Precision agriculture in the Victorian Wimmera – grower perspectives

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Abstract

Interest in Precision Agriculture (PA) has increased rapidly in the Victorian Wimmera over recent years. Many growers have invested in guidance systems and yield monitors, but few are using the technology to manage spatial variability across farming zones. This is partly due to the cost of adoption, difficulties in integrating components and problems with data interpretation. The amount of variability present and whether PA solutions can be economically used to manage different zones are important questions that growers should consider. Groups such as Wimmera Conservation Farming Association are addressing these questions by using focus farms to measure efficiency gains against the capital outlay of different PA systems. An economic analysis showed the cost of a system with 2 cm auto-steer, variable rate sowing equipment and yield maps would add about 8% or $20.00/ha/year to average input costs over 5 to 10 years on a farm cropping 1000 ha annually. The justification of this extra cost will depend on the situation, particularly the degree of variation present, efficiency gains, yield increases and/or the value growers place on factors like reduced operator fatigue, extended working hours and certain environmental benefits. PA technology has decreased in cost since its introduction and if this trend continues, adoption is likely to increase in the future. Interested growers can evaluate the technology by engaging contractors with PA tools.

Key Words

Economic analysis, integrating components, agronomy, environment

Introduction

The Wimmera region incorporates about 1 Mha of rainfed cropping land in western Victoria. Average annual rainfall ranges from 300 to 500 mm and soil type from fragile sands to fertile cracking clays. Cropping is dominated by winter cereals, grown in rotation with a variety of winter pulse and oilseed crops. The decline in grazing enterprises since the 1990's has not only increased cropping intensity with shorter pasture leys and fewer fallows, but also extended cropping into non-traditional areas (ABARE 2006). Economic, agronomic and environmental factors have driven a shift towards reduced tillage and stubble retention, albeit with an ever growing reliance on herbicides. Farm sizes are continually expanding with a typical cropping enterprise in the Wimmera now being around 1200 ha, with individual paddocks of 50 ha or more. Larger paddocks tend to have greater spatial variation due to differences in soil type, previous management or other factors, often creating a need to manage individual zones within larger paddocks differently (Figure 1). Compared to two decades ago, tractors and machinery have not only increased in size, efficiency and accuracy of input delivery, but can now operate effectively in non-traditional farming systems, such as direct drilling into standing stubble. Recent years have also seen changes in the availability and affordability of technology such as machinery guidance, yield mapping, remote sensing and an array of data collection tools such as electromagnetic soil surveys. This technology is commonly known as Precision Agriculture (PA) and provides an opportunity to create and manage zones within larger paddocks differently. This paper examines some of the issues involved with adopting this technology from a grower's perspective.

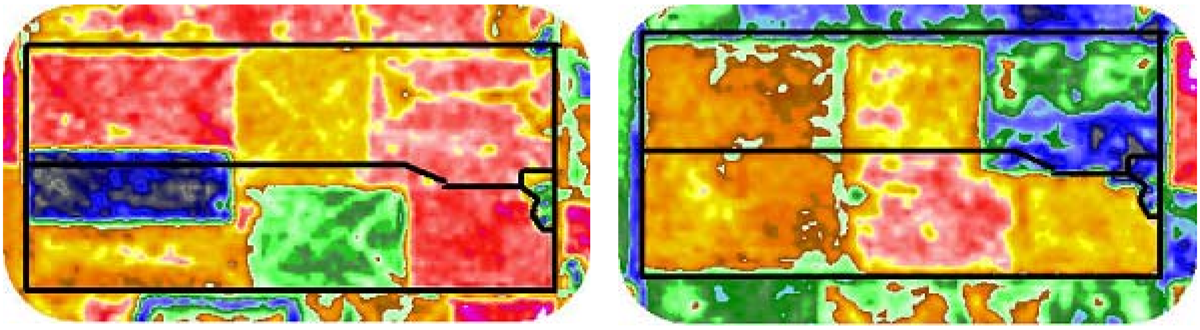


Figure 1. Example of variation in the Normalised Difference Vegetation Index (NDVI) as a result of merging 7 paddocks into two 65 ha paddocks in spring 1991 (left) and the same paddocks in spring 1997 (right).

Principles of precision agriculture

The term Precision Agriculture (PA) can be ambiguous due to the range of practices and agricultural enterprises it encompasses. Essentially the philosophy involves integrating information and technology with farm management systems. In broadacre cropping, PA generally involves Site-Specific Crop Management (SSCM) where as opposed to uniform, differential treatments are applied to zones within paddocks to better match inputs with soil and crop requirements (McBratney and Whelan 2001). PA tools have been available for over a decade, but interest has increased recently due to the declining cost of yield monitors and accurate guidance systems. Remotely sensed data and variable rate controllers have also become more accessible to growers. Whilst machinery guidance systems are a tool of PA, fully integrated SSCM systems generally require that at least *four* elements are used to manage spatial variability within paddocks.

1. Spatial referencing
A fundamental element of SSCM is the need to accurately determine positions within paddocks. This is usually achieved with Global Positioning Systems (GPS) incorporated into machinery guidance equipment.

2. Spatial variation
The viability of SSCM depends on the degree of spatial variation in paddocks (Pringle *et al.* 2003). Growers typically estimate spatial variation using sensors in harvesting equipment to generate spatially referenced yield maps that portray differences in crop performance within paddocks. Due to seasonal and other factors, it is generally suggested that yield trends be identified from yield maps over several years. The cause of any variation present then needs to be established using an array of physical sampling or remote sensing tools.

3. Management zones
Layers of spatially referenced data then need to be interpreted and matched to agronomic solutions with the aim of formulating different management zones within individual paddocks. Spatially referenced agronomic treatment maps are then produced and checked for accuracy (ground truthed).

4. Variable-rate technology
Finally, agronomic treatment maps are loaded into variable-rate units enabling inputs such as pesticides, fertiliser, sowing rate and sowing depth to be adjusted in real time as machinery passes over different zones within paddocks, *i.e.* differential action or SSCM.

Whilst the principles of SSCM are relatively simple, the processes of interpreting data, formulating and applying agronomic solutions to increase efficiency and/or yields are problematic and complex. Growers also need to consider whether the additional costs of SSCM tools are warranted and this is likely to depend on the magnitude of variation present, the effectiveness of variable rate controllers to apply agronomic solutions, economic and environmental benefits (Pringle *et al.* 2003).

Wimmera Conservation Farming Association

The Wimmera Conservation Farming Association (WCFA) was established in 1985 with a mission statement of “caring for our soils to improve production”. From conception WCFA has been involved with developing and promoting a range of soil conservation farming practices and in designing sowing equipment capable of handling high stubble loads. Ongoing investigation into technological innovations in cropping led to a survey of farming systems currently used by WCFA members and the launch of a PA project titled “Making Innovative Agriculture Pay”.

Survey of farming systems used by WCFA members
A survey concerning farming systems and the adoption of PA was mailed to the 300 WCFA members in March 2006. Of 147 respondents, 90% employed reduced tillage cropping systems and 33% sought more information on no-till and Controlled Traffic Farming (CTF) systems. The survey indicates that 42% of members used some form of PA tool, with auto-steer guidance being the most common technology

currently utilised (Table 1). Of the members who had invested in PA tools, a total of 57% had auto-steer to less than 10 cm accuracy and the farm size of 83% of these growers exceeded 1000 ha. Yield maps were collected by 28% of members that used PA technology. Relatively few members used remote sensing or other tools to identify the cause of spatial variation within paddocks and even fewer (<4% of members with PA tools) had Variable Rate Technology (VRT) incorporated into sowing equipment. Furthermore, not all members with VRT sowing capabilities are using the technology to manage spatial variability within paddocks.

Table 1. Precision agriculture tools used by Wimmera Conservation Farming Association members in 2006; a) % of all survey respondents and b) % of 76 respondents that currently use some form of PA tool.

Precision agriculture tool	a) All respondents (%)	b) PA respondents (%)
Steering/guidance		
Auto-steer 2 cm	16	32
Auto-steer 10 cm	13	25
Auto-steer <100 cm	2	4
Sub metre guidance, including light bars	27	53
Marker arms	1	2
Other		
Yield maps	14	28
Aerial photos	3	7
Electromagnetic 38 or Gamma radiometric soil surveys	3	7
Sowing equipment with variable rate technology	2	4
Auto depth on sowing equipment	<1	1

* Sum of responses exceeds 100% as some participants use more than one precision agriculture tool.

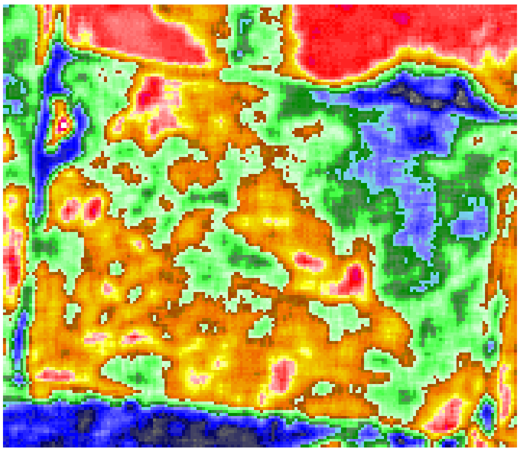
The results of the survey and further discussions with WCFA members revealed that whilst some growers have machinery guidance systems, yield maps and/or VRT sowing equipment, very few are integrating these components with other PA tools and agronomic solutions to achieve SSCM in the Wimmera. Discussions also revealed that this is at least partly due to the cost of adopting further PA tools during a series of poor seasons, lack of information, difficulties in integrating components, problems with interpreting data and in applying agronomic solutions. Accurate guidance systems can alone increase fuel and input efficiency by reducing over or under lapping and operator fatigue, but is this expense justified in the current economic climate or can these savings be achieved simply by using marker arms or adopting CTF systems.

Making innovative agriculture pay

In 2005, WCFA initiated a project funded by National Landcare Project and supported by the Victorian Department of Primary Industries, to investigate the return on investment of PA tools on a commercial scale. The project aims to evaluate the feasibility of integrating a range of PA components to achieve SSCM in the Wimmera. Six focus paddocks were established over a range of soil types in the region. Five paddocks are being managed with 2 cm auto-steer systems, benchmarked against one freehand CTF paddock. Prior to the project, some growers had obtained Electromagnetic (EM38) soil maps and several seasons of yield maps. Historic satellite and other aerial imagery including Normalised Difference Vegetation Index (NDVI) and Crop Water Stress Index (CWSI) dating back to 1991 are also being accessed. It is expected that all focus farms will be utilising at least EM38, gamma radiometric and potential or actual yield maps from 2006.

Data collected in the 2005 season confirms that gamma radiometric, bare earth aerial photography and EM38 surveys are valuable in identifying changes in soil type in the region, although the pixel size of available gamma radiometric data is relatively coarse (75 m). EM38 surveys can also estimate soil water contents and salinity levels. Satellite biomass images near anthesis proved to be an accurate indicator of yield for cereals where water was not limiting, but correlations between these images and actual yields were generally poor for oilseeds, pulses and all crops under drier conditions. In one instance, there was a strong negative relationship between the anthesis biomass of a pulse crop and actual yield. Whilst inconsistencies in the relationship between anthesis biomass and actual yield can be caused by errors in data collection and interpretation, they can also be due to a range of environmental, agronomic or management factors, particularly water availability (Rodriguez et al. 2005). Similarly, the project has identified that variations in actual yield are not always correlated with changes in soil type reinforcing that crop yields are dependent on many factors, not just soil type. Despite these issues, the accumulation of these and other data is creating a valuable resource for developing fine scale SSCM systems in the future.

A further observation is that the conventional PA zoning techniques of identifying a small number of broadly defined zones is hard to apply to the Wimmera due to the close mosaic of related soil types that incorporates fine scale variations (Figure 2). This may contribute to the low adoption rate of SSCM in the region. The challenge is to find an acceptable spatial unit size to manage soil on a finer scale and develop variable-rate technology capable of adjusting inputs on a continuous basis. Theoretically, the fine tuning of soil conditions to alleviate limitations and increase potential yield is plausible, although rainfall intensity patterns across paddocks and seasonal interactions between all factors needs to be considered.



Legend

Black-blue-green	alkaline clay
Brown to yellow	neutral, hard setting clay
Yellow to red	acidic loam over clay

Figure 2. Bare earth aerial imagery showing small scale variation in soil type in a 49 ha Wimmera paddock.

WCFA is currently collating historical biomass images with water stress and actual yield data to investigate the possibility of integrating all components into practical agronomic solutions. The challenge is to improve the correlation between known data and agronomy, combined with accurate seasonal forecasts to develop seasonally adaptive SSCM. For example, in a wet year low yielding regions within a paddock might benefit from high rates of fertiliser and in a drought year, high yielding areas could benefit from less fertiliser to slow growth and conserve water. Planning is also underway to explore the utility of using real-time remote sensing (satellite, aerial or tractor mounted green sensors) to better match nitrogen applications with crop requirements in the Wimmera. Given progress in the first year, the project should deliver interesting results and hopefully solutions, enabling interested growers to more easily and economically adopt SSCM in the future.

Economic analysis of precision agriculture in the Wimmera

Most growers consider the concept of PA interesting, but adoption requires that there is reason to invest in this technology. The decision on whether to move towards SSCM will for many growers at least partly depend on economic factors. An economic analysis was undertaken to determine the cost of using a range of PA tools to achieve SSCM in the Wimmera (Table 2). The analysis assumes an average production cost of $250.00/ha and an 8% opportunity cost foregone over the useful life of each component. All PA components are assumed to be compatible (software and hardware) and able to be retrofitted into current machinery with no additional cost. Gross margins or the financial benefits of SSCM are not presented here because of large discrepancies that can occur between environments, farming systems, crop types and the degree of spatial variability present. The reader can deliberate as to whether the financial or other benefits of adopting SSCM are justified against the costs of this technology provided. Costs are calculated for Basic (B) and Advanced (A) SSCM scenarios, with the basic scenario incorporating auto-steer to 2 cm accuracy, VRT sowing equipment, a yield monitor in harvesting machinery and data management software (Price 2005). In addition to these components, the advanced scenario also utilises a range of other PA tools listed in Table 2.

The analysis demonstrates that adopting basic SSCM system would add about $20.00/ha or 8% to average input costs on a typical farm cropping 1000 ha annually in the Wimmera. The justification of this expense will vary between individual situations, but given that 83% of WCFA members who have invested in some form of PA tool have a farm size exceeding 1000 ha (including the senior author) suggests that the cost is warranted on at least larger cropping enterprises. Adopting the advanced system would increase input costs by $53.95 or 22%, which may be much harder to justify. The relative cost of both SCCM systems decreases as the cropped area increases because the cost of PA components incorporated into tractors, application and harvesting equipment does not change until multiple units are required, i.e. the point where more than one tractor and VRT application unit are required to manage the cropped area. The WCFA survey indicated that many growers have purchased accurate auto-steer systems, but few are using technology to achieve SSCM. Table 2 indicates that accurate guidance systems are the single most expensive component of SSCM, costing around $50,000 for 2 cm auto-steer with access to a single frequency signal. In comparison and assuming that the source of variation and agronomic solutions can be established and implemented at minimal cost, the other tools required to achieve basic SSCM are less expensive (yield monitor + VRT sowing equipment + software = $32,000). Speculatively, this might imply that the low rate of SSCM adoption in the Wimmera is due to factors other than only the financial cost of PA technology.

Table 2. An economic analysis of basic (B) and advanced (A) Site Specific Crop Management (SSCM) scenarios on different areas in $/ha and as proportion of production costs which are assumed to be $250/ha before SSCM.

PA component	**Cost**	**Life**	**Area cropped annually (ha)**				**System**
Guidance and application	**($)**	**(years)**	**500**	**1000**	**1500**	**2000**	
Marker arms	8,000	10	2.88	1.44	0.96	0.72	
Light bar	4,500	5	2.52	1.26	0.84	0.63	
Auto-steer <100 cm	10,000	5	5.60	2.80	1.87	1.40	
Auto-steer 10-30 cm	20,000	5	11.20	5.60	3.73	2.80	
Auto-steer 2cm, steer single frequency base	50,000	5	28.00	14.00	9.33	7.00	BA
Variable-rate air seeder	15,000	10	5.40	2.70	1.80	1.35	BA
Auto spray	8,000	5	4.48	2.24	1.49	1.12	A
Depth control	5,000	15	1.47	0.73	0.49	0.37	A
Direct inject chemicals	30,000	15	8.80	4.40	2.93	2.20	A
Implement steering	30,000	20	7.80	3.90	2.60	1.95	A
Monitoring, sampling and agronomy							
Yield monitor	15,000	15	4.40	2.20	1.47	1.10	BA
Protein monitor	23,000	15	6.75	3.37	2.25	1.69	A
Green seeker (nitrogen and weed targeting)	15,000	15	4.40	2.20	1.47	1.10	A
Gamma radiometric survey ($/ha)	20	20	2.60	2.60	2.60	2.60	A
Soil grid maps ($/ha)	10	20	1.30	1.30	1.30	1.30	A
Remote sensed biomass index ($/ha)	2	1	2.16	2.16	2.16	2.16	A
Leaf area index ($/ha)	7	1	7.56	7.56	7.56	7.56	A
Electromagnetic 38 soil survey ($/ha)	4	10	0.72	0.72	0.72	0.72	A
Consultant/analyst ($/ha)	15	10	2.70	2.70	2.70	2.70	A
Data management software	2,000	2	2.32	1.16	0.77	0.58	BA
Basic SSCM setup (B)			**40.12**	**20.06**	**13.37**	**10.03**	
Additional cost per ha			*16.1%*	*8.0%*	*5.4%*	*4.0%*	
Advanced SSCM setup (A)			**90.85**	**53.95**	**41.64**	**35.49**	
Additional cost per ha			*36.3%*	*21.6%*	*16.7%*	*14.2%*	

*Assumes equal annual repayments over the life of each precision agriculture (PA) component with an opportunity cost of 8%, that all existing equipment can be retrofitted with units at no additional cost and that PA guidance and application equipment are compatible.

Increased efficiency through accurate machinery guidance systems can alone deliver quantifiable returns to growers. White (2006) estimated that accurate auto-steer systems could save growers 5 to 15% on input costs (fuel, pesticides and fertiliser) by reducing over or under lapping and by increasing the timeliness of operations, facilitating night spraying for example. In the Wimmera, yield increases of 10 to 20% have been reported where lentils are sown directly in between rows of standing cereal stubble (VicNoTill unpub.). This enables lentils to use the cereal straw for support, thereby reducing lodging and increasing harvest efficiency. These benefits would alone suggest that the cost of accurate auto-steer systems is justified on farms cropping more than 1000 ha annually in the Wimmera. Further yield increases could result from reduced soil compaction where guidance technology encourages the adoption of CTF systems.

Advanced SSCM scenarios are more expensive, but gross margin increases of up to $57.00/ha have been recorded in Western Australia as a result of matching inputs with crop requirements or potential yield estimates, within zones created in larger paddocks (Robertson et al. 2006). Assuming similar gains could be achieved in the Wimmera, this return is only marginally higher than the cost of adopting the advanced SSCM scenario proposed in Table 2, assuming 1000 ha are cropped annually ($53.95/ha). The potential for only a marginal increase in profit, difficulties in applying SSCM to paddocks with small scale variation in soil type, the need for a higher level of management skills and the increased risk incurred by having higher production costs coupled with unreliable seasons, means that growers are likely to be cautious about adopting advanced SSCM systems in the Wimmera at this point in time. Costs could be reduced by only using a selection of the tools proposed in Table 2 or limiting sampling to specific areas within paddocks, rather than grid sampling whole paddocks. The results of the WFCA Making Innovative Agriculture Pay project may also influence the adoption rate of SSCM in the region. PA technology has substantially decreased in cost since its introduction and if this trend continues, these tools and SSCM are likely to become more widely utilised in the future.

Precision agriculture: Strengths, Weaknesses, Opportunities and Threats analysis (SWOT)
Whilst economic factors are often an important consideration in adopting new technologies in agriculture, other factors including lifestyle and environmental implications also need to be considered. For example, some older growers may use the technology to ease workloads or to maintain interest in farming, whilst their younger counterparts may be more concerned with the idea of keeping up with technology and self satisfaction. Because some of these aspects are difficult to measure, a SWOT analysis was undertaken to further investigate the current situation and future possibilities for SSCM in the Wimmera.

Strengths
The information gathering process associated with the adoption of SSCM generally increases the manager's knowledge of each paddock. Understanding the pattern and cause of yield variability within paddocks can enhance decisions on crop selection, agronomic management or alternative uses. Such analysis may also identify physical or chemical soil constraints that are easy to correct improving fertiliser management, hence yields and gross margins. Machinery guidance systems and improving the accuracy of input delivery automatically increases the efficiency of fuel, pesticide and fertiliser use. In addition to economic benefits, this has certain environmental benefits such as reduced greenhouse gas emissions and offsite contamination from pesticides or fertilisers. The precision application of nitrogen fertilisers in mid-row banding or liquid form can reduce losses to the atmosphere or leaching and improve efficiency by better matching applications with crop requirements throughout the growing season. Precision guidance has the potential to reduce herbicide use where band spraying or inter-row cultivation are adopted for weed control. It can also reduce operator fatigue and perhaps the amount of time needed to complete paddock operations, thereby increasing the amount and quality of time that can be spent doing other things (social benefits!). Growers purchasing PA tools are investing in rapidly improving technology that is becoming cheaper over time.

Weaknesses
The initial cost of PA technology may still be limiting adoption of SSCM in the Wimmera, especially given the variable seasons over the past ten years. Return on investment will be greatest after the initial years, but carrying this cost until returns are realised may be challenging for many growers. At current prices, the adoption of some PA tools will only be economically viable for larger enterprises (>1000 ha). The benefits of SSCM are yet to be widely demonstrated in the Wimmera and this appears to be partly due to limited information, few consultants with specialised skills developing SSCM systems and the small scale variation in soil type. Data interpretation is complicated by the inconsistent use of colour scales to depict superior or inferior paddock characteristics, e.g. red may indicate productive regions on a yield map, but saline regions on an EM38 map. Similarly, there is no definitive standard for data transfer between a range of hardware and software components from different manufacturers leading to compatibility issues. Access to differential GPS signal to achieve 2 cm accuracy is also an issue in the Wimmera with many growers having to contribute to the purchase of base stations. At least locally, PA appears to be driven by resellers promoting the technology, as opposed to researchers finding agronomic

solutions to manage spatial variability within paddocks. Consequently, some growers have purchased machinery guidance systems and are now searching for methods to integrate these components with other PA tools to achieve SSCM.

Opportunities
If the viability of SSCM is demonstrated in the Wimmera, there will be opportunity for consultants to create a service industry to manage data collection, interpretation and the application of agronomic solutions. This would create a need for specialised skills in this field, potentially boosting local training institutions. There is a need to develop user-friendly software to interpret various layers of spatial data into agronomic solutions. Such software could contain modules to interpolate values between sampled locations, create management zones and program variable rate controllers. It could also record crop inputs which might have implications in the event of litigation, especially for pesticides. Crop modelling using historic paddock and climate data combined with seasonal outlook forecasts has the potential to enable seasonally dependant SSCM. Real time crop monitoring could then be used to further adjust crop inputs according to paddock variation and seasonal conditions. These tools would be valuable in risk management and the production estimates generated might benefit financing and marketing. Measuring the quality of cereals (protein) and oilseeds (oil content) could lead to means of segregating grain whilst harvesting, with marketing benefits. The number of sowing, spraying and harvesting contractors with PA tools is increasing, making data collection and other PA tools more accessible to growers interested in evaluating the technology. Some data and collection techniques used in PA could be used in collaborative research with other fields like geology and environmental science.

Threats
Without a sound understanding of data interpretation and equipment compatibility, there is a danger that the full benefits of SSCM will not be realised. Many tools commonly used in PA rely on GPS signal, which if becomes unavailable for any period of time can lead to delays in paddock operations. Examples include postponed spraying where growers had planned to spray at night and delayed harvesting where complete yield maps are desired. Over-reliance on guidance systems and associated technology could lead to loss of skills in machinery operation over time. There are potential issues between growers and consultants regarding the ownership of raw and processed paddock data (McBratney and Whelan 2001). To help ensure repeat business, some PA consultants retain raw data, which growers would have to pay for again on changing service providers. Lastly, agronomic solutions developed to manage spatial variability over the last ten dry years may require modification to match inputs, with changed crop requirements in wetter years.

At this point in time, the SWOT analysis indicates the greatest strengths of PA relate to efficiency gains in paddock operations and input application. Significant weaknesses include difficulties in applying practical agronomic solutions to manage spatial variability and demonstrating measurable results at the paddock level. Furthermore, PA would benefit from more consistency in data presentation (colour scales) and greater compatibility between the range of software and hardware components from different manufactures. There are strong opportunities to develop a specialist consultant sector with skills in linking a range of spatial and other data with applied agronomy and PA tools to achieve SSCM. Major threats include dependence on GPS signals and the loss of some traditional machinery operation skills, such as the ability to drive in straight line without this technology. Spatial technology could also assist with the development of slave, robot or autonomous machinery, potentially reducing labour requirements and the cost of human errors, but this would also lead to a loss of human machinery operators in rural communities.

Grower perspectives and experiences with precision agriculture in the Wimmera
When asked what PA is, in almost every case growers answer that it involves auto-steer or GPS systems. Few differentiate the difference between PA and SSCM, VRT or GPS tools and all the other acronyms and terminology that need to be decoded to have conversations on this topic. In general, most growers that are interested in PA have already purchased some tools, particularly guidance systems, without considering the possibility of moving towards SSCM in the region. Whilst guidance systems can improve efficiencies and the timeliness of operation, installation and calibration can be frustrating. Many growers exchange guidance units between several pieces of machinery to increase benefits, particularly in terms of carrying out night operations, such as spraying and lentil harvesting. Depending on machinery width, GPS guidance can also lead to reduced soil compaction if ‘tram tracking’ or CTF systems are adopted.

Efficiencies can be further improved by removing of internal fences. The presence of obstacles like trees and rises can greatly affect GPS signal and quality, whilst slopes can cause equipment to track incorrectly compromising accuracy. As farmers become familiar with guidance technology, they often become 'addicted' and upgrade to more accurate systems. Surveying (calculating position) for 2cm guidance accuracy can be time consuming due to satellite positioning or environmental effects, especially when signals are lost regularly. This time delay can be overcome by reducing accuracy settings or by using dual frequency systems.

Yield maps are still regarded as a good source of information, providing that care is taken to ensure accuracy during harvest. Operators only have one chance to collect harvest data per season and incomplete sets are difficult to interpret. Seasonal, soil water and agronomic factors can cause discrepancies in relative yield data across zones within paddocks between years (flip/flop zones). There is a vast amount of relatively coarse information such as gamma radiometric surveys, digital elevation data, Land Resource Assessment of soils and bare earth aerial imagery available for the Wimmera. These data-sets can be refined using rapid soil measurement techniques and 'ground truthing' to identifying potential crop management zones for fine-scale SSCM. Direct injection spraying systems have not been widely adopted, possibly due lack of information and demonstration of the benefits in the area. Such systems can not only facilitate site-specific pesticide application, but also reduce costs, operator exposure to chemicals, the need for mixing or cleaning tanks and the amount of excess chemical dumped.

Although guidance systems can be a useful tool, a number of mishaps have occurred due to complacency, inexperience with the technology or human error. These include running over fences when operators fall asleep, hitting power poles or trees with cultivator bars or spray booms and damaged tyres from implements as a result of turning too sharp because auto-steer was engaged before machinery was appropriately aligned. Problems have also occurred in managing and storing data, for example losing the co-ordinates of the initial AB line for inter-row sowing in between seasons. There have also been cases where growers have spent a lot on money on PA tools and data collection, to discover that the main factors causing poor or variable yields were cheap and easily remedied agronomic problems such as molybdenum deficiency.

The development of fine scale SSCM systems for the Wimmera will require long term projects that involve close collaboration between farmers, consultants and researchers to establish the cause of variation and how it is best managed. This process would benefit from manufacturer involvement so that hardware and software components can be developed to apply agronomic solutions within different parts of individual paddocks. Growers currently have limited access to people with expertise in SSCM who understand Wimmera conditions. As opposed to first purchasing auto-steer and other PA tools with the notion of eventually achieving SCCM, growers could perhaps engage contractors to gather accurate soil, plant and yield data for a few seasons. The amount of variation present and feasibility of applying agronomic solutions could then be established and reasoned against the expense of purchasing PA tools to achieve SCCM.

Conclusions

The adoption SSCM is proving difficult in the Wimmera, partly due to the fine scale variations in soil type and the cost of PA technology during a series of dry or unpredictable seasons. The success of SSCM depends on obtaining high correlations between the cause of spatial variation and seasonal climate data to generate agronomic solutions and manage crops according to potential yield in each zone of a paddock. Economic benefits from machinery guidance systems resulting from improved efficiency are potentially justified when cropping over 1000 ha per year, however fully integrated SSCM systems are unlikely to be economically viable in the region at this point in time. If the cost of PA tools continues to decrease over time, adoption is likely to increase in the future and this will be facilitated by the continued collection of paddock and other data. The implementation of PA systems would greatly benefit from the standardisation of data presentation protocols, software platforms and hardware compatibility so that these tools can be more easily integrated. Research organisations and funding bodies need to commit to long term projects that integrate the use of PA tools and find practical agronomic solutions to manage spatial variability in the Wimmera. There is opportunity to conduct such work in collaboration with a range of other disciplines working with spatial information.

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