be ameliorated. Follow-up soil sampling would be required to confirm the exact nature of the constraint and feasible management interventions. In this example, different sets of feasible management interventions would be required for the low yielding areas through the use of NDVI in conjunction with yield mapping.

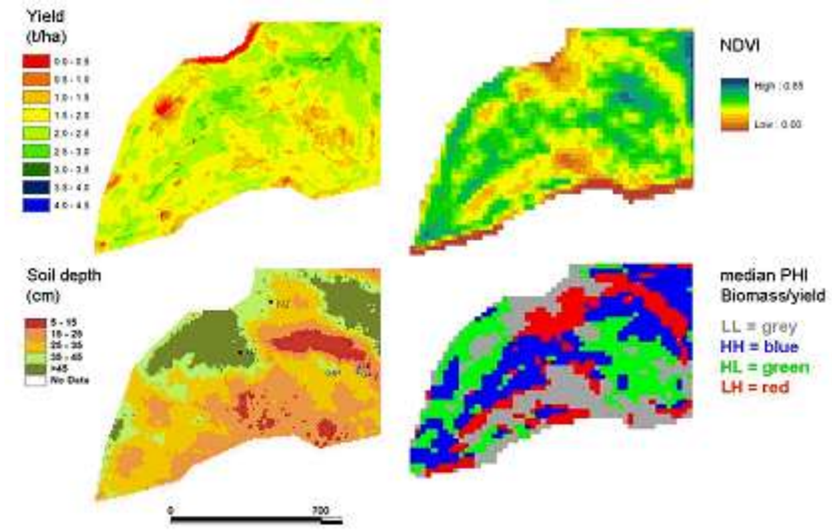

Figure 1: Yield, NDVI, soil depth, and NDVI (biomass)/yield classification on a single field at Buntine, WA.

Environmental issues and landscape management

While much emphasis to date in PA has been on managing within-field variability for increased profitability there exists considerable scope to use PA technologies at greater spatial scales to manage farms and (sub) catchments. Examination of spatial information such as NDVI, airborne geophysics and elevation at whole-farm and catchment scales in WA has shown the persistence of soil-landscape features than traverse field boundaries and the occurrence of landscape-scale processes such as salinisation and waterlogging. This sort of information has been used to identify areas with both low productivity and excessive contributions to drainage and nitrate leaching (Wong and Asseng 2006). These areas can be used to re-think the location field boundaries, tree-planting and watering points for livestock, and matching of land use to soil type. The use of PA technologies to inform landscape management is only beginning and has much potential.

Industry development

Adoption of PA is like any other innovation in that it is influenced by a number of variables (e.g. Marsh and Pannell, 1997) including:

- the relative advantage (or perceived profitability) of the option relative to current practice,
- compatibility with current farming practices,
- ease of acquiring and utilising the option,
- trialability of new option (can it be tested on a small scale?),
- observability of the risks, advantages and limitations of the option by both the farmer and neighbouring farmers, and

- social context (will adopting the option improve the farmer's social esteem and/or provide opportunities for sharing the experience).

While PA equipment is relatively easy to acquire and use, a commonly-cited frustration with growers who purchase a new piece of PA equipment is that it will often not work with their current equipment and hence is incompatible with their current farming practices. Reasons for incompatibility from manufacturers include protection of intellectual property and the expense of R&D to make components compatible with specific brands. Companies are addressing this issue in many ways such as investing in R&D to make systems compatible, investing in making systems compatible if requested and the user is willing to pay, or developing a one-system solution that is capable of all PA applications (guidance, VRT, yield mapping, auto-boom switching). In Europe, CANBus ISO11183 is an emerging standard to help overcome this problem, although it will not solve all incompatibility issues. There are some challenges with implementing a standard system yet to be overcome to convince the industry this approach is the solution. It is important for growers to be aware of equipment compatibility issues when they buy new equipment. This includes knowing what they want the system to be able to do; asking up front if it will work with their current equipment and what support will be offered to get the systems working.

Application of PA systems by farmers can be hindered by a lack of technical support and training to implement PA systems. This includes the need for PA equipment suppliers to provide back up support to users as a consequence of equipment incompatibility and that current equipment is still not developed to "plug and play". Manufacturers are addressing this in their service delivery using combinations of 24 hour phone support, field technicians and training local dealers and customers. There is also a need for consultants to help growers capture, interpret and devise management actions based on the large amounts of information generated by PA tools. Some of this need is a consequence of a lack of farmer confidence in using computer-based technologies. The WA PA team is developing training courses for growers and consultants on the basics of PA, how to zone a field and using variable rate technology. Training is also being conducted with local PA manufacturers to build their capacity and help overcome barriers to the use of computer-based technologies.

Observability of the risks, advantages and limitations of PA by the farmer can be difficult because of the lack of a baseline for comparison, benefits being slow to accrue particularly in early stages of implementation, and seasonally variability. We are adding to a growing collection of case studies of how growers are applying PA in a range of situations to better quantify benefits. A commonly-cited benefit that is difficult to quantify in financial terms is that PA technologies enable farmers to carry out on-farm research with their equipment at a scale and in a manner relevant to their specific mode of operating (Cook et al 1999).

The researchers in WA are working with the industry to determine benefits, accelerate and support the adoption of PA by looking at technical, research and communication issues that may be hindering the process or that can be implemented to enhance the rate of adoption. This is achieved via a steering group that comprises researchers, consultants and growers with a keen interest in PA.

Conclusion

Good progress has been made in research and development in PA in WA in the areas of quantifying economic benefits, methods of zoning and interpretation of cause of variability and possible means to manage it for increased profitability. Progress is still to be made in making PA systems easier to use by farmers.

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