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CURRENT STATUS AND FUTURE DIRECTIONS OF PA IN AUSTRALIA

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Abstract: Australia’s relatively dry climate, weathered soil, large average farm size and low farm income subsidy provide unique conditions which intuitively suit the incorporation of PA into farm management. Australian producers regard PA as a means of improving resource-use efficiencies initially, with risk and environmental management benefits following. Producers of broadacre crops, grapes and rice have been the most active in assessing which tools are most suited to their farming systems. The initial phase of adoption has seen vehicle navigation systems, crop yield mapping and soil apparent electrical conductivity (ECa) mapping being the tools most adopted. These tools have shown Australian producers that there are considerable savings to be made in input costs and that each farm and each field can provide information to improve its management. The future should bring greater use of field- and farm-scale information to tailor inputs to manage crop quality and quantity, target market premiums and continue to manage the Australian agricultural environment with best management practices.

Key Words: Australia, Precision Agriculture, Production Efficiency

INTRODUCTION

To explore Precision Agriculture (PA) in Australia it is important to understand what PA means to the Australian agricultural community. Numerous definitions PA exist and people across the globe have different ideas of what PA should encompass. However, the essence of PA is really quite clear: that enacting appropriate and timely responses to variability in agricultural production will provide economic/environmental/social benefits. A more specific definition that reflects this philosophy has been provided by the US House of Representatives (US House of Representatives (1997).

Precision Agriculture:

> “an integrated information- and production-based farming system that is designed to increase long term, site-specific and whole farm production efficiency, productivity and profitability while minimising unintended impacts on wildlife and the environment”.

This definition identifies PA as a "whole-farm" management strategy (not just for individual fields) that utilises information technology and that the aim of management is to improve production and minimise environmental impact. It also refers to a farming system which, in agriculture today, may include the supply chain from the farm gate to the consumer. Importantly it also acknowledges that precision agriculture can relate to any agricultural production system, not just cropping enterprises. Animal, fisheries and forestry industries can apply PA techniques.

A second definition is useful to narrow the PA philosophy down to its implementation in cropping systems.

Site-Specific Crop Management (SSCM)

> "A form of PA whereby decisions on resource application and crop management practices are improved to better match soil and crop requirements as they vary in the field"

This definition espouses the idea that PA is an evolving management strategy. The focus here is on decision making with regard to resource-use and not necessarily the adoption of information technology on farm (although many new technologies will aid improved decision making). The decisions can be in regard to changes across a field at a certain time in the season or changes through a season or seasons. The inference is that better decision making will provide economic, environmental and social benefits. From a farm management perspective this definition provides a direct goal regardless of a producer's PA adoption level or proposed entry point into PA. The very real practical benefits that can be considered at present include:

i) optimising production efficiency
ii) optimising quality of output and operations
iii) minimising environmental impact
iv) minimising risk

It is at these different levels that Australian agricultural industries are exploring and embracing the PA philosophy. And it is not difficult to see why.

Australia is a relatively dry continent which includes a wide range of soil types that are typically old, strongly weathered and relatively infertile. The land is populated by 21 million people, with only 4.0% of the total workforce directly employed in the agricultural sector. The continent covers 769.4 million hectares (ha) of which 57.9 % (445.1 million ha) is under agricultural use. Of the agricultural land, 26.7 million ha (5.9%) is cropped and the vast majority used for animal grazing operations (ABS 2007). Irrigated land (including crops and pastures) is less than 1% of the total land used for agriculture (ABS 2006). Of the total 129,934 farming businesses in 2006, there were approximately 41000 broadacre/row cropping enterprises (combineable crops, cotton, grapes, sugar) with an average farm size of 1570 ha. Across the agricultural industries, the level of government support is equivalent to 4% of farming income (OECD 2006).

Under these physical and economic conditions, Australian farming industries must maintain a high degree of efficiency and self-sustainability to compete in the increasingly global agricultural markets. The potential benefits offered by the philosophy of PA are well tailored to helping Australian farmers achieve these goals. This paper will concentrate mainly on the current and future use of SSCM in Australia. Readers are directed to Cook *et al.* (2006) for a history of the early development of PA in Australia.

THE PRESENT STATUS OF SSCM IN AUSTRALIA

In Australia, the type and degree of variability found on individual farms and fields is related to the geographical location, landscape and previous management at each site. This is crucial as it means that there is no single management prescription that can be defined for SSCM. But, it also provides the greatest impetus for exploring the use of SSCM, because the best information for optimally managing each farm/field will undoubtedly be derived from within its own boundaries. The PA concept exists today as a response to this realisation, and a generalised outline of how PA is being introduced to Australian crop farming systems (broadacre, horticulture, viticulture) can be defined (Table 1).

Table 1. Generalised steps to making progress with precision agriculture.

Steps	**Tools & Techniques that PA can offer**
1. Optimise average crop management.	Crop scouting and soil sampling tools, vehicle guidance and auto-steering, simple paddock experimentation tools.
2. Determine the magnitude, extent and responsiveness of spatial and temporal variability.	Crop scouting and soil sampling tools, yield monitors, soil sensors and remote sensing, more advanced experimentation, analytical and modelling tools.
3. Optimise the production input/output ratio for quantity and quality. *(to maximize gross margin and minimize environmental footprint)*	Crop scouting and soil sampling tools, crop yield and quality monitors, soil sensors and remote sensing, vehicle guidance and auto-steering, advanced experimentation, analytical, modelling and decision support tools, variable-rate controllers
4. Output quality control and product marketing.	Crop quality monitors and segregation tools, variable-rate controllers, application map recording, electronic information tagging and recording, process control technology
5. Maintaining resource-base and operation information.	Crop scouting and soil sampling tools, mapping capabilities and specialized storage software

In Table 1, the steps are usually considered in numerical order so that the most benefit is gained with the least additional cost. This does not mean they cannot be applied in conjunction, but each additional step in this process does require some new tools or techniques to be acquired and applied. Steps 2 and 3 are where most research work is concentrating in Australia in an effort to identify practical ways to quantify and respond to observed variability, but much depends on the scale and causes of the identified local variability. Many leading producers are well down this path on their properties.

Once any alterations are put in place to optimise the ‘average’ or uniform management on a farm, then causal relationships between soil/crop factors and yield are explored at the within-field scale along with the extent to which these relationships vary across the field/farm. This information is used to determine whether the observed variability warrants changes in differential treatment and if so, direct a route through a SSCM decision methodology.

GENERAL APPLICATIONS

Vehicle Navigation

Of the PA tools, this has had the greatest impact to date on Australian farm management. Advances in Global Navigation Satellite System (GNSS) technology since 1999 have opened the door for steering guidance, steering-assist and auto-steering systems for use on agricultural vehicles. These systems have been pioneered in Australia and widely adopted initially for spray guidance but are increasingly used for controlled-traffic farming (CTF) (Tullberg, 2001). CTF is essentially based on a variable-rate control process: controlling the quantity of trafficked area in a paddock to a minimum using vehicle navigation systems. There are approximately 30% (~13,000) of the broadacre/row crop farmers with some form of guidance system and 40% (~ 5000) of those with autosteer function (Johnston, 2007).

CTF has provided sustainability benefits (such as minimisation of soil compaction, allowing inter-row sowing and cultivation for reduced disease impact and herbicide dependence), economic benefits (by minimising input overlap, improving soil water management and improving timeliness of operations) and social benefits (such as reducing driver fatigue) (Webb *et al.*, 2004).

In a national first, a network of Continuously Operating Reference Stations (CORS) has been established in Victoria to provide state-wide RTK differential coverage. Known as 'GPSnet', the system is working towards enabling local farming groups to join the network and receive broadcast corrections. The success of autosteer systems in broadacre agriculture has now seen their adoption increasing in the sugar-cane industry where the increasing practice of retaining vegetative matter for later use in biofuel production makes vision difficult at harvest.

Variable-Rate Ameliorants and Fertilser

Yield mapping in broadacre/row cropping enterprises (using real time yield sensors or remotely sensed yield surrogates such as NDVI) has shown that spatial variation in yield can be typically 2-3 fold in grain crops (Clifford *et al.*, 2006) and up to 10 fold in grapes (Bramley & Hamilton, 2004). Producers are quickly accepting that this production variability has implications for setting yield and quality goals and crop nutrient use.

Australian producers are attempting to understand this variation by matching the yield data with equally intensively observed soil and terrain information. In Australia, it is well understood that the most dominant influences on yield variability (other than climate/rainfall) are the more static soil physical factors such as soil texture, soil structure, and organic matter levels. These are known to indirectly contribute to the moisture storage, cation exchange capacity and nutrient availability of the soil.

Gathering direct data on these attributes at a fine spatial scale is problematic, but a number of correlated attributes can be gathered relatively swiftly. The apparent electrical conductivity of the soil (ECa) has been shown to provide correlation with a number of the deterministic physical soil parameters and to provide corroboration of the spatial yield pattern in many fields. Paddock topography has also been shown to provide an indirect indication of variability in soil water movement and soil physical and chemical attributes - again usually due to a high correlation with a deterministic attribute such as soil texture or depth. Topography information, gathered using sub-decimetre GNSS, also provides indirect information on microclimate attributes that influence crop production potential. Both soil ECa and topography need be gathered only once across the area of interest.

Many Australian broadacre producers now routinely gather yield data using their own or contract harvesters and those with autosteer systems can collect data for the DEM during all navigation operations (tillage, sowing, spraying etc).The soil ECa maps are generally gathered using a local contractor who uses an Electromagnetic Induction (EMI) instrument such as the EM38 or an Electrical Resistivity (ER) instrument such as the Veris 3100.

In some obvious instances these layers can be used directly to formulate management plans. For example, in broadacre irrigated fields the topography can be used to derive cut/fill maps for leveling purposes. In areas of Australia where some of the soil types present are typically low enough in pH to limit crop growth, the application of lime (CaC03) is required every few years. Using the soil ECa to direct soil sampling into regions of differing soil characteristics allows differential lime requirements to be calculated to minimise the quantity and optimise the impact of that which is applied.

However, when there is not an obvious amelioration action evident, the construction of potential management classes (PMC) for further investigation is gathering acceptance. Crop production maps obviously contain information on seasonal production that is essential to this process. Beginning this process without information on the spatial variability in the saleable product would appear to be financially imprudent. In Australia the delineation of PMC is most routinely tackled using multi-temporal remotely sensed imagery (Adams & Maling, 2004) or multivariate analysis combining crop yield, soil ECa and topography/terrain attributes (Whelan & McBratney, 2003)

Including information on soil and landscape variability in the PMC decision process allows these important factors to influence the subsequent sampling and management of a field. Using the variation in the production indicator factors - crop yield, soil ECa and topography/terrain - as a basic data set to delineate areas of homogeneous yield potential has proven successful in a variety of regions in Australia (Whelan & Taylor, 2005). The response of inputs/ameliorants to these factors will of course be site-specific, but the significance of their influence appears not.

At the ACPA we have developed a procedure that has been adopted by farming groups around the nation (Taylor *et al*., in press). In general the process is:

- Measure spatial variability in the paddock production potential (at present best simply described by soil ECa maps, crop yield maps, and digital elevation models)
- Determine number and location of potential management classes using multivariate clustering if the variation is deemed suitable.
- Direct soil/crop sampling and analysis within the management classes to investigate practical causes of variation.
- Interpret test results and instigate remedial action if indicated. If analysis suggests variable-rate nutrient treatment is warranted, rate changes are formulated based on soil test data and crop requirements, replacement theory or within-field experimentation for input response is designed and analysed.

Of course other data layers that may be locally pertinent and gathered at the same spatial scale may be included (e.g. soil depth, gamma radiometrics, product quality).

Other Variable-Rate Treatment Options Used In Australia

In implementing differential treatment, many quantity-based operations that influence crop yield are being targeted to achieve desired yield goals. Ideally, the control segment of any variable-rate application should optimise both the economic and environmental product of the field. In Australia the economic considerations are dominant as there is little regulatory control on the chemistry of the agricultural environment. However, most crop producers are well aware that maintaining a healthy environment is important for sustainability and therefore economic success.

Besides traffic, fertiliser and ameliorants, Australian producers are also targeting variable-rate treatment for:

- Harvest (e.g. wine grapes for quality based on management class, wheat and barley for protein based on management class and real-time sensors)
- Sowing rates (e.g. higher cereal rates in previously mapped areas of chemically resistant ryegrass)
- Pesticide application (e.g. real-time plant sensors for application in fallow fields)
- Irrigation water (e.g. block by block vineyard irrigation based on soil ECa and imagery)
- Crop growth regulators (e.g. aerial PIX application in cotton based on vigour imagery)

INDUSTRY SPECIFICS

Broadacre Crops

Savings in input costs (chemicals, fuel, labour) of between 5% and 15% are often quoted by farmers using vehicle navigation systems. This is obviously going to be farm-specific due management differences and farm layout. However, even at 5%, with the large farm sizes in Australia this provides significant savings and swift payback of equipment costs. Further savings in the cost of herbicide are being achieved using the ‘Weedseeker’ technology for real-time variable-rate application of herbicide. Savings of between $20 -$30 per hectare are being documented (Brownhill, 2006).

In on-farm experiments, the variable-rate application of fertilisers using potential management classes has shown savings in fertiliser cost of between $5 and $35 per hectare in South Australia, Victoria and New South Wales (Whelan & Taylor, 2005; Whelan, 2007). The magnitude of these benefits has been corroborated by a whole farm economic analysis conducted across 6 properties in New South Wales and Western Australia where PA technologies had been widely implemented (Robertson et al, 2007).

Viticulture

The majority of the Australian wine grape harvest is undertaken by machine. Two Australian companies produce grape yield monitoring systems that can be retro-fitted to grape harvesters. The viticulture industry has the advantage of a perennial crop which has been shown to provide a fairly stable spatial pattern of yield variability from season to season (Bramley & Hamilton, 2004).

This stability and a growing understanding of the link between quality parameters, yield and soil/terrain conditions (Bramley, 2005) is allowing the construction of management classes using yield, soil ECa and terrain. These classes show the potential to define areas for differential harvesting to segregate the fruit on quality and allow the winery to target wine quality grades (Bramley et al. 2005). The industry is also using aerial imagery to map vigour prior to harvest, so that in certain cases picking can be scheduled to obtain a more uniform ripeness throughout the block. Financial benefits from these processes have been shown to range between 3% to 70% of the grape fruit value (Bramley et al., 2005).

Aerial imagery is also extensively used to detect disease in the vineyard before it becomes visually obvious from the ground. The vigour imagery has also been used to successfully delineate irrigation zones for variable-rate irrigation (Proffitt & Malcolm, 2005). Where new vineyards are being established, it is quite common for soil ECa maps to be used to direct soil sampling and the subsequent block and variety layouts across vineyards.

<u>Rice</u>

The New South Wales rice industry has continued to progress in its application of SSCM. Aerial imagery is now used to target in-season sampling for NIR tissue tests at panicle initiation (PI) and, in conjunction with the decision support system 'maNage rice' (Angus *et al.*, 1996), variable-rate N application maps can be constructed for aerial fertiliser application across management classes. Recommendations to rice-growers now also include the use of soil ECa maps to determine variability in yield potential, so that in conjunction with the in-season imagery and tissue testing, N application maps for both the PI stage, and prior to sowing the next crop, can be matched to soil/crop requirements (NSW DPI, 2006).

COMERCIALISATION

OmniStar subcribes it's VBS and HP correction services across the nation and a metres/sub-metre maritime navigation beacon correction service is freely available to many producers within 250km of the coast. AGCO, Case IH and John Deere all operate dealerships around the country that market and support proprietary PA equipment and software. There are another 10 companies that make and or market vehicle guidance equipment and other PA hardware (monitors, controllers, variable-rate implements etc.), 3 that provide other commercial PA software solutions, 4 that provide imagery services, 7 that provide soil ECa mapping and 7 that provide commercial data analysis and storage solutions.

The majority of Australian broadacre growers own their own harvester and yield monitors are becoming quite standard. Combine harvest contractors selling yield data is not common yet. Grape growers (except the large integrated wine companies) normally use contract harvesters and the number equipped with yield monitors is increasing.

EXTENSION

The Southern Precision Agriculture Association (SPAA) is a professional association which exists to promote the development and adoption of PA technologies within the Southern Hemisphere. It has over 200 members drawn from a broad range of industries and provides newsletters, training and field days.

The Grains Research and Development Corporation (GRDC) has just completed a large research program on PA for the Grains Industry in Australia that culminated in the release of the 'Precision Agriculture Manual' (GRDC 2006). The GRDC together with the Cotton Research and Development Corporation and the Grape and Wine Research and Development Corporation are presently funding the construction of training materials for industry and tertiary level workshops and courses in PA.

A wide variety of generic and industry-specific educational material is available through the ACPA website (http://www.usyd.edu.au/su/agric/acpa). A manual on Precision Viticulture (Proffitt *et al*., 2006) has been released to aid practical application of PA in vineyards and the Tramline Framing Technical Manual (Webb, 2004) provides information for all farming industries interested in CTF.

THE FUTURE OF PRECISION AGRICULTURE IN AUSTRALIA

The recent significant rises in fertiliser and fuel prices make the benefits of adopting the PA management philosophy more financially enticing, especially in the broadacre cropping industries. Environmental considerations will be weighted more in decisions as the political landscape changes to reflect broader societal concerns and authorities introduce regulations accordingly. This, along with the desire to get greater value from PA guidance hardware, will see a greater use of variable-rate technologies across Australia

Given that soil moisture is the major limiting factor in the majority of cropping industries, the ability to swiftly measure available soil water capacity (AWC) and ultimately soil water content across whole fields would be of great benefit. Research into estimating AWC using more easily measured soil geophysical parameters is under way (Wong *et al.*, 2006). It is also apparent that the real-time measurement of soil chemical parameters in the field would greatly increase the ability to accurately manage soil chemistry. The development of such sensing systems is progressing in Australia (Viscarra Rossel *et al.*, 2005).

Australian producers will begin to gather product quality information to a greater extent so that input management can be tailored to output quality as well as quantity. Sensors to measure quality parameters such as protein (cereals) sugar content (grapes, cane) oil (rapeseed, corn) will become more widely utilised. The whole concept of PA will be more widely extended to whole-farm management as producers extend the results of on-farm trial work.

A number of Australian producers are trialing the combination of historical production data with real-time crop data (e.g. Yarra N-Sensor; Greenseeker) to manage nitrogen inputs. This would enable application decisions to be 'seasonally responsive' and greatly reduce financial risk. As wireless internet networks and 'smart dust' sensors improve it is likely that the measurement of climatic and crop condition variability across vineyards and orchards will become more common.

Producers are now beginning to utilise more techniques for product tracking to attract quality premiums. Barley producers in Australia are now uploading spatial production information that is linked to final beer production in Japan. This will become more widely used in many industries as producers seek niche and premium markets. Spatial production information will also be more widely used to tailor production insurance premiums to reflect actual output and not agreed estimates. Spatial production and application information will also find wider use in environmental auditing and occupational and site management across most cropping industries

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REFERENCES

Adams, M.L. and Maling, I.R. (2004). Simplifying management zones – a pragmatic approach to the development and interpretation of management zones In Australia. In: R.H. Rust & W.E. Larson (eds), P*roceedings of the 7th International Conference of Precision Agriculture*, ASA/SSSA/CSSA, Madison, WI, USA (CD Publication).

Angus, J.F., Williams, R.L. and Durkin, C.O. (1996). maNage rice: decision support for tactical crop management. *Proceedings of the 8th Australian Agronomy Conference.* Australian Society of Agronomy.

Australian Bureau of Statistics (ABS). (2006). *Water use on Australian farms 2004-5,* ABS Publication 4618.0 www.abs.gov.au.

Australian Bureau of Statistics (ABS). (2007). *Year Book Australia, 2007.* ABS Publication 1301.0 www.abs.gov.au.

Bramley, R.G.V. 2005. Understanding variability in winegrape production systems. 2. Within vineyard variation in quality over several vintages. *Australian Journal of Grape and Wine Research* 11:33-42.

Bramley, R.G.V. and Hamilton, R.P. 2004. Understanding variability in winegrape production systems. 1. Within vineyard variation in yield over several vintages. *Australian Journal of Grape and Wine Research* 10:32-45.

Bramley, R.G.V. Proffitt, A.P.B., Hinze, C.J., Pearse, B. and Hamilton, R.P. 2005. Generating benefits from precision viticulture through selective harvesting. In: J.V. Stafford (ed.) *Precision Agriculture '05, Proceedings of the 5th European Conference on Precision Agriculture*, Wageningen Academic Publishers. pp 891-898.

Brownhill, D. (2006). Using 'Weedseeker' spot spraying technology in cropping systems. In: *Proceedings of the 10th Annual Symposium on Precision Agriculture in Australasia*, Sydney, Australia. http://www.usyd.edu.au/su/agric/acpa/symposiums/Proceedings_06.pdf

Clifford, D, McBratney, A.B., Taylor, J.A. and Whelan, B.M. (2006). Generalised analysis of spatial variation in yield monitor data. *J.Agric. Science* 144: 45-51.

Cook, S.E., Adams, M.L., Bramley, R.G. and Whelan, B.M. (2006) Australia. In A. Srinivasan (ed.) *Handbook of precision agriculture: principles and applications*. Food Products Press, NY. Pp529-566.

Grains Research and Development Corporation (GRDC) (2006). *Precision Agriculture Manual.* CD Publication http://www.grdc.com.au/director/research/agronomy

Johnston, P. (2007). personal communication.

NSW Department of Primary Industries (NSW DPI). (2006). *2006 ricecheck recommendations: a guide for rice crop management for improving yields, grain quality and profits and environmental sustainability.* NSW DPI. 24p.

Organisation for Economic Co-operation and Development (OECD). (2006). *Agricultural policies in OECD countries: at a glance 2006.* OECD 117p.

Proffitt, T., Bramley, R., Lamb, D. and Winter, E. (2006). *Precision Viticulture.* Winetitles Pty Ltd, SA. 92p.

Proffitt, A.P.B. and Malcolm, A. (2005). Zonal vineyard management through airborne remote sensing. *Australian & New Zealand Grapegrower & Winemaker* 502: 22-27.

Robertson, M., Carberry, P. and Brennan, L. (2007). *The economic benefits of precision agriculture: case studies from Australian grain farms*. CSIRO, Australia. 46p.

Taylor, J.A., McBratney, A.B. and Whelan, B.M. (2007). Establishing management classes for broadacre grain production. *Agronomy Journal*. (in press).

Tullberg, J.N. (2001). Controlled traffic for sustainable farming. *Proceedings of the 10th Australian Agronomy Conference 2001,* Australian Society of Agronomy.

US House of Representatives, (1997). *Bill No. H.R.2534. An Act to reform, extend and repeal certain agricultural research, extension and education programs and for other purposes. Title IV - New research, extension and education initiatives. Subtitle B - Precision Agriculture* *http://thomas.loc.gov/cgi-bin/query/z?c105:H.R.2534:*

Viscarra Rossel, R.A., Gilbertson, M., Thylen, L., Hansen, O., McVey, S. and McBratney, A.B. (2005). Field measurements of soil pH and lime requirement using an on-the-go soil pH and lime requirement measurement system. In: J.V.Stafford (ed) *Precision Agriculture '05, Proceedings of the 5th European Conference on Precision Agriculture, Uppsala, Sweden,* Wageningen Academic Publishers, The Netherlands, pp 511-520.

Webb, B., Blackwell, P., Riethmuller, G. and Lemon, J (2004). T*ramline farming systems: technical manual.* Department of Agriculture Western Australia Bulletin 4607. 89p http://www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/LWE/LAND/CULT/BULLETIN4607_PART1.PDF

Whelan, B. (2007). Road paddock – variable-rate P results. In: *Precision Ag News*. Southern Precision Agriculture Association 3 (2) pp5-7.

Whelan, B.M. and McBratney, A.B. (2003) Definition and interpretation of potential management zones in Australia. In: *'Solutions for a Better Environment' - Proceedings of the 11th Australian Agronomy Conference*, 2-6 February 2003, Geelong, Victoria. Australian Society of Agronomy. CDROM ISBN 0-9750313-0-9. http://www.regional.org.au/au/asa

Whelan, B.M. and Taylor, J.A. (2005). Local response to nitrogen inputs: advancing SSCM within Australia. In: J.V.Stafford (ed) *Precision Agriculture '05, Proceedings of the 5th European Conference on Precision Agriculture, Uppsala, Sweden,* Wageningen Academic Publishers, The Netherlands, pp 865-872.

Wong, M., Oliver, Y., Robertson, M. and Witwer, K. (2006) Technologies to estimate plant available soil water storage capacities at high spatial resolution. In: Turner N.C., Acuna T. and Johnson, R.C. (eds). *"Ground-breaking stuff". Proceedings of the 13th Australian Agronomy Conference,* 10-14 September 2006, Perth, Western Australia. Australian Society of Agronomy.