5th Australian Controlled Traffic and Precision Agriculture Conference

University of Western Australia, July 16-18, 2007

Welcome to the 5th Australian Controlled Traffic Conference. This is the first time this national conference has been held in Western Australia, the first time "Precision Agriculture" has been added to the title, and it is the first time the Conference has been run under the auspices of the Australian Controlled Traffic Farming Association, which was formed at last year's conference.

These conferences had their beginning in Rockhampton in 1995 on the initiative of Don Yule and Jeff Tullberg. These two gentlemen had the vision, insight and drive to promote controlled traffic as a means of avoiding the soil degradation caused by farm traffic compacting soil. At the time, the vision was shared on this side of the continent by our own Paul Blackwell who locally replicated their vision and drive. Geographic separation has seen developments occur somewhat independently on opposite sides of the continent, notwithstanding occasional visits in both directions.

Since Rockhampton, successive conferences have been held in Gatton in 1998 and 2000, and last year in Ballarat, Victoria, and over the period since 1995 a large amount of technology, mainly catalysed by satellite navigation, has become available. This technology is inexorably changing the nature of cropping in all its forms across Australia and indeed the world. While the cutting edge of this technology may not be in Australia, even though this country in undoubtedly one of the world leaders, let me make this prediction, Australian farmers will soon be the largest group of practitioners and will probably end up as the world leader of the technology.

The reasons for making this prediction are probably self-evident to many farmers, particularly Western Australian farmers, and they are these:

- Most Australian farms are large by world standards, and the trend is for them to become even larger.
- Large farming programs place enormous organisational and operational pressures on farmers to undertake their programs on time with a high level of efficiency to keep costs to the minimum.
- The large distances from urban centres mean labour is in short supply, highly priced and often has a sub-optimal level of skill and experience.
- Guidance, precision steering systems and geographic information systems interfaced with a variety of sensing technology, which is increasingly factory-installed in tractors, sprayers and harvesters, provides farmers some assurance of quality control when using under-skilled labour.
- Climate change, or at least unusual and highly variable seasonal conditions, is forcing farmers to continually seek new and innovative ways to obtain better use of decreasing and highly variable rains and to protect crops and grain from weeds, diseases and pests, and the operational precision and control offered by this technology provides further opportunities to be innovative.

The Program for the Conference has been assembled with several objectives clearly in mind.

- First the Conference needed to be farmer focused and build on the experience of earlier conferences.
- Second it needed to provide a range of technical and farmer expertise that was useful and/or new for both farmers wanting to begin adopting these new technological ways of farming and for those wishing to continue to refine or improve on the practices already adopted.
- Third it needed to attract presenters that had new insights to all facets of precision farming, from soil management, to guidance and sensing technology, and to innovative ways it is being assembled and used in a wide cross-section of agricultural industries.
- And fourth, it needed to provide opportunities for interaction and discussion between a wide range of experts and practitioners in an environment that facilitates discussion and resolution of issues concerning farmers.

The Organising Committee believes it has achieved all these objectives, and has received considerable assistance to do so from a range of industry and commercial sponsors, for which we are very thankful. The Committee encourages delegates to participate actively in the Workshop sessions and seize the opportunity provided to get as much from their attendance as possible. Thank you, and best wishes to you all.

Greg Hamilton (DAFWA)
Chairman
5th Australian Controlled Traffic Conference

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High Resolution Multi-spectral Imagery

Jim Baily, AirAgronomics

AIRAGRONOMICS

Having been involved in broadacre agriculture until 2000 I perceived a need for a high resolution remote sensing service to be readily available to broadacre agriculture by providing data on an as need basis. This led me to forming AirAgronomics and subsequently becoming involved with SpecTerra services, who fortunately were based in Perth and being leaders in the field enabled me to proceed with the concept. Since 2000 AirAgronomics has supplied data on an as need basis to agronomists, farmers, farmer research groups, DAFWA, and WANTFA. AirAgronomics is now contracted by SpecTerra Services to carry out all their aerial acquisition in Western Australia and on occasions assist in other states.

SPECTERRA SERVICES PTY LTD

SpecTerra Services is a Western Australian based company offering a niche airborne remote sensing technology service. The company was incorporated in July 2000, following 10 years of research and development led by Dr Frank Honey. The company's primary focus is providing high quality, high resolution Digital Multi-Spectral Imagery (DMSI) for vegetation mapping and monitoring projects.
DMSI is a low cost, high value decision making tool utilised by agricultural, mining, forestry and other land use management industries.
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TECHNOLOGY OVERVIEW

Digital Multi-Spectral Imagery (DMSI)

DMSI is a digital aerial imaging product tuned specifically to provide high detail and sensitive information for mapping and monitoring vegetation types, growth stage, health, density and distribution. DMSI is image data of the same scene recorded simultaneously through 4 narrow spectral bands. The Digital Multi-Spectral Camera system integrates 4 individual digital imaging devices (CCDs) capable of measuring ground reflectances at high resolution (0.5 metre – 2 metre) and high sensitivity within visible and near-infrared wavelengths.

Each of the 4 bands of information collected contain important and unique data. Wavelengths of incident electromagnetic energy are either absorbed, transmitted or reflected in varying proportions by ground features according to their chemical physical properties. By measuring ground reflectances at selected wavelength positions, features displaying similar characteristics maybe automatically grouped and mapped for GIS integration and further ground based investigation.

The camera system is flown in light aircraft at varying altitudes according to the required pixel resolution (or sample point size), and "frames" of imagery are acquired along GPS controlled flight lines. The acquired frames are corrected for geometric and radiometric distortions then ortho-rectified and mosaicked to form a seamless image map of the area of interest.

The system is capable of covering over 50,000 hectares in a single flight day at 1m resolution.

Advantages of DMSI

High pixel resolution for sensitive spatial and spectral characterization of individual ground features

High spectral resolution provides sensitive information for:

- discriminating and mapping variations in vegetation type, density, distribution and health,
- and monitoring for changes in vegetation status and condition between successive survey flights.
- Natural Colour and False Colour Infrared images acquired simultaneously.
- no further digitising required.
- GIS ready.

Allows consistent and rapid interpretation (spectral and textural analysis) across multiple broadscale areas of interest using automated image classification techniques.

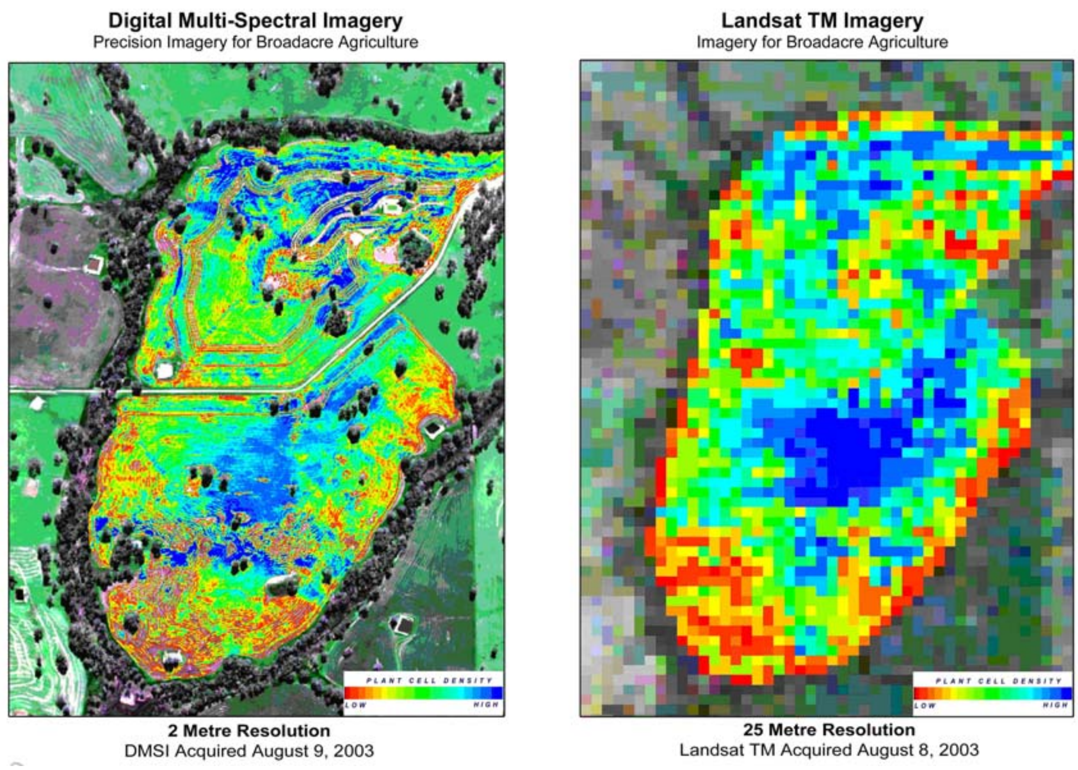


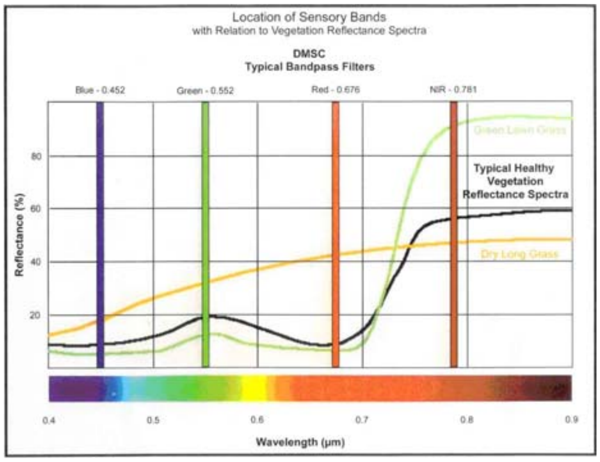
Figure 1: The advantage of high resolution Digital Multi-Spectral Imagery (DMSI) over satellite systems

As can be seen from the above example the difference is in the detail, the other main differences are:

DMSI	Satellite
Typically 0.5 to 2metre pixel resolution;	25metre pixel resolution;
Highly sensitive to leaf density, plant stress and other physiological attributes;	Moderately sensitive to plant stand density. Low sensitivity to plant stress and other physiological attributes;
Flexible airborne system for gathering data at optimum time under optimum conditions;	Infrequent passes at optimum time (16 day interval) and no data when there is cloud cover;
Data available within days of the overflight;	Data historical due to distribution lag time;

Standard bandpass filters for vegetation mapping

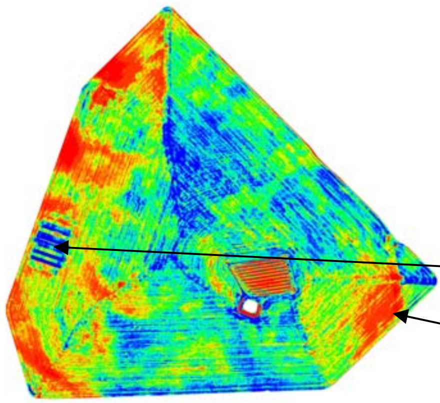
The DMSI narrow band-pass filters are easily interchanged for specific applications, however the 4 spectral bands utilised for vegetation mapping and monitoring are 20 nanometres wide and centered about the principal reflectance spectra features of vegetation.



DMSI Spectral Band and Vegetation Reflectance feature
1. Blue – 450nm (leaf pigment absorption)
2. Green – 550nm (relatively higher reflectance and transmission)
3. Red – 675nm (strong chlorophyll absorption)
4. Near Infrared – 780nm (high infrared reflectance "plateau")

Change detection

Where multi-temporal DMSI data sets exist, comparisons can be made to identify the location and extent of changes in foliage density, composition and health. Quantification and statistical analyses across broad scale areas can be made with the incorporation of localized ground based data and GIS interrogation techniques.
The example below shows the changes over a 10 week period of damage that occurred to a paddock due to severe frosting, this technique presents a meaningful representation of sensitive changes that may be occurring and not necessarily visible to the naked eye. A recent example has been research done in the phytopthera prone areas of the Gnangara groundwater mound, north of Perth DMSI detected changes over a 12 month period, that ground observers were not even aware of.



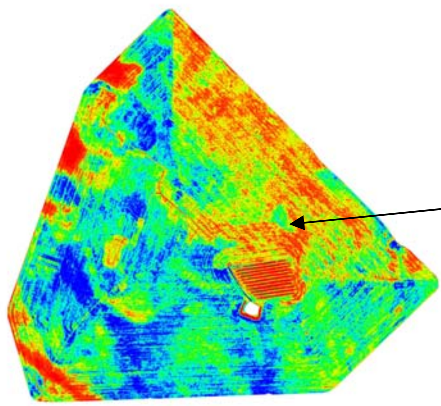
Example from a wheat crop at Borden WA

PCD 1 Taken 31 July 05

This is a typical Plant Cell Density (PCD) showing all the normal variations across the paddock Ideally the data could be used to indicate areas for strategic nutrient sampling allowing informed decisions how to manage the crop further into the season

Frost trial area, note areas of high input (blue)

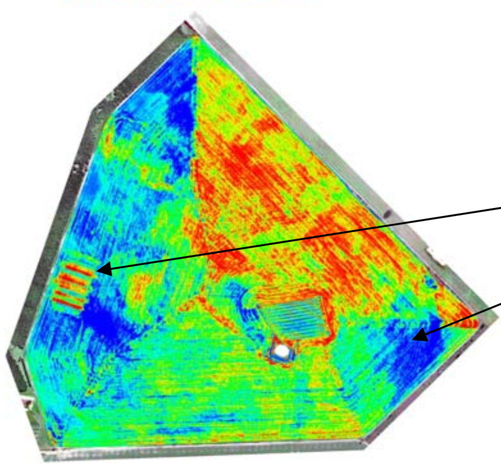
This area was suffering from water logging



PCD 2 Taken 30 October 05

Note there are a number of changes in this PCD

Boomspray tracks, glyposphate sprayed to control weeds several days before image taken



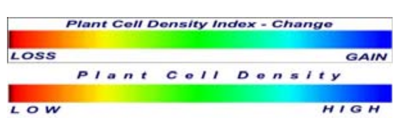
Change Detection
(The difference between the two images above)

On discussion with the farmer and his son the areas with the most change were the areas most affected by frost

Note changes in the trial area, areas showing up red were the blue high input areas in PCD1

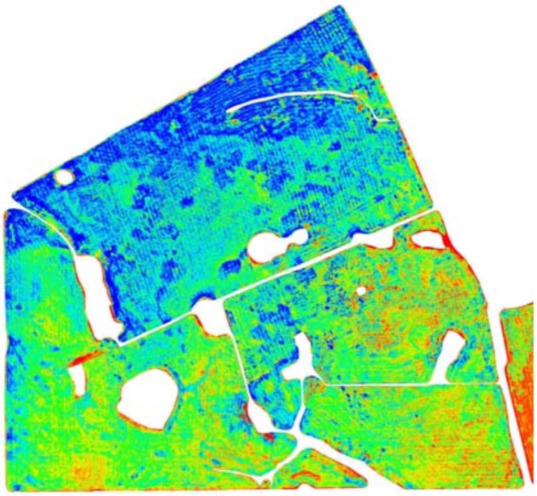
The wet waterlogged area actually picked up due to thinning out of plants and was not frost affected.

A fully geo-referenced image allows the user to be guided to areas of interest and perform accurate informed analysis in areas of interest



Plant Pigment Index (PPI)

The varying pigments associated with plant leaf structure absorb blue solar wavelength (420 to 470 nanometres) the more heavily pigmented the plant leaves the deeper the absorption of blue wavelengths. Different species have varying levels of pigmentation and therefore varying absorbtion/reflectance of blue wave lengths. While green wavelengths (540 to 560 nanometres) are mostly transmitted through the leaf regardless of species. Therefore by examining the ratio blue band (DMSI Band 1) and the green band (DMSI Band 2) it is possible to differentiate between plant species.

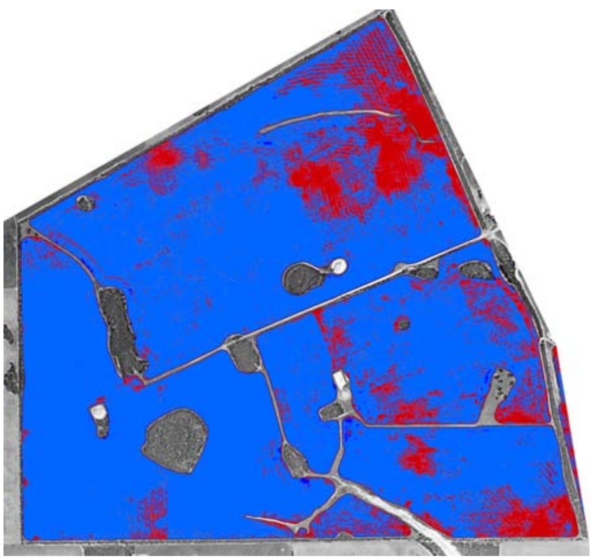


Example from a wheat crop at Esperance WA

PCD taken the 25 Sept 06

Typically shows the normal spatial variation across the paddock, the intention was to map areas of ryegrass in the paddocks to enable management decisions prior to harvest.
Using the PCD map gave no indication whatsoever of where these areas of ryegrass infestations were.

Of interest these paddocks are controlled traffic which eliminates the headland effect seen in the change detection example



Plant Pigment Index (PPI)

PPI has been derived from the original data collected which is embedded in the PCD data easy process to look at the ratio between the blue and green bands.

The red area known areas of ryegrass, it is worthwhile noting the concentrations in header trail lines that may have been carried from the main infestation

As with all Remote Sensing it is essential to ground truth to confirm that the data is correct.

CONCLUSION AND OPERATIONAL LOGISTICS APPLICABLE TO BROADACRE

The DMSI system is a proven tool for mapping and monitoring vegetation across a range of land use industries including viticulture, environmental monitoring and plantation forestry. This knowledge is directly transferable for practical and valuable applications of the technology in large scale broadacre cropping operations. DMSI is fast becoming an affordable and key knowledge tool in the Precision

Agricultural process. With camera systems located regionally the data is now readily available to growers looking to take advantage of within field variability inherent in all farming systems.

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ACKNOWLEDGMENTS

Andrew Malcolm, managing director of SpecTerra Services for his assistance.
Farmers whose data I have used in these examples.

Adopting Controlled Traffic on an Average-sized Property in an Economically Rational Way

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BACKGROUND

My property is situated mid-way between Brookton and Corrigin about 200km east of Perth in the Central Wheatbelt. When the seasons used to be normal the annual average rainfall was 330mm and the growing season rainfall (May to October) was 240mm. All the soils on my property are duplex with A-horizons ranging from gravely sand through to grey clay. The major soil type is however, is loam over clay. The property has a total area of 2,280ha, of which 2,135ha are arable. This includes a recent purchase of 1130ha of neighbouring land which happened to become available in an otherwise stable ownership environment. Cropping occupies 84%, or 1,793ha of the arable area, and sheep graze the remainder 342ha. The topography is gently undulating over 90% of the arable land. The remaining 10% is best described as flat. Our cropping program includes wheat, lupins, barley, canola and field peas.

HISTORY OF MY CONTROLLED TRAFFIC AND PRECISION AGRICULTURE ADOPTION

My first acquaintance with the technology that is now becoming the norm, rather than rare was in 1996. In that year I obtained my first yield mapping capability and this began to open my eyes as to the productivity variability across my cropping program. Around the same time I heard of the work that Dr Paul Blackwell of DAFWA was doing with controlled traffic and the possibility of improving the efficiency of my operations, both in terms of movement around paddocks and in terms of minimising inefficiencies in the operations of seeding, spraying, mid-season fertiliser applications and harvest appealed to me, and I purchased some marker arms in 2001. These provided my first experience with controlled traffic.

I persevered with the marker arms for four seasons and upgraded to auto-steer for the 2006 season. Like other data (see Blackwell in these proceedings) reductions in the order of 20 per cent have been achieved in the amount of fuel used.

Now my interests lie in increasing the productivity of the less productive areas of my cropping area. Each year I compare yield maps, and I have now identified those areas that are always less productive. These are currently being analysed for nutritional deficiencies, and some ameliorative applications of potassium have been spread in a relatively rudimentary form of zone management.
Some form of profitable zone management is now my immediate challenge.

MY SYSTEM

Currently my machinery is based on a 3m trackwidth. However, the tyre widths are not matched, and my tractor still has dual rear wheels. As my machinery replacement program and budget allow, I plan to progressively achieve a 100% match in trackwidth and tyre width. The ultimate decision on any of my replacement upgrades is confidence that the improved level of performance will be profitable in its own right.

My machinery and operations compacted 41% of the land before I started. The proportion currently compacted by tracks is 26%. Ultimately, I will decrease the area compacted by my machinery tracks to 13%. During harvest the chaser bin travels down an adjacent track and pulls across parallel with the harvester until it fills. It then moves back onto the adjacent track and moves off the paddock.

CHALLENGES OVERCOME AND REMAINING

Overcome

The significant challenge I have had to deal with so far is not the layout or operational pattern of controlled traffic working, but the need, time and expense of making sure my runs were not obstructed by:

- clearing odd trees that align with the central portion of my machine runs;
- clearing rocks;
- removing grade banks and drains; and
- installing roaded catchments to fill dams, to replace of the grade banks.

Trees that align with the edge of my runs are retained because the overlap involved in avoiding them is minimal.

These challenges are common for any farmer starting to adopt controlled traffic, and warnings of their likely occurrence and advice on options to handle them is now easily have been provided by Departmental experts and farmers who have adopted Controlled Traffic. The orientation of the controlled traffic tracks are determined by the shape of the paddock. The tracks are aligned with the longest fence in each paddock. I have not experienced any problem with rain running from my tracks and causing erosion or waterlogging in depressions. I put this behaviour down to improved soil conditions creating less runoff, and tracks that run obliquely across the slope so that any run off from them infiltrates into the seedbed on the downhill side of the track. I am quite confident that this option will work because measurements (Blackwell *unpubl.*) on my property have shown the soil between tracks has up to 300 times the infiltration capacity of the tracks. My stubble management practice prevents avoids seeding problems with successive crops. The stubble is cut short and the chaff is caught in a trailing chaff bin, which is dumped in the paddock when full. The chaff is either sold as stock feed or burned in the paddock. Weed and disease management is routine.

Remaining

I have an occasional difficulty with the reliability of my GPS signal, which is probably a sensor problem that can be overcome by an upgrade. The base station has to be moved sometimes, which requires a recalibration with each move to re-establish exact positioning on the existing tracks. This is a challenge that other farmers share with me and again is an issue that Paul and others have recorded.
I aim to adopt as much precision in the management of zones of differing productivity. So far I have identified and classified ‘high’ ‘moderate’ and ‘low’ productivity areas and have undertaken site specific analyses of the soil in these areas. So far, the only identifiable treatment has been zonal applications of potassium fertiliser as this has been the only nutrient shown to be deficient. I am keen to find other treatments that will raise the productivity of the ‘moderate’ and ‘low’ productivity areas and will invest appropriately when I am confident I have a profitable solution.

CONCLUSIONS

Although I do not have explicit financial records of the costs and benefits of auto-steer, my bottom line indicates that the cost was recovered in one year!! How you may ask? Well, as many will have heard from a number of sources, particularly from Paul Blackwell and Bindi Isbister of DAFWA, I have achieved this through a combination of the following factors:

- Increased ease of operation (on the operators and machines) for all activities, spraying, seeding, applying mid-season fertiliser dressings and harvesting;
- Increased efficiency of seed, fertiliser and spray applications;
- Improvements in soil conditions over and above those attributable just to the adoption of no-tillage practices;
- Noticeable reductions in the draft and fuel usage, through better traction on the tracks and the reduced draft requirements for the soil between our tracks, which has markedly improved in condition.

My experience leads to the overall conclusion and recommendation for those thinking of adopting controlled traffic and precision agriculture, and this is that the most economic way of adopting this new way of farming is to first buy a guidance system and a yield monitor. These do not have to be the latest and most precise. Taking this economic and somewhat conservative route allows one to learn and adapt their operations incrementally with little or no financial risk.

REFERENCES

Blackwell, P. (2007). Development of Controlled Traffic in WA and Future Directions Integrated with Precision Agriculture these proceedings).

Yield Limiting Factors in Relation to Precision Agriculture along the South Coast of WA

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INTRODUCTION

The South Coast region (SCR) of WA, incorporating the southern part of the Katanning region, and the Albany, Jerramungup and Esperance regions, comprises an area of about 5 million ha. The region experiences a strong seasonal Mediterranean climate with cool, wet winters and hot summers. The rainfall in the region ranges from 700-800 mm near the coast to 300 –350 mm at a distance of 150 to 200 km from the coast. The soils in the region range from deep siliceous sands, Fleming gravelly sands on clay to grey clays. Crops grown in the region include wheat, barley, canola, lupins, oats, field peas and some opportunistically summer fodder crops.

Using the 'rule-of-thumb' to estimate water-limited yield potential of French and Schultz, a yield potential for cereals for the 450-700 mm annual rainfall zone of 4.5 – 8 t/ha should be expected and for canola, 3 – 4 t/ha. A more sophisticated approach using crop growth models estimated about 3.5 t/ha for a drier than average year and 6.2 t/ha for a wetter than average year for the Katanning region. However a benchmark survey from 1996 to 2001 of current yields showed an average wheat yield of 2.7 t/ha, 2.4 t/ha for barley and 1.4 t/ha for canola (Hill and Wall work, 2002).

On the Esperance Sandplain soil, work carried out in the mid 1990s showed that in the absence of water-logging and non-wetting, crop yields were amongst the highest in the nation. Commercial canola yields of 3.5 t/ha and experimental barley yields > 7 t/ha have been produced on the Sandplain soils (Hall, 2003). However, such yields are now very rarely achieved let alone sustained.

Failure to achieve the yield potential are attributed to physical, chemical and biological constraints associated with the dominant soil types in the SCR. Many of these are duplex soils with large differences in soil texture between the top- and the subsoil. The dense structure of the clayey subsoil severely restricts the internal drainage which results in waterlogging during the winter months, a time when winter sown crops are most susceptible to waterlogging. Significant yield reductions have been recorded due to waterlogging (Zhang *et al*, 2005c, Setter and Waters, 2003). It has however been demonstrated by Bakker *et al.* (2005) that waterlogging can be reduced and yields increased by improving the surface drainage using raised beds

In the absence of waterlogging a soil physical constraint such as soil compaction could also limit the rooting depth and therefore the plant available water and nutrients, particularly toward the latter part of the growing season when higher temperatures increase the evapotranspiration. The large and heavy tractors with very wide tyre-prints used under moist conditions, such as occur at seeding time, would be the main contributor to soil compaction. It is however difficult to estimate how wide spread this problem is in the SCR in the presence of duplex soils, soils that are naturally compact at depth..

The soil physical/chemical constraint of non-wetting is common in many of the soil types in the SCR and limits the plant available water particularly at the break of the season. Claying of the top soil has been carried out for a number of years to remedy this problem with many positive results (ie. yield increase).

The low soil fertility of many soil types dominant in the SCR is a further constraint in achieving the water-limited yield potential of many crops. A baseline study by Hill and Wallwork (2002) found that farmers in the high rainfall zone typically applied an amount of fertiliser of 50 – 70 kg/ha. That is only enough for half the potential wheat yield of 6 t/ha however in view of the uncertainty of the weather (ie. waterlogging, drought) applying more fertiliser can be very inefficient and/or uneconomical.

In summary many of the limiting factors for a sustainable production are well understood but not often identified in the field let alone the remedies implemented by the farmers. This paper describes the effort to identify these factors, some possible remedies and implications for precision agriculture.

METHODOLOGY

During the 2006 growing season some paddocks occupied by the major soil types representative of the SCR were selected on five properties located at Tambelup, Woodginellup, Gairdner, Jerramungup and Jerdacuttup, representing the breadth of the region. The paddocks were monitored during the season using digital multispectral images (DMSI), intensive soil sampling, determining the texture, moisture and nutrition for the major and micro elements, crop tissue testing at each sampling point and yield maps at the end of the season.

Following the results of 2006 and in consultation with the collaborating growers possible limiting factors, other than the lack of rain, were identified and some remedies in the form of field trials determined. Most of the trials were implemented by the farmers as large strips also to be harvested by the farmers. During the 2007 growing season detailed monitoring of crops and soils in the strip trials continues and will include again the use of high resolution DMSI and yield maps which will assist in the interpreting of the treatment results particularly where variable soil types and positions in the landscape might affect productivity.

RESULTS 2006

A number of variables and the range in each paddock investigated at the five farms are presented in Figure 1.

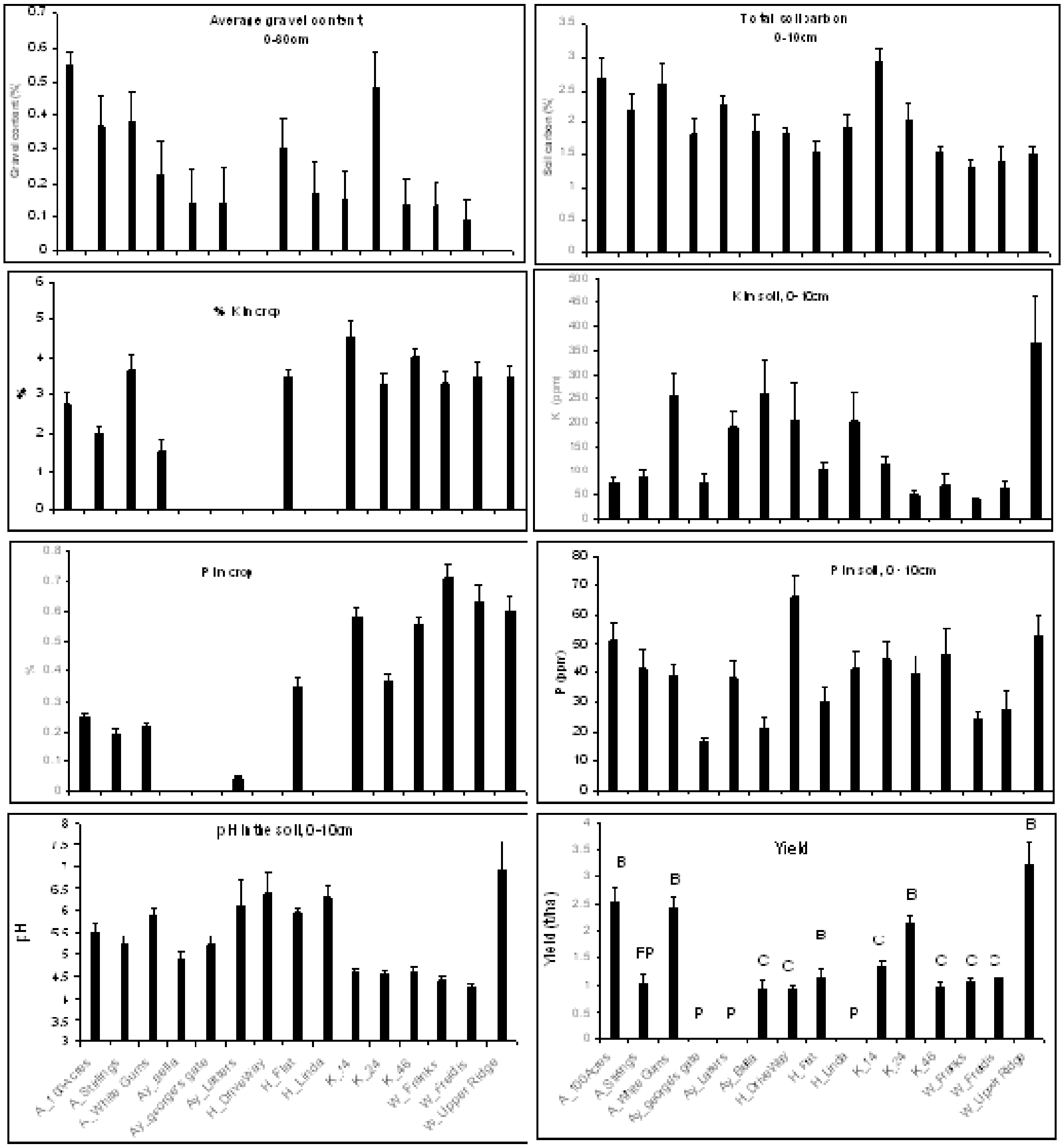

Figure 1. Some soil and crop tissue properties and the corresponding yield and standard deviation of the observations in all the paddocks.

All but two paddocks consisted of predominant gravely duplex soils but the range of gravel content between the paddocks varied considerably which affected the amount of soil moisture stored in the middle of July, see Figure 2.

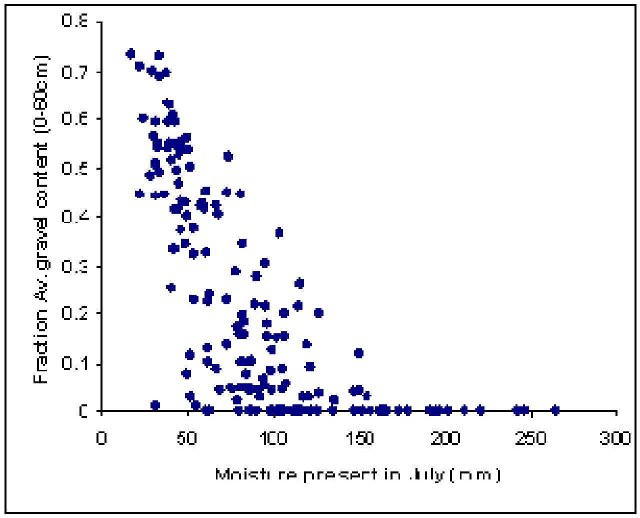

Figure 2. Soil moisture stored in the top 60 cm as a function of the fraction of gravel in 0 to 60 cm

The carbon levels in the top 10 cm also varied considerably between paddocks with some variation within the paddock, typically with a range of 1.2% to 3.7% for the highest mean C% paddock levels and 0.9% to 1.5% for the lowest mean. There was little variation in the K and P levels of the crop within the paddocks but considerable variation existed between paddocks. There was very little correlation between the soil P and K status and the level of P and K in the crop. The soil pH varied little within the paddock except for Ay-Latters, H-Driveway and W-Upper ridge where the pH varied by up to almost 3.5 units. In these three paddocks different soil types were identified where the pH was different which was also reflected in a different barley yield at W-Upper Ridge but not in the canola at H-Driveway. The range in yields as a function of the soil moisture present in July as presented in Figure 3 reflects this response.

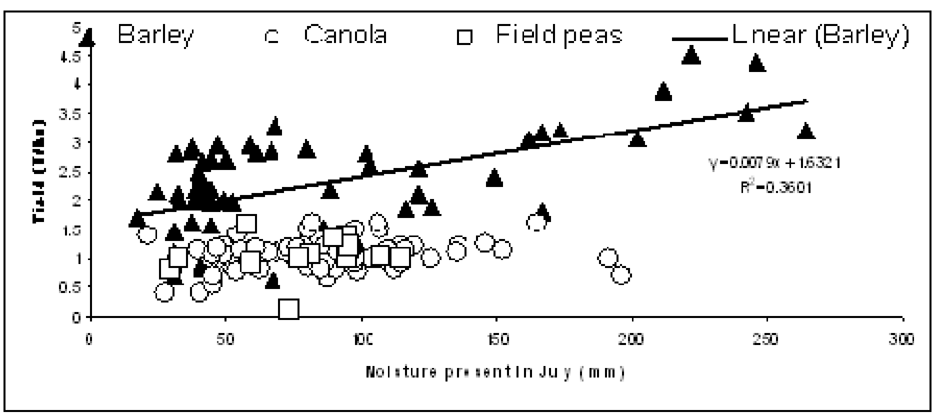

Figure 3. Yield at all the sampling sites as a function of the soil moisture in July 2006.

The barley responded to the variation in the moisture which was mainly determined by the difference in soil type but the canola did not respond in the same way. The canola yield was fairly similar between the various paddocks even though the growing season rainfall varied from 163mm in Jerramungup to 235mm at Jerdacuttup. Other than the relationship between barley yield and soil moisture no other obvious correlations were found between yield and other variables such as OC, total N, P, K, EC, pH or EC.

The low growing season rainfall would have played a major role in establishing the yield potential hence reducing the impact of other possible yield limiting factors. However despite the well below average rainfall there was still a range in the yield across each of the paddocks as indicated by Table 2, indicating that certain factors other than rainfall were affecting the yield. The yield potential was obtained from the Potential Yield Calculator (Tennant *et al*., 2000)

Table 2. Location, growing season rainfall (GSR), the crop types, the mean, minimum and maximum yield obtained in the paddock and the potential yield solely based on GSR.

Location	GSR (mm)	Crop	Mean (t/ha)	Min (t/ha)	Max (t/ha)	Potential (t/ha)
Tambelup	182	Canola	0.92	0.39	1.48	0.78
Wooginellup	193	Barley_1	2.4	1.7	2.8	2
		Barley_2	2.5	1.6	3.3	2
		Field peas	1	0.8	1.6	1.2
Jerdacuttup	235	Barley	3.2	1.8	4.5	5.1
		Canola_1	1	0.8	1.2	2
		Canola_2	1.1	1	1.2	2
Jerramungup	163	Barley	1.13	0.6	1.7	2.08
		Canola	0.91	0.7	1.2	0.8
Gairdner	218	Barley	2.1	1.6	2.5	4.2
		Canola_1	1.3	0.8	1.6	1.68
		Canola_2	0.97	0.7	1.2	1.68

At times the maximum obtained in the field was larger than the potential (Tambelup and Wooginellup) while at other times it was lower (Remainder of the locations). It is possible that this reflects the general agronomy approach of the farmers (“aim for the max” or “play it safe”) and should be distilled a little further using 2007 data.

From the soil analysis several factors were identified as possibly yield limiting based on conventionally acceptable levels and trials were designed to test the effectiveness of some of the remedies. A summary of these is presented in Table 3.

Table 3 The location, paddocks, main finding of the soil and crop survey in 2006 and the proposed field trial for the 2007 season

Location	Paddock	Main finding, 2006	Field trial, 2007
Tambelup	1,2	Very compacted soils (clay)	Deep ripping
	3	Water repellence	Claying
Wooganellup	1	Low pH at surface and at depth	Liming and deep cultivation
	2	Low pH at depth	Deep cultivation
	3	Water repellence	Claying
Gairdner	1	Low K levels	K response trial
	2	Limited fertility	Various fertilisers (WMF) + and – microbes and CSBP
	3	Low pH	Liming
Jerramungup	1	Various soil types	Response to in-season N, according to soil type
	2	Low K and water repellence	K response, claying
	3	Nematodes	Break crop and nematices
Jerdacuttup	1	Low K	K response
	2	Low pH at surface and depth	Liming and deep ripping
	3	Hard-setting reddish soil	Gypsum response

From the survey and the monitoring of several paddocks it became clear that general crop management is a large contributor to intra-paddock variability. Liquid-N spray overlap, header strips, spreader overlap, seeder problems and herbicide damage were some of the causes of an increase in the intra-paddock variability responsible for 5% to 100% yield variation within the paddock. With careful management these factors can be brought under control therefore reducing the intra-paddock variability.

CONCLUSION

From the survey it was obvious that the inter-paddock variability was more prominent than intra-paddock variability which is much easier to manage from a precision farming point of view. Managing paddocks separately based on soil and tissue testing is within easy reach of many farmers without the need for greater detail in their soil and crop sampling strategy. Careful crop management would reduce the management effects on the yield variability further.

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Development of Controlled Traffic in WA and Future Directions Integrated with Precision Agriculture

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DEFINITIONS

In this discussion paper, 'precision technology' includes the equipment and systems considered in 'Tramline farming' (TLF), 'Controlled Traffic farming (CTF), 'Raised Bed farming (RBF) and 'Precision Agriculture' (PA), especially 'Variable Rate Technology' (VRT).

INTRODUCTION

For many growers and consultants there is a wide and bewildering choice of for precision technology, competing strongly with other current concerns of finance for machinery replacement, adequate farm size and the attraction of suitable staff. The choices some growers have already made may not have been the best, in hindsight. Costs of yield monitors, remote sensed images and variable rate equipment are also relatively less than many modifications and guidance systems required for controlled traffic or tramline farming. This has encouraged some growers to move into variable rate technology first; not necessarily the best choice for early improvement of farm profitability and efficiency. It is important to estimate the possible priority and sequence of the best purchases and changes. Grain growing in Australia is also challenged by an increasing frequency of dry seasons; assessment of the role of precision technology to best manage these circumstances is important to minimise financial risk for those considering adopting the improved cropping systems offered by precision technology.

BENEFITS OF CTF/TRAMLINE FARMING IN WA

Research in WA since 1997 has identified the following benefits to grain growing from CTF/Tramline farming :- (1) A more robust grain growing system; better grain yield and quality. (2) Less wastage of inputs by more precise driving. (3) shielded spraying option.
The size of these benefits and their relative contribution to net farm income for medium rainfall sandplain farming systems are summarised in tables 1 and 2; from Blackwell et al. (2003). **About 70% of net financial benefit comes from traffic control after deep ripping.**

Table 1. The grain yield and value from 9m wide harvester cuts for normal or controlled traffic after initial deep cultivation in 1997 at Mullewa, Western Australia

Crop (year)	Lupins(1998)	Wheat(1999)	Canola(2000)
Measured yield (Normal Traffic)	1.10	2.43	0.94
Measured yield (Controlled Traffic)	1.21	2.75	1.04
Benefit of CT over NT (%)	10	13	11
Benefit kg/ha	110	316	103
Average grain price at farm gate	170	172	313
Benefit $/ha (average = $35/ha)	18.7	54.3	32.4

Table 2. Potential net financial benefits of CTF, on a whole farm basis for WA, with 2000 ha of sandy soils and lupin/wheat/canola/wheat rotation in medium rainfall; 2003 prices

Source of benefit ($/ha)	Area applied to	Gross benefit Benefit x Area	Estimated cost $/ha	Net benefit $/ha/yr (%)
Traffic control (40)	100%	40 x 1 = 40	3.3#	37 (**69**)
Input saving (15)	100%	15 x 1 = 15	7.5 *	7.5 (**14**)
Fuel saving (3)	100%	3 x 1 = 3	Nil extra***	3 (**6**)
Weed control in lupins (30)	25%	30 x 0.25 = 7.5	1.5**	6 (**11**)
Total $/ha		65.5	12	53

\# average costs/ha of machinery track modifications from five case studies in WA.
* $15,000 p.a. for four years for dGPS autosteer on the 2000 ha property; minor cost to match widths.
** shielded sprayer worth $30,000 for 2000 ha of lupins over 4 years; autosteer already purchased..
*** machinery modifications already done for compaction control covers this cost.

Similar estimated gross margin benefits from the first year of CTF adoption have been calculated for other soils with clay or gravel dominated textures (Blackwell et al 2004a)
(4) Firm permanent tramlines and weaker soil between tramlines reduce power requirements for traction and cultivation. The measurements and records from paddock experiments and farm records showed **about 20% less fuel use by use of tramlines in No-Till** (Blackwell et al. 2004b). Figure 1 shows an example of the fuel savings from in-paddock monitoring of tractor fuel consumption.

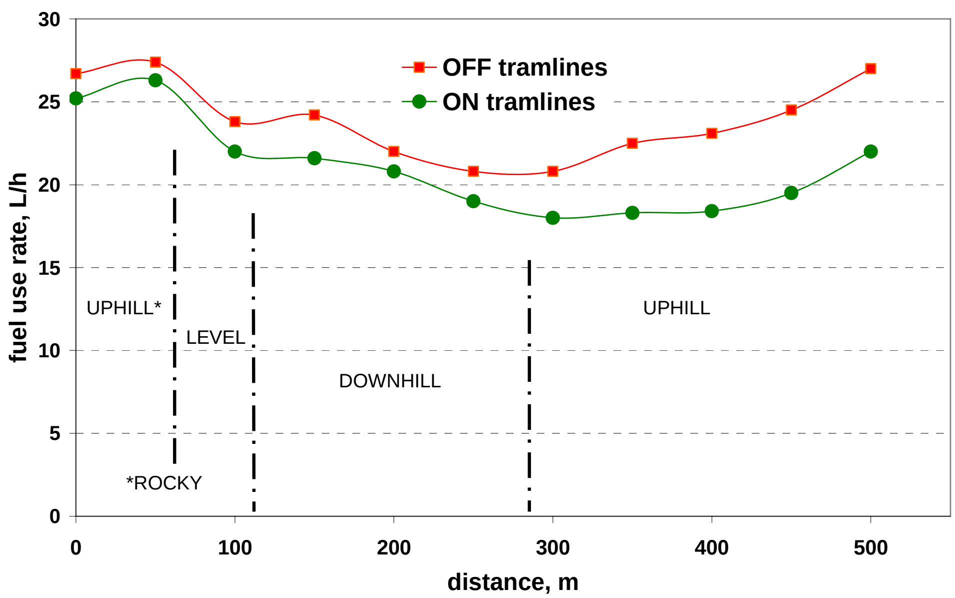

Figure 1. An example of fuel use with or without tramlines for a herbicide spraying operation at Minninnooka farm near Geraldton. The effect of slope on tractor movement is indicated, as well as the surface condition. Tramlines reduce fuel use by reducing rolling resistance.

Technical details on how to apply the principles of controlled traffic within a tramline farming systems and capture some of the benefits are described in a technical manual available from http://www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/LWE/LAND/CULT/BULLETIN4607_PART1.PDF

Possible downsides of using such precision technologies may be:

- poor compatibility of tramline based field traffic layouts with surface water control structures and revegetation patterns in the landscape

- increased soil erosion risk when surface cover is low and the topsoil is compacted by grazing; especially gully development, when tramlines are across slope
- satellite dependence, risks of serious interruptions from downtime of navigation systems.

To capture these possible benefits and avoid possible downsides we need a broad understanding of the technical opportunities and costs of the new technologies and strategies to reduce risks and capture the best net benefits for each situation and in the best sequence.

An integrated view

This paper offers an INTEGRATED VIEW of all the new technologies by considering which ones offer the best early benefits, and which rely more on others to provide later benefits. Cropping area drives many of these total benefits from new technologies thus it easier for larger programs to repay higher costs of autosteer and smaller programs (often those who do not use hired drivers) to cover the costs of marker arms. Despite this, the benefits of better soil management and new ways of sowing or spraying between or in rows can still be captured, whatever the guidance technology chosen. Precision agriculture's benefits from farming zones differently with variable rate technology come from accumulated knowledge of paddocks; thus it is more sensible to plan that technology as a later development. A farmer in New South Wales was quoted in a meeting in 2003 as follows: "We started with yield monitoring, then went to variable rate technology then to controlled traffic. **With hindsight we should have reversed the order!**" This is a good indication that those in WA who move into the new technologies, or who are already partly involved, need to get the adoption sequence sorted out to ensure the best benefits. Peter Stone in "Do the sums to check precision pays it's way" Farming Ahead No 148 May 2004 pp 18-20 also concluded "When the benefits of reduced compaction and greater traction are added, tramlining is a more certain investment than the use of precision agriculture for fertiliser zone management".

The Figure 5 is a flowchart that proposes a pattern of adoption of precision technology for cropping in a beneficial time sequence. The proposed sequence begins at "apply to the whole farm" in the flowchart. A yield monitor and suitable steering guidance technology are the first purchases. The monitor allows an early start to collecting as much annual yield data as possible for multiple growing seasons; this will help later choices of where and when to apply soil amelioration and variation of inputs. The appropriate guidance technology is the foundation for the traffic control system and the 'platform' from which to apply novel agronomic techniques for appropriate benefits. Benefits of reduced driver fatigue, reduced wastage of fertiliser seed and fuel will be gained from this first stage.
Progress to investment in swath and wheel track matching will enable traffic control and with the guidance system provide the basis for the majority of technical benefits to crop production (from yield improvement, through greenhouse gas reduction to offset running benefits). Somewhere in this part of the sequence decisions may occur on specialist tools, such as bed formers and shielded sprayers, according to the relative importance of waterlogging control and reduction of weed control costs for each individual farm.

The yield variation data, as well as biomass data, acquired over the seasons since purchase of the yield monitor will then allow more precise identification of zones of poorer yield within paddocks. Visual Soil Analysis (VSA) and analysis for subsoil constraints (SSC) may then diagnose the cause of poorer yield and proscribe a suitable economic remedy; e.g. deep cultivation with some chemical stabilisation. When the major economically rectifiable constraints have been corrected, the remaining variation in productivity and gross margins will be largely due to differences in soil fertility and leaching potential. Then a sequence of paddock based trials will help identify how variation of inputs by VRT may better match the nutrient requirements of different zones, as well as accommodate the needs of different weed populations and disease risks. At that stage there will be no further challenges and there will be more time to relax!

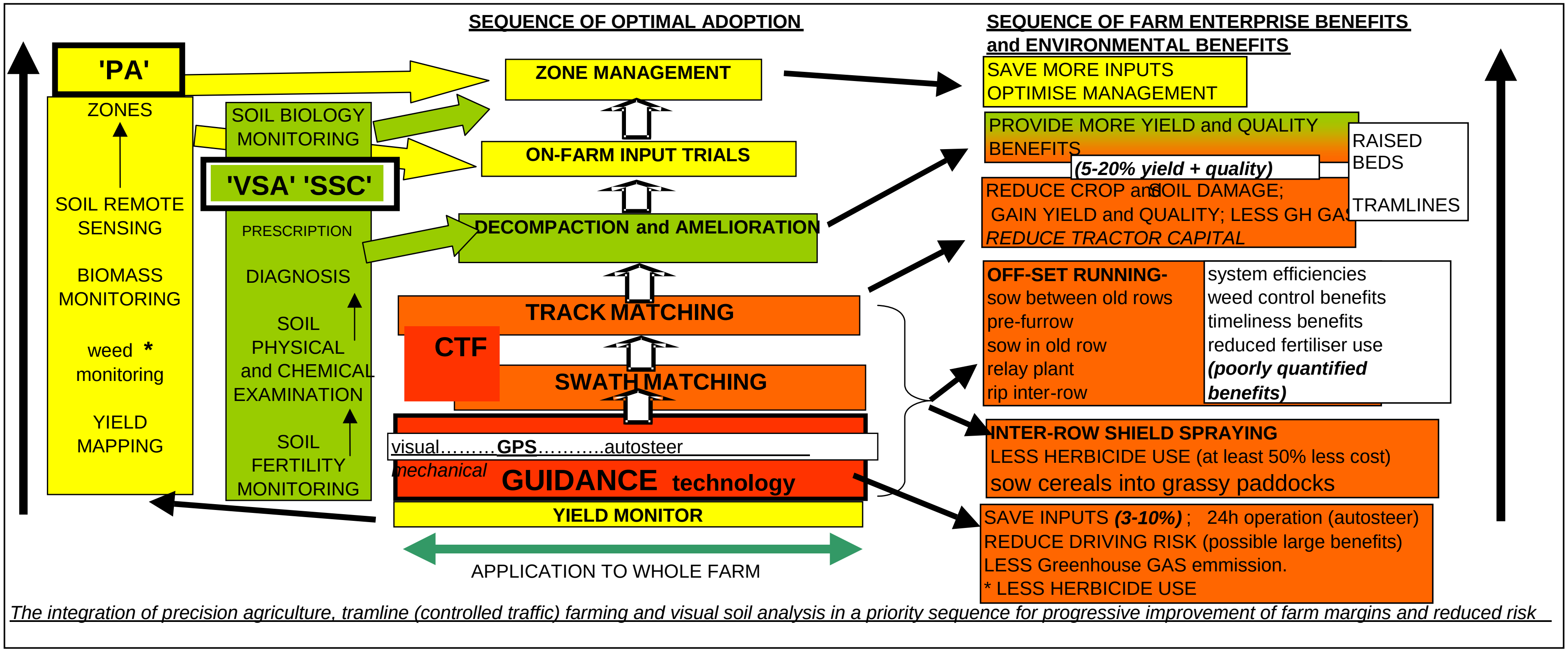

Figure 5. A flowchart showing the integration of Controlled Traffic Farming, Precision Agriculture and subsoil improvement

Better husbandry of the environment and carbon trading

Controlled traffic/tramline farming, precision agriculture and soil examination offers more than financial and risk management to the farm enterprise. More precise operations and the segregation into different zones (tramline, row, inter-row, 'soil type') allow the farm and regional environment to benefit from the following.

- Generally less herbicide and fertiliser use from managing paddocks in 'zones' of approximate soil types, as well as treating patches of weeds instead of the whole paddock with a herbicide; thus less opportunity for herbicide to drift into remnant vegetation and waterways.
- Less greenhouse gas production (CO_2 from fuel burning and N_2O from nitrogenous fertiliser losses in wet conditions) due to less fertiliser application with little overlap. Blackwell et al. (2004b) showed there was also a potential of 200 tonnes of CO_2-equivalent saved annually for every tonne of extra grain production by CTF (assuming an estimated 10% yield benefit on 2.5t/ha). These savings in emissions may attract carbon credit trading from other emitters of greenhouse gas to benefit the farm budget.
- Easier integration with in-paddock tree planting; with compatible matching between swath widths, especially odd ratio fits of sprayer to seeder.
- Possible integration with surface water control structures when broad-based banks are used with downhill tramline patterns; especially for raised beds. The downhill tramlines and furrows minimise overland flow concentration and the rollover banks (with good surface cover) minimise risks of high surface water flow rates.

Controlled Traffic for dry seasons

There is growing evidence that there is a shift in rainfall and evapotranspiration patterns in the northern agricultural region of WA towards less frequent and lighter winter rains combined with increased rates of evapotranspiration rates. We now have some evidence that the soils with low clay content can retain more plant available water for dry conditions when they are not as loose as possible, but firmed by a process such as rolling before seeding (Blackwell, 2005). A trial at East Binnu, NE of Geraldton, investigated the effect of pre or post seeding traffic on grain yield from a sandy soil in a dry growing season; 170 mm of winter rain in 2004. The results, in figure 3, confirmed the suspicions of some observant farmers that light compaction, or 'firming' can be beneficial to yield in a dry season for deep ripped sandy soils.

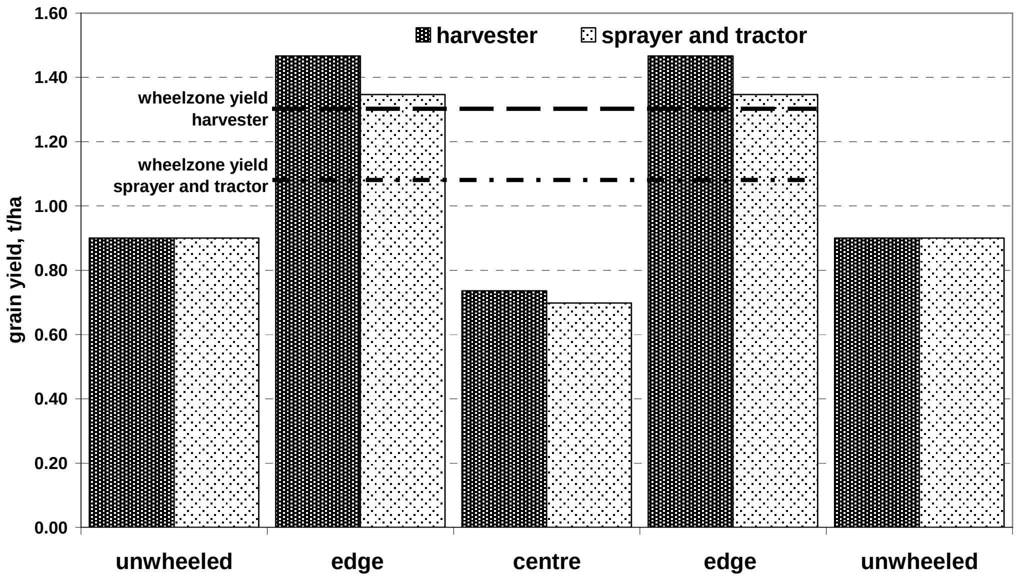

Figure 3. Effects on yield by traffic on deep ripped sand in a dry season. The harvester was used in the previous season, the sprayer before seeding. The 'wheel zone' is twice the wheel width and 'edge' measurements came from the unwheeled crop next to the wheelmark and half the width of the wheelmark. 'Centre' is the central 50% of the wheelmark

Compaction under the centre of cropping traffic wheelmarks, after deep ripping, reduced yield; even in dry seasons. 'Firming' from lateral forces alongside wheelmarks improved yield. Post seeding traffic and intense traffic from seeding plant was more detrimental and produced net negative effects on yield. Appropriate firming a loaded roller after deep ripping sandy soils and pre-seeding should help to improve yields from deep ripping and reduce yield loss in dry seasons. Coil packers may be too light to achieve this firming effect.

The most important current consideration of many farms in WA considering conversion to CTF is 'Will the investment in CTF be more profitable than the equivalent expenditure on improving work rates at seeding to help adapt to a drying climate?'

The number of days when soil is adequately moist for seeding declines as rainfall becomes less frequent and of smaller amount; especially when higher temperatures and stronger winds induce faster evaporation of available soil moisture. A cropping program faced with fewer seeding days needs a higher work rate to enable the same area to be cropped within the same calendar period and maintain the planned income potential. Higher work rates at seeding can be achieved by widening the seeding bar and increasing row spacing without increasing tine number; this enables the same tractor power to be used. Wider row spacing will also enable higher forward speed to improve work rate. If a work rate is increased by 20% then the grain production from each planting opportunity will be more than the increase from conversion to CTF (approx 10% at best in the first year). If the increased work rate also allows earlier planting of each paddock, there will be corresponding increases of yield from earlier time of sowing which may not be available from conversion to CTF. This analysis needs quantification in more detail, but is most likely to be a net benefit for investment in improved work rate, compared to investment in CTF, when rain events are fewer and the whole cropping program is difficult to achieve without improvements to work rate.

CONCLUSIONS AND FUTURE DIRECTIONS

To gain earlier financial benefit from precision agriculture and tramline farming, purchase guidance first (GPS autosteer or one marker arm), as well as a yield monitor, then finance machinery modifications to capture benefits of compaction control. Later, after some management of subsoil constraints and input trials, variable rate technology may be worthwhile to gain the most from ‘precision technology’.

Environmental benefits may include potential for carbon credit trading.

Penalties from ‘over loosening’ sand by deep ripping in dry seasons in a CT system can be reduced by firming with appropriate rollers after deep ripping.

Caution is advised for investment into CTF for the drying climate of the WA wheatbelt; the same investment in improved work rate at seeding may be more profitable.

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The Use and Effects of Controlled Traffic Farming

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ORIGIN OF PAPER

The Use and Effects of Controlled Traffic Farming is a project which was conducted from April to December 2006 by Jacob Bolson, an undergraduate agricultural engineering student in the Department of Agricultural and Biosystems Engineering at Iowa State University. The project was supervised by Dr. Amy Kaleita, Assistant Professor of Agricultural and Biosystems Engineering. Data collection took place near Waterloo, Iowa, United States, at the Mitchell Farm. Funding for the project was provided by the Practical Farmers of Iowa—Iowa State University College of Agricultural On-Farm Research and Demonstration Program.

CONTROLLED TRAFFIC FARMING

What is controlled traffic farming (CTF)? CTF is an agricultural production method in which the same wheel tracks are used by all field operations, to the extent possible. The implementation of Global Positioning Systems (GPS) in agriculture has taken a significant role in the adaptation of CTF methods by the use of machines equipped with high-accuracy autosteer. With high-accuracy autosteer, farmers are able to see consistent repeatability from year to year and between different fields. Thus, it becomes increasingly possible to operate equipment in permanent, well-defined, and precise tracks.

Potential benefits of CTF are numerous. Because compaction is limited to the tracks, overall infiltration of water into the soil is increased. Improvements in soil structure also mean that drainage is improved, allowing an early warm-up of the soil in the spring. Furthermore, the improved seedbed conditions result in more even germination. As a result, overall yields from CTF can be 5-23% higher than fields with non-CTF practices, despite the unplanted wheel tracks, which generally account for approximately 16% of the total field area. Other benefits include decreased soil erosion, higher organic matter retention due to decreased tillage, and increased moisture retention. CTF can also reduce operating costs in addition to increasing yields. Fuel usage can be lowered, due to higher tractive efficiency, as well as the lower energy requirements for tillage. Also, with less need for intensive tillage, lighter tractors can be used.

CTF does have disadvantages. Equipment investment can be quite intense or very minimal, depending on the current status of the operation. Implement widths must be of equal width or multiples of each other in order for CTF to work. If the implement widths are not set up this way, following permanent, well-defined tracks is not feasible. In addition to implement widths, machines need to be equipped with high-accuracy, GPS powered autosteer. Without high-accuracy autosteer, GPS error can lead to vehicle travel outside of the specified wheel tracks. With the vehicle traveling outside of the wheel tracks, the purpose of CTF is defeated. Implement drift is also something which can cause issues in CTF. Tow-behind implements tend to drift more than integral (3-point hitch) mounted implements. Depending on the level of implement drift, an implement such as a strip-till bar or planter can drift into a wheel track.

Management becomes more intensive with a CTF operation. There is no more "just drive into the field." Records need to be kept on the location of the wheel tracks through an in-field marker and/or electronic storage via GPS coordinates. These records must be very strict so that consistent wheel track usage can be kept constant. If these records are not accurate, GPS error will only magnify any problems may occur.

Rutting is also a problem which can develop over time. As the wheel tracks get repeated use and the crop bed soil structure improves, the height of the wheel tracks can become lower that the adjacent crop bed. At time of heavy rainfall, this height difference can lead to the wheel tracks acting as waterways. This can lead to erosion problems on the wheel tracks.

OBJECTIVE

Controlled traffic is an agricultural production tool whose effects are largely unknown in a Midwestern United States environment. The objective of this research project was to collect water infiltration, soil resistance, and
crop yield data for a Midwestern United States farm utilizing controlled traffic as a tool in their agricultural production and then provide that data to agricultural producers interested in controlled traffic.

THE MITCHELL FARM

The CTF system used by the Mitchell Farm is based on 30 foot (9 meter) implement widths and 120 inch (3 meter) wheel track width. The general cropping procedure on the Mitchell Farm consists of a corn and soybean rotation. Corn in planted in 30 inch rows and soybeans are planted in 15 inch rows. The Mitchells combine, tractors, and sprayer are fitted with RTK-powered autosteer. The fertilizer cart for the strip till bar, as well as the corn planter and soybean air seeder, are fitted with RTK-powered implement guidance. Tire size information for the tractors and combine is provided in Table 1.

Table 1. Machinery tire sizes

Vehicle	Front tire size	Rear tire size
CaseIH MX270 Tractor	600/70 R30	710/70 R42
John Deere 8530 Tractor	600/70 R30	710/70 R42
CaseIH AFX8010 Combine	900/60 R32	600/65 R28

MATERIALS AND METHODS

Site description

The water infiltration and soil resistance data collection site consisted of soils which were generally of the silty clay loam type. The CTF field was in its third growing season of controlled traffic at the time of data collection. The production history of the non-CTF field was unknown.

Water infiltration

Infiltration is defined as the process of water entry into the soil, collected in units of depth per unit of time. The data in this project was collected in units of millimeters per hour ($^{mm}/_{hour}$). Infiltration can be influenced by a number of factors that often occur at the soil surface or within the soil, such as physical soil characteristics, soil surface cover, and soil water content. Increased levels of soil resistance (compaction), a physical soil characteristic, can result in greatly reduced infiltration rates.

Two types of infiltrometers were considered for collecting water infiltration data: single-ring (Figure 1) and double-ring (Figure 2). In comparing the two models, the single-ring model has a distinct size and weight advantage. The single-ring model permits rapid, unsupervised measurement of infiltration through an automated data collection system. However, the data from a single-ring model can be influenced easier by factors causing an abnormal increase in infiltration rate, such as plant roots and wormholes. A double-ring infiltrometer is not as easily influenced by these factors because the infiltration data is collected over a larger area. Despite the potential for abnormal infiltration rates, it was decided to use the single-ring model because of its size advantage (Figure 3).

Soil resistance

A Jornada impact penetrometer was chosen to capture soil resistance data because it provides results independent of the user when developing a soil resistance profile. There are two key issues with standard "push-type" penetrometers. First, "push-type" penetrometers do not give a resistance profile; they only give maximum soil resistance. Second, the soil resistance value which is displayed by the penetrometer is a function of how the probe is pressed into the ground. A Jornada impact penetrometer solves both of these problems by developing a 24 inch resistance profile and providing consistent results. The impact penetrometer works by dropping a 2 kilogram weight from a set height on to a striker plate. The striker plate hits are counted for every 2 inches of soil penetration. This data is then used to map the resistance profile. The 2 inch soil penetration value can be changed to meet user preference. Figure 3 provides a visual description of the Jornada impact penetrometer with Figure 4 showing an example of soil resistance data collection.

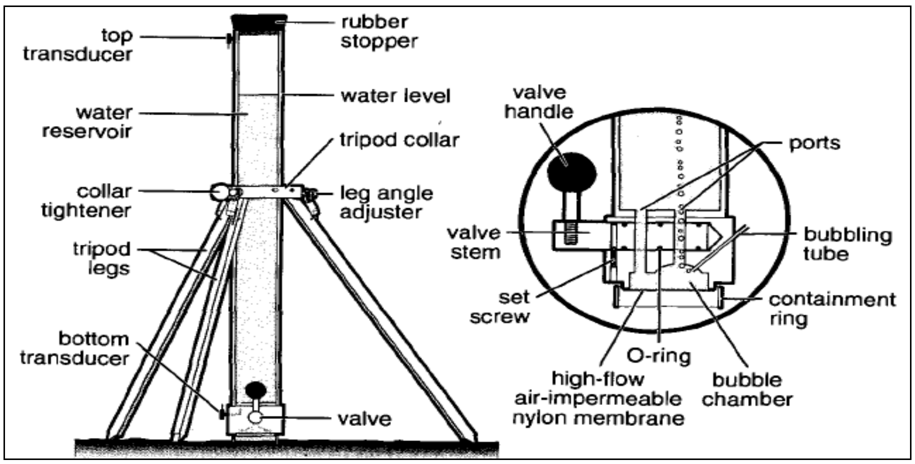

Figure 1. Schematic diagram of the single-ring infiltrometer (*(image courtesy of Fangmeier, et al.)*

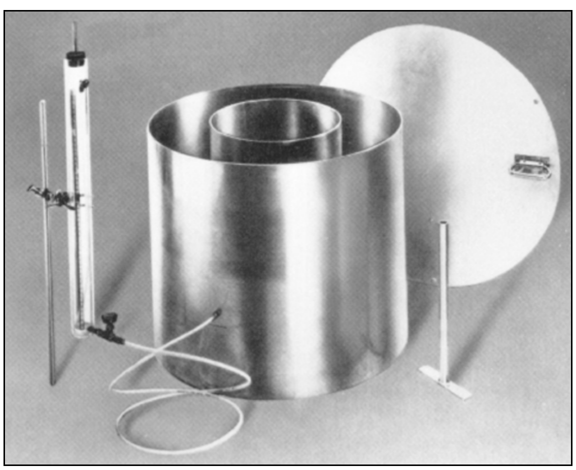

Figure 2. Double-ring infiltrometer *(image courtesy of www.rickly.com)*

Figure 3. Water infiltration data collection

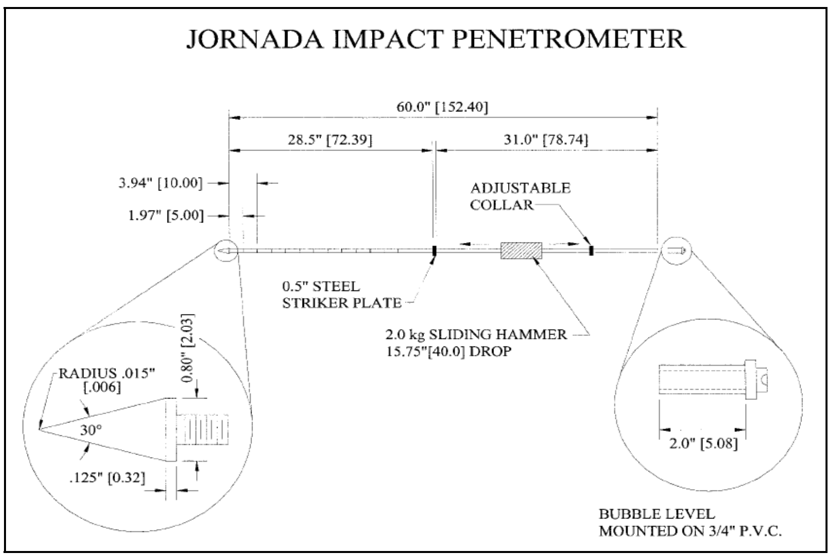

Figure 4. Jornada impact penetrometer

Figure 5. Soil resistance data collection

Crop yield

In order to collect crop yield data, a partnership was formed with Robert Recker of Cedar Valley Innovation, LLC. Crop yield data was collected in a row-by-row manner using equipment provided by Mr. Recker (Figure 6). It was decided to collect crop yield data in this manner so that row-by-row yield comparisons could be made, something which is not possible when collecting data from multiple rows at once. The crop yield data from each crop row was calculated using a yield monitor and then adjusted accordingly using data from a weigh wagon. All corn row lengths were approximately ½ mile.

RESULTS AND DISCUSSION

Water infiltration

Table 2 provides a list of basic water infiltration rates referenced to various soil types. The rates linked with each soil type are theoretical rates based on assumed soil properties. Data was successfully collected from only CTF transect 1 instead of all four transects and 25 of the 26 non-CTF points (non-CTF transect 1 plus non-CTF transect 2). Figures 7 and 8 provide the data collected in these two environments with Table 3 providing a summary of the data. It was expected that once the results from the infiltration data collection were compiled, there would be a substantial difference between the CTF wheel track, CTF crop bed, and non-CTF rates. However, the data proved to be inconclusive.

Figure 6. Crop yield data collection

Table 2: Basic water infiltration rates

Soil type	Basic infiltration rate ($^{mm}/_{hour}$)
Sand	Less than 30
Sandy loam	20 to 30
Loam	10 to 20
Clay loam	5 to 10
Clay	1 to 5

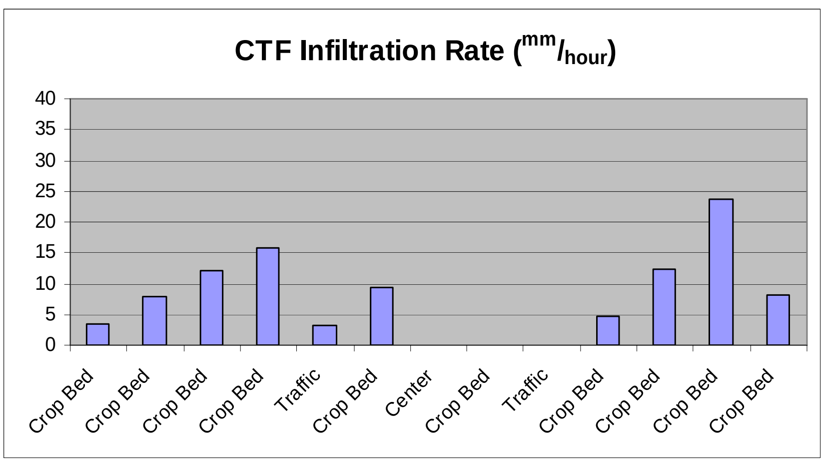

Figure 7. CTF transect 1 infiltration rate

Table 3: Infiltration data summary

Environment	Average infiltration rate ($^{mm}/_{hr}$)	Standard deviation ($^{mm}/_{hr}$)
CTF wheel track	4.4	6.2
CTF crop bed	19.3	19.1
Non-CTF	21.6	26.5

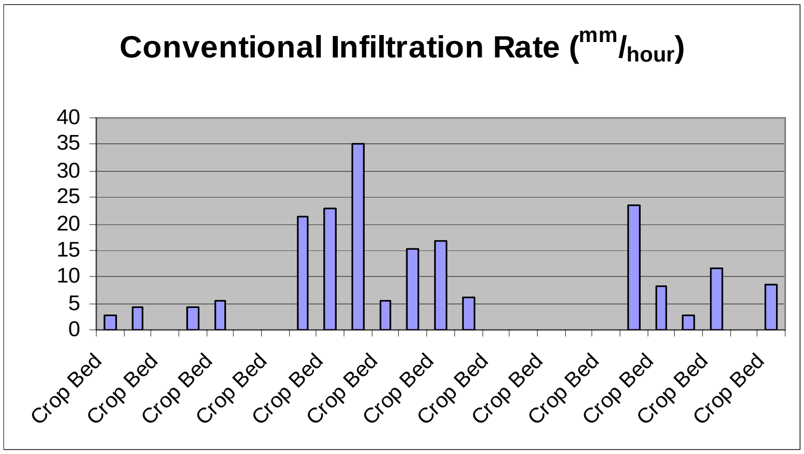

Figure 8. Non-CTF infiltration rate (transects 1 and 2)

Soil resistance

Stating that a specific soil resistance level inhibits crop root development is difficult because soil resistance is a function of many factors: soil texture, moisture content, bulk density, etc. Appendix Figures 19, 20, 21, and 22 provide the soil resistance data captured at four CTF transects with Appendix Figures 23 and 24 providing resistance data for two conventional (non-CTF) transects. The CTF soil resistance data points were collected in 30 inch increments across each transect with the data point naming schematic originating at the center of the transect. The naming schematic was defined as follows, using 1/W/3 as an example:

- Transect number (1)
- Data collection location: west of transect center or east of transect center (west)
- Distance from transect center in 30 inch increments (3 x 30 = 90 inches from center).

The conventional data was also collected in 30 inch increments across the two transects but the data point naming schematic originated at the outer edge of the transects.
The resistance levels are per two inches of soil depth. As expected, the soil resistance in the wheel tracks of the CTF transects was significantly higher than the crop beds. A key observation to note is that the wheel track compaction penetrates to a depth of approximately 8 to 10 inches. Before data collection took place, it was expected that this compaction would reach to greater depths. Another key observation is the soil resistance levels from the two non-CTF transects; there were data measurement points within the conventional transects which had soil resistance levels higher than wheel tracks in the CTF transects. This shows the harm which random wheel traffic in a field can do, resulting in crops growing in areas of high soil resistance. Figure 9 provides a summary of all soil resistance data. The aforementioned note about soil resistance becoming relatively uniform after 8 to 10 inches is shown clearly by this graph.

Crop yield

When collecting the crop yield data, the purpose was not to compare actual yields but consider yield trends. CTF yield data are provided in Figures 10 and 11 with conventional yield data provided in Figure 12. The yield data in Figure 10 is from 12 rows of broadacre corn with the data in Figure 12 from 12 rows of strip intercrop corn. Strip intercropping is a cropping procedure in which strips of corn and soybeans are alternated across a field: 12 corn rows, 12 soybean rows, 12 corn rows, 12 soybean rows, etc. This procedure is used to increase corn yields by capitalizing on the increased sunlight usage by the outer rows.

As shown by the CTF crop yield data in Figure 10, there is noticeable yield variability from row-to-row. In a conventional cropping practice, this variability can come from a variety of factors: planter problems, fertilizer application problems, compaction, etc. By utilizing a CTF cropping procedure, compaction can virtually be eliminated from the list of possible problems leading to yield reduction. A conventional cropping procedure does not allow this elimination, no matter the tillage practice. This is supported by the soil resistance data discussed earlier in which there were levels of conventional soil resistance higher than the CTF wheel track resistance. Figure 11 shows less row-to-row variability, resulting in an overall increase in total yield. Also, the yield increase of the outer 4 rows shows the benefit of strip intercropping. Figure 12 shows another excellent example of noticeable row-to-row yield variability over 32 total rows, two passes of a 16 row planter. Again, this exemplifies the need to reduce the number of factors which can cause yield reduction, which is an advantage of CTF.

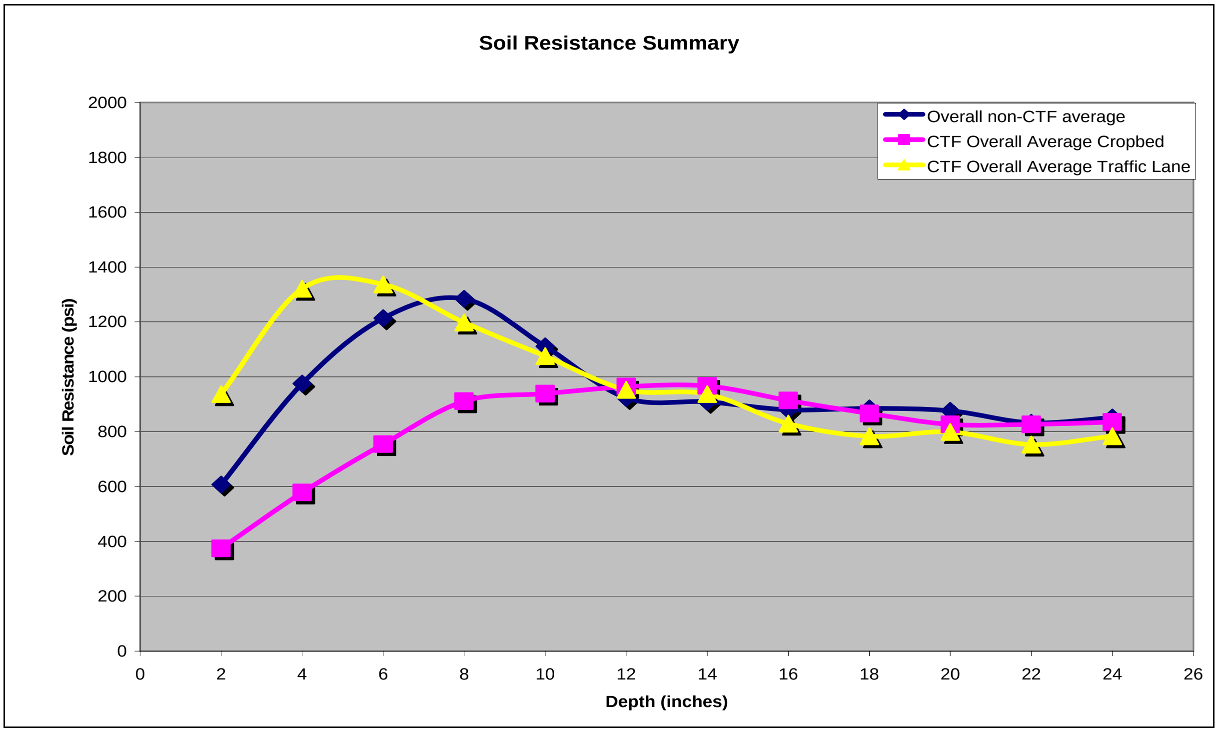

Figure 9. Soil resistance summary

Additional observations

Besides the water infiltration, soil resistance, and crop yield, other general observations were made. First, it is difficult to quantify some of the benefits of CTF. For example, on July 1 a walk was taken around the fields in which the water infiltration and soil resistance data were collected. Figures 13 and 14 provide images taken on that day. The left side of Figure 15 is a CTF wheel track and the right side is a crop bed. On July 1, there had been no precipitation for many weeks and the soil appeared to be very dry. As expected, the non-CTF soil was hard and crusty; its condition resembling that of a CTF wheel track. However, even though the soil was very dry, the CTF soil was still soft and had no surface layer, which the non-CTF did. The overall health of the CTF soil appeared to be substantially better.

CTF DISADVANTAGES

There are four key disadvantages of CTF:

- Cost
- Management
- Row spacing
- Wheel track rutting

The initial cost of CTF can be large. Initially, capital may need to be invested in equipment so that implement widths are equal or in odd multiples of each other. Also, an investment in high-accuracy auto-steer may need to take place as CTF is nearly impossible without auto-steer. In additional to financial investment, CTF does require an external level of management. The locations of the permanent wheel tracks must be recorded and logistics for crop harvest must be carefully planned.

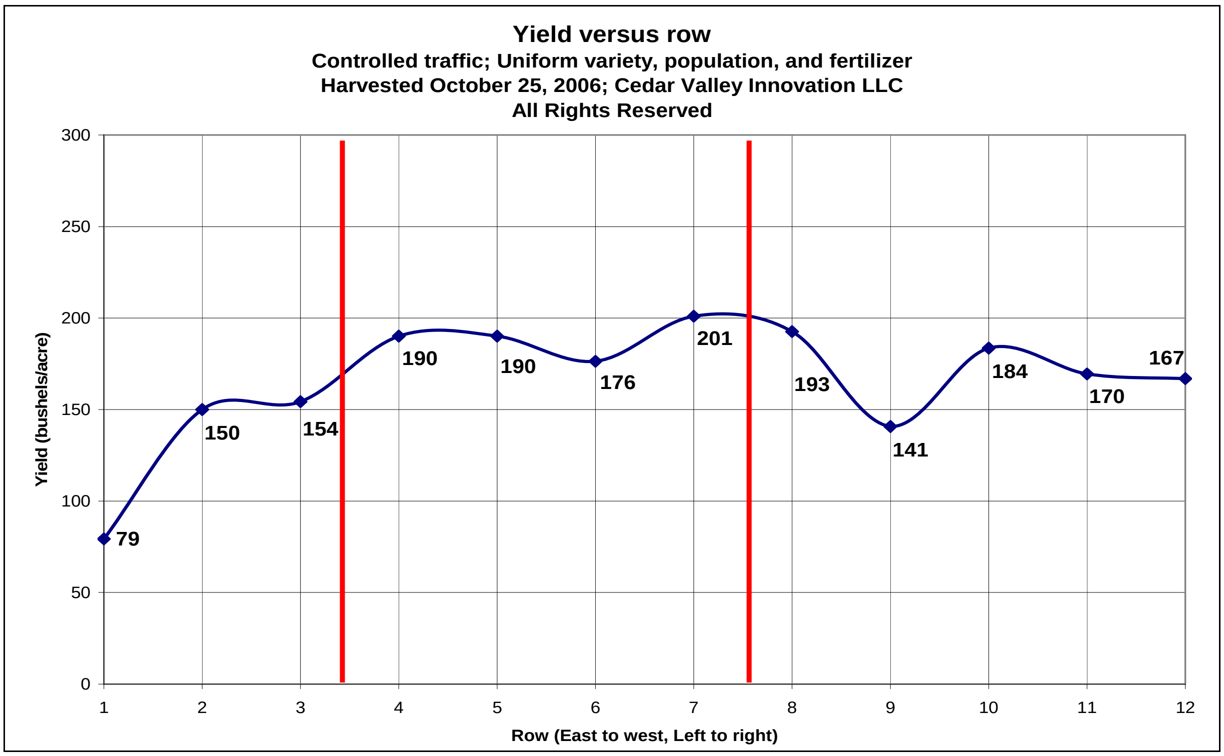

Figure 10. Yield versus row; controlled traffic; uniform variety, population, and fertilizer
(Red lines denote traffic lanes)

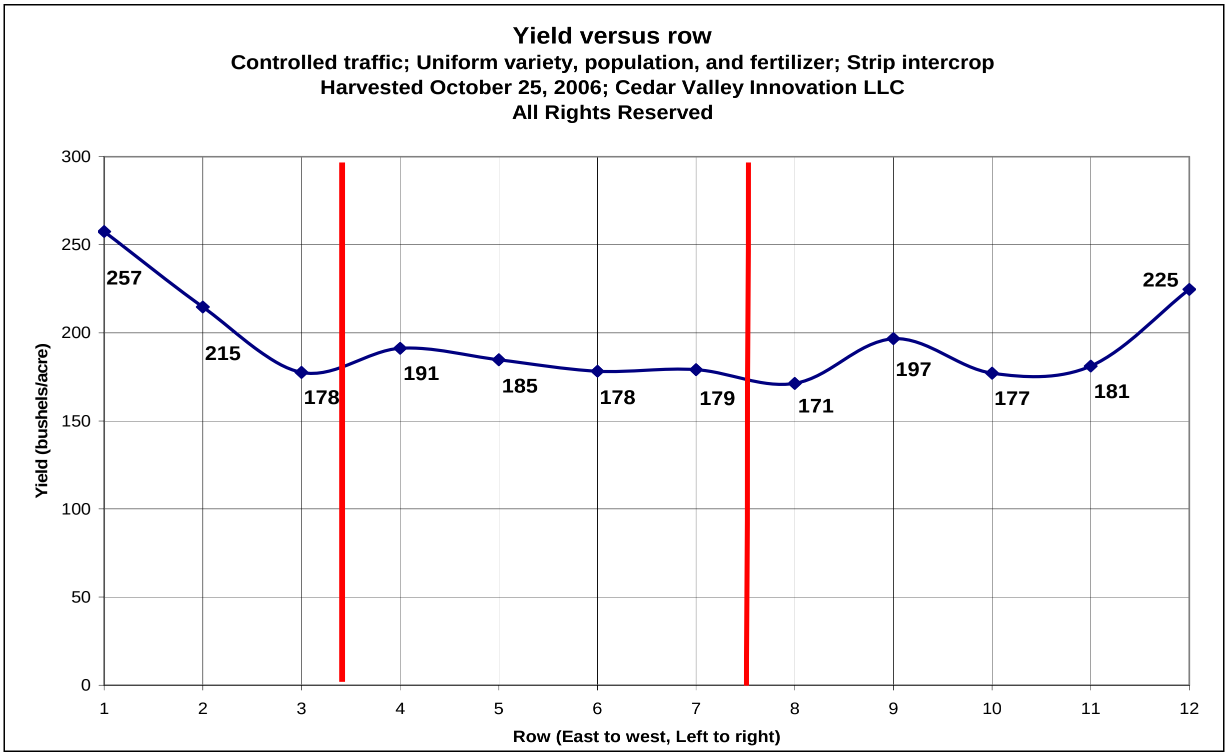

Figure 11. Yield versus row; Controlled traffic; Uniform variety, population, and fertilizer; strip intercrop (Red lines denote traffic lanes)

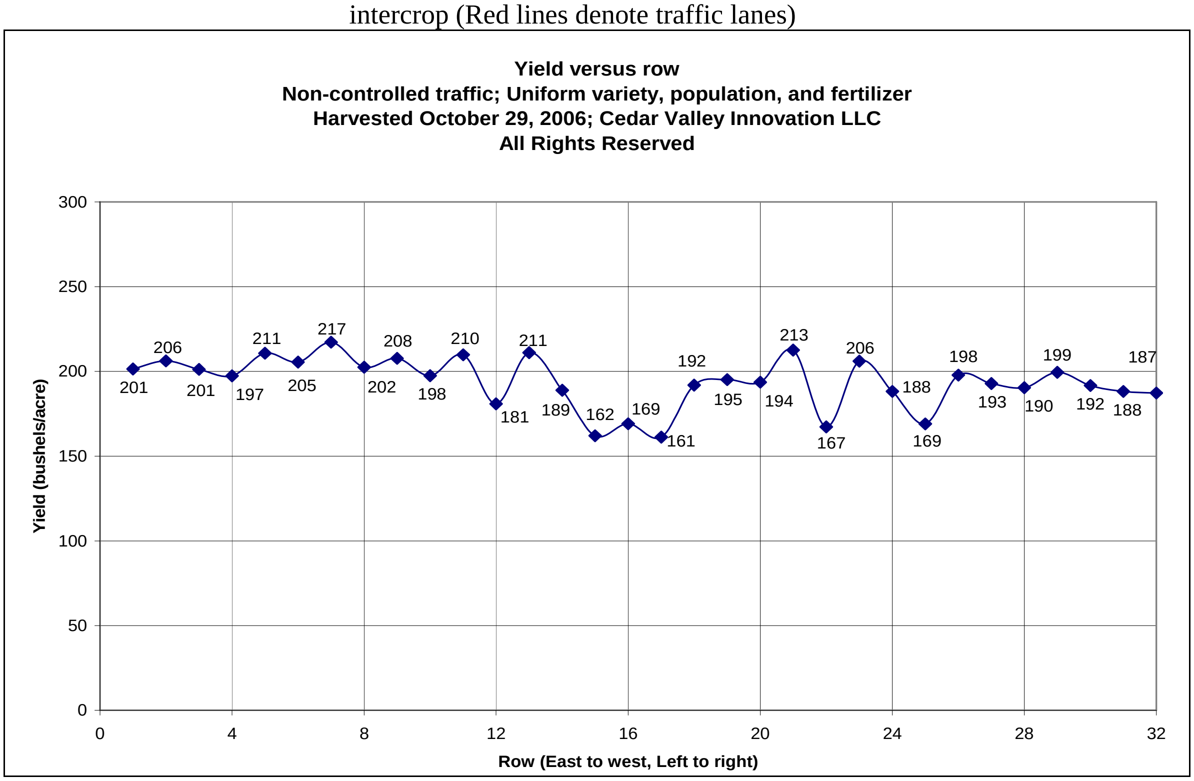

Figure 12. Yield versus row; non-controlled traffic; uniform variety, population, and fertilizer

Figure 13. July 1, 2006 CTF soil surface

Crop row spacing must be carefully considered in a CTF environment. In a corn and soybean rotation, many times the crops use the same row spacing. This creates a challenge in a CTF cropping procedure because the end result will be trying to grow one crop in the same location as the previous year's crop. This problem has been addressed on the Mitchell Farm by utilizing a 15 inch soybean row spacing, which places the soybean rows 7.5 inches on either side of the previous year's corn row. However, in a system which requires the use of equal row spacing between different crops, a strong solution to the crop overlap problem has not emerged.

Figure 14. July 1, 2006 non-CTF soil surface

Figure 15. Wheel track height (left) versus crop bed height (right)

Wheel track erosion is also an issue with CTF. Over time, the height of the wheel tracks can becomes lower than the surrounding crop beds. As of June 2006, this height difference was approximately 2 inches across the Mitchell Farm (Figure 15). In times of heavy rainfall, these wheel tracks can act like waterways and because of their high levels of compaction, water infiltration is low and therefore, erosion can take place. There are isolated locations on the Mitchell Farm where wheel track erosion had led to the wheel track-crop bed height difference up to 4 inches. Currently, there is not any equipment on the market specifically for addressing the height difference. However, there are producers who have developed their own tools as well as thought being given towards adapting equipment engineered for filling in pivots left by center-pivot irrigation systems. An example of one of these tools is shown in Figure 16.

Figure 16. Bigham Brothers pivot track disc filler (image courtesy of *http://www.bighambrothers.com/trackfiller.htm*)

INTERNATIONAL CTF

Popularity of CTF in Australia is very strong and widespread with popularity in the United Kingdom continually increasing. The Australian Controlled Traffic Farming Association is an excellent resource for general and Australian-specific CTF information: http://www.actfa.net/. CTF Solutions is also an excellent Australian-specific CTF resource: http://www.ctfsolutions.com.au/.

Controlled Traffic Farming, Ltd. is a company in the United Kingdom which serves as a general and United Kingdom-specific CTF information source: http://www.controlledtrafficfarming.com/. From November 18 to 24, 2007, CTF in the United Kingdom was experienced first-hand courtesy of Tim Chamen, proprietor of Controlled Traffic Farming, Ltd. Figures 17 and 18 show a tractor set up for CTF and a CTF field, respectively.

CONCLUSION

Controlled traffic farming (CTF) is an agricultural production method which, when compared to non-CTF, produced more consistent row-to-row crop yields and lower levels of soil resistance (to a depth of 8 to 10 inches). Water infiltration between the two production environments produced an inconclusive comparison. CTF does have disadvantages such as cost and wheel track rutting

FURTHER RESEARCH

Further research should concentrate on continuing collection of water infiltration, soil resistance, and crop yield data. Research should also explore methods of utilizing CTF in an environment where year-to-year crops use identical row spacing. Horizontal compaction from the wheel tracks should also be researched to determine its effects on crop rows adjacent to the tracks.

ACKNOWLEDGEMENTS

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Figure 17. Tractor configured for 3 meter (120 inch) CTF

Figure 18. CTF field in the United Kingdom

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Does the Direction of In-field Controlled Traffic Affect Runoff, Erosion and Crop Yield?

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Controlled traffic farming is increasingly being adopted by agricultural industries to improve farming efficiency and manage the risk of soil compaction, runoff and erosion. Quite often to maximise field efficiency the longest run coincides with being parallel with the slope and this goes against the historical recommendation of farming on the contour to reduce runoff and erosion. This paper presents results from a long term field trial on a self mulching cracking clay soil (2000 to 2004) to examine the effect of a down slope and across slope controlled traffic layout on runoff, soil loss and crop yield. Runoff and soil loss was higher from the down slope layout compared with the across slope layout (40 v 30 mm/yr and 0.9 v 0.7 t/ha/yr). Crop yield was not affected by traffic layout.

Key words Controlled traffic, zero tillage, down slope, across slope, layout

INTRODUCTION

Controlled traffic farming is a system where traffic lanes are kept separate from plant growth zones. This enables soil compaction to be restricted in extent and managed and soil conditions for crop growth to be optimised. To maximise in-field efficiency the longest run is selected, which usually coincides with the longest fence-line. This results in traffic layouts occurring at varying angles across slopes and, if present, crossing contour banks at oblique angles.

To simplify layout it has been suggested that traffic direction should be down slope, which is a major constraint to adoption since previous advice has been to farm on the contour on sloping areas, to minimise runoff and erosion. Runoff will naturally flow down the wheel tracks, along cultivated sowing lines and crop rows. To manage runoff and erosion, in down slope layouts, all water must drain with no reverse flow or be retained in low spots and directed to a safe disposal area, such as a contour bank or grassed waterway, and all runoff within the traffic lanes, tillage furrows and crop rows must remain contained within these zones with cross flow being prevented (Yule, 1995).

Studies have shown that wheel tracks contribute to runoff and erosion on sloping land, with the amount varying depending on slope, rainfall intensity, surface cover and surface management (Reed, 1986; Basher and Ross, 2001). To reduce runoff and erosion it has been suggested that traffic layouts should go across the slope or that traffic lanes be cultivated to slow water movement (Reed, 1986). These practices may be impractical to implement and to some extent compromise the benefit of controlled traffic in the first instance; field access at appropriate times for weed or insect control.
This work was undertaken to provide further insight on the direction of controlled traffic on sloping ground to enable informed decisions with respect to layouts and the potential for runoff and erosion.

MATERIALS AND METHODS

A long term trial was established north of Emerald in central Queensland on the property Moonggoo (S23.15763^0, E148.05545^0). The site consisted of a 230 ha paddock which was divided into two cropping frequency treatments (opportunity cropped outside traditional planting window, south paddock and conservative cropped within traditional planting window, north paddock), each of which was divided into two direction of traffic treatments: 1). controlled traffic down slope (DTS) and 2), controlled traffic across slope (ATS) with both treatments being zero tilled. The average slope within the DTS treatment was 1 - 2 % while that for ATS treatment was 1 %. The cropping sequence for the trial is shown in Figure 1.

The soil at the site is a self mulching black vertisol (Isbell, 1996) with some typical properties shown in Table 1. Runoff was measured through flumes installed at the outlet of each contour bay, with water height being recorded using a data logger. Pump samplers were used to automatically collect water samples for sediment analysis. Pluviometers were located adjacent to each treatment with data being logged on a daily basis. Greater detail is provided by Rohde et al (2000).
No statistical analysis is possible since treatments were not replicated as only one bay for each treatment was instrumented. Data was collected from 2000 to 2004.

Table 1. Typical soil properties for the soil at Moonggoo (after Irvine 1998).

Parameter	Surface	Subsurface
pH	8.0	8.4
Exchangeable Na (%)	0.6	1.7
Electrical conductivity (mS/cm)	0.06	0.1
Clay content (%)	67	74
Plant available water (mm) (0-0.9 m)	170	

RESULTS AND DISCUSSION

Total annual rainfall exceeded the long term average in 2000 (946 mm v 579 mm) with all other years being below the long term average. There was no runoff or soil loss from any treatment in 2002 or 2003. With one exception runoff and soil loss from the DTS treatment was greater than that from the ATS treatment in all years (Figures 2, 3, 4 and 5). This is consistent with the findings of other research (Reed, 1986; Basher and Ross, 2001; Titmarsh pers. comm.., 2006). The exception occurred in 2004 where extensive rilling occurred resulting in greater runoff and soil loss from the ATS treatment (Figures 3 and 5). However, in contrast Rohde et al (2000) and Stevens and Collins (2000) found that, on a duplex soil, across the slope layouts produced greater runoff and greater soil loss compared with a down slope layout. For all years of measurement the conservatively cropped treatment (Figure 2 and 4, north paddock) resulted in less runoff, which is contrary to previous work (Carroll et al, 1997), and soil loss compared with the opportunity cropped treatment (Figure 3 and 5, south paddock), with the exception of 2000 where the reverse was the case. Also, in 2004 for the opportunity cropped area greater runoff and soil loss occurred from the ATS than from the DTS area (Figure 3 and 5), which is similar to the findings of Stevens and Collins (2000). This result needs to be put into context in that the preceding crop was chickpea, which provides very little stubble to protect the soil surface. The effect of stubble cover can be inferred from runoff and soil loss. When wheat was a preceding crop the amount of runoff and erosion was reduced in the following year, compared with say sorghum or chickpea, where stubble levels were not as great and losses were larger. Mean soil loss was greater from DTS compared with ATS for all years with the exception of 2000 where the reverse was true (data not shown). The results show the variable nature of runoff and soil loss events, with greater losses occurring during periods of high rainfall. The mean annual runoff was 40 and 30 mm per year and mean annual soil loss was 0.9 and 0.7 tonnes per hectare per year for DTS and ATS. The greatest soil loss of 2.9 t/ha, occurred from DTS in a year of high rainfall (Figure 4). We speculate that the majority of runoff was generated from the wheel tracks, but it was not possible to differentiate runoff from particular zones in this trial. This is something that needs to be addressed in future work, as it should be easier to control runoff from the tracks compared with the whole paddock.

Crop yield was not adversely affected by the direction of layout (Figure 1). There was a slight depression in yield for the ATS compared with DTS for both conservatively cropped and opportunity cropped areas. However, yield tended to be lower under opportunity cropping than under conservative cropping, but it should be noted that different crops were grown in each area (Figure 1).

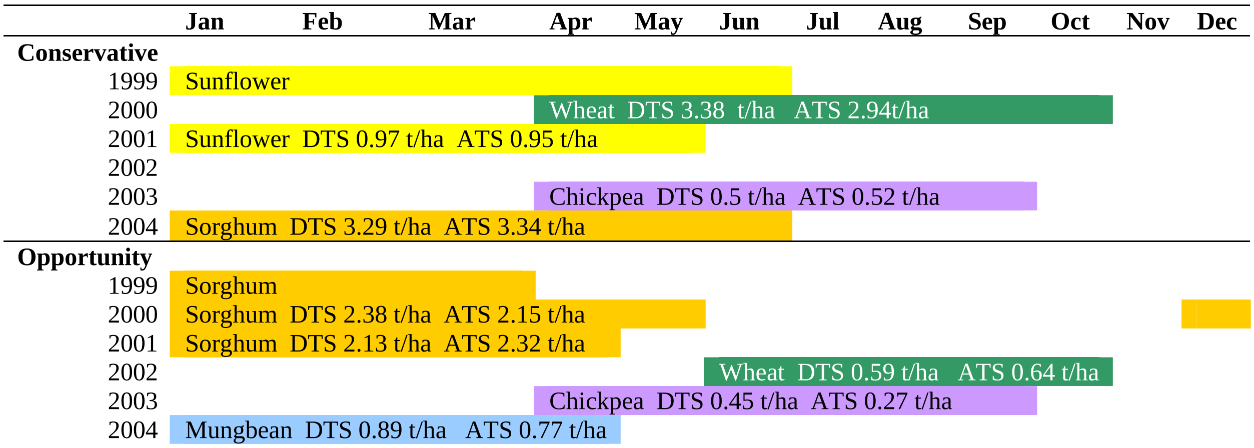

Figure 1. Cropping sequence and yield (t/ha) for the trial from 1999 to 2004

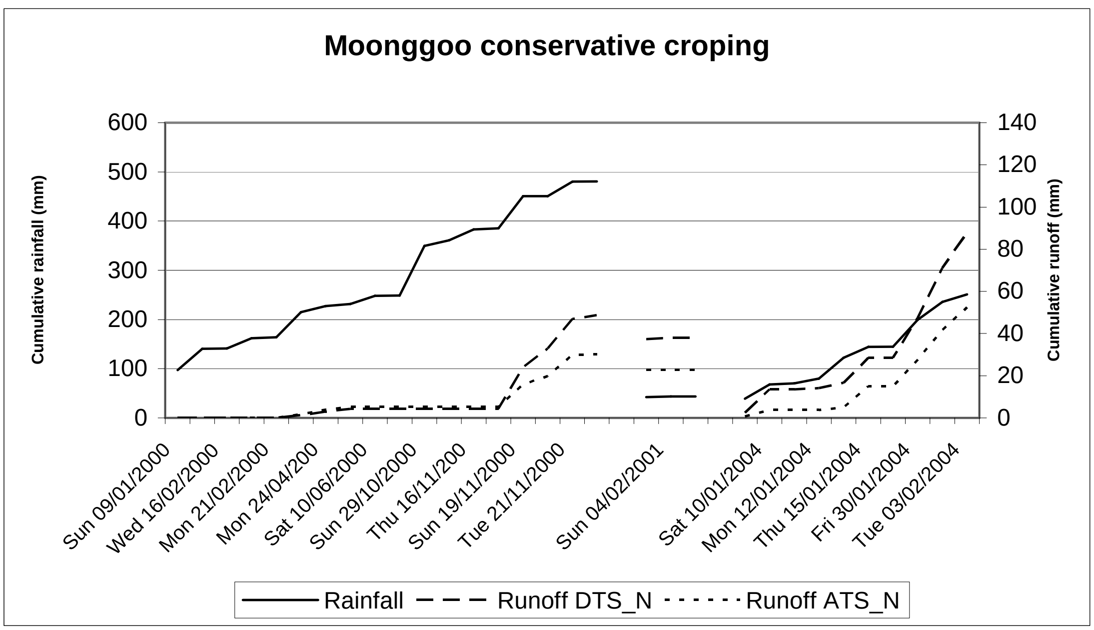

Figure 2. Cumulative runoff (mm) from conservative cropped DTS and ATS from 2000 to 2004

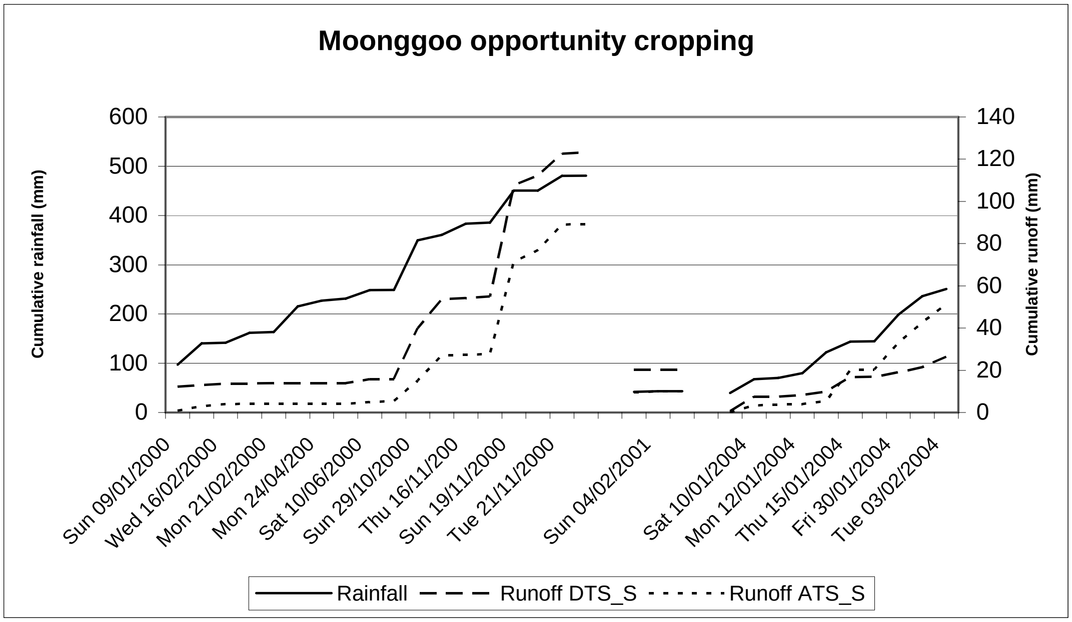

Figure 3. Cumulative runoff (mm) from the opportunity cropped DTS and ATS from 2000 to 2004

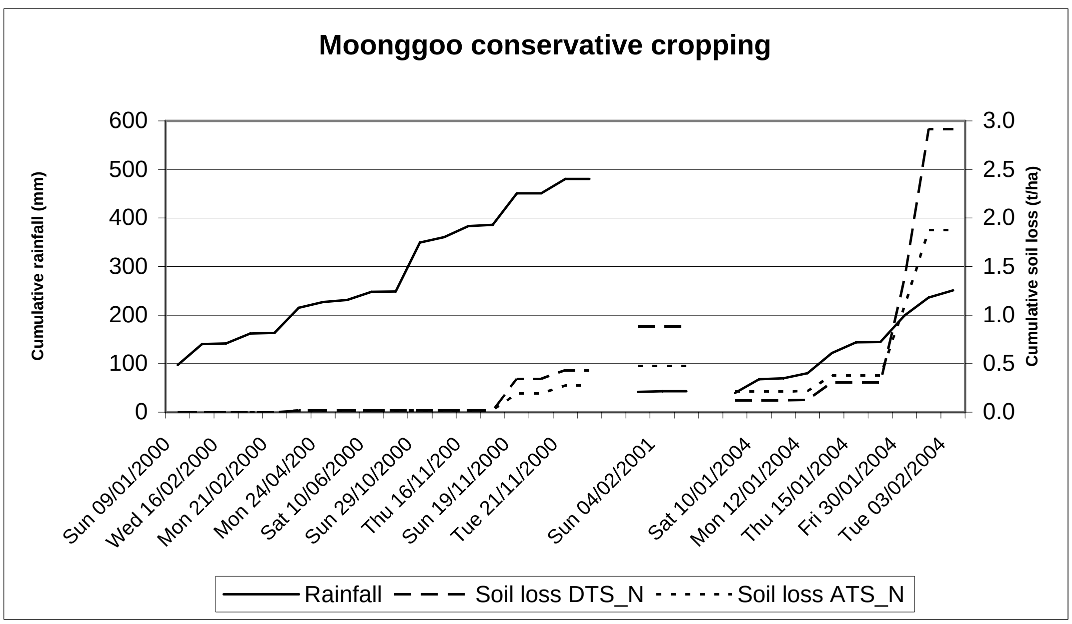

Figure 4. Cumulative soil loss (t/ha) from conservative cropped DTS and ATS from 2000 to 2004

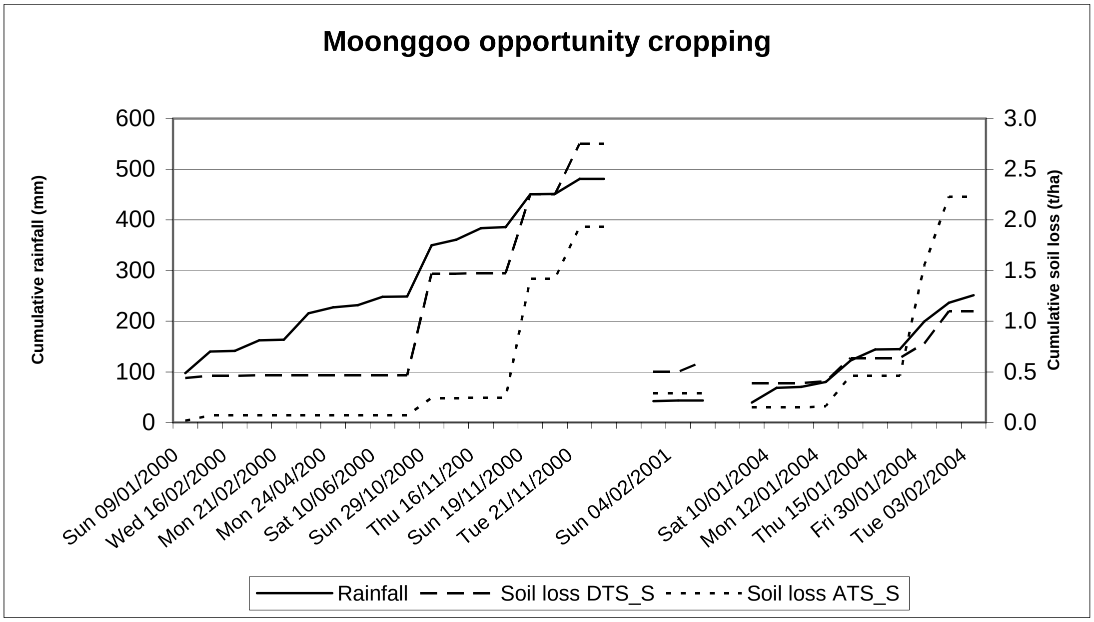

Figure 5. Cumulative soil loss (t/ha) from opportunity cropped DTS and ATS from 2000 to 2004

The amount of runoff and erosion will depend on many factors such as rain intensity, antecedent soil moisture, slope, length of slope and amount of stubble cover. Each factor needs to be considered in deciding a direction of traffic and perhaps a compromise taking all into account will be the longest run notwithstanding that this may be down slope.

It should be remembered that the monitoring occurred during a dry period compared with the long-term average rainfall, which contributed to the low runoff and soil loss. However, even under these circumstances the direction of controlled traffic had an effect on runoff and soil loss, with more runoff (40 v 30 mm) and soil loss (0.9 v 0.7 t/ha) occurring with down slope orientation compared with across slope layout. Runoff and soil loss was greater in higher rainfall years. Direction of traffic layout had little effect on crop yield. Further work should be undertaken to identify where runoff and erosion originate from within controlled traffic systems to aid in remedial measures.

ACKNOWLEDGMENTS

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Demystifying Guidance - Steering a Straight Line through the Hype

Wayne Chapman and Tim Neale, CTF Solutions

ABSTRACT

This paper will explain the basic operating parameters of farm GPS systems and the various levels of accuracy they offer. It will identify their applicability to PA and CTF and integrating precision steering into a farming system for maximum impact. Some practical aspects of machine guidance troubleshooting will be discussed and future advances in differential signal technology and networked solutions examined.

Keywords: Sub metre, RTK, Repeatability, Pass to pass, CORS

INTRODUCTION

GPS has been around a while, Australian engineers were the first to develop the algorithms needed to steer a tractor from GPS input in 1995/6. The GPS (American DOD) network consists of 28 Satellites in orbit around the earth while the Glonass (Russian) system has approximately 24 satellites in orbit. Galileo is a European consortium currently preparing to launch another constellation. To effectively pinpoint a position on the earth the GPS receiver needs to see at least 4 satellites at the same time. This locates the position to within 5-15m since Selective Availability (US Defence Force scrambling) has been turned off. To achieve higher accuracies various additional satellite signals are analysed, this can bring the position down to around 1-3m. To improve again the receiver uses correction signals in various forms to refine and remove the errors inherent in the system. Correction signals can be broadcast as free to air; - Marine beacon, or as various proprietary signals - Omnistar, Starfire, etc. via communication satellites. This commonly known as differential GPS, and accuracies range from 0.7m. to sub 10cm.

For the highest possible accuracies, a local RTK (Real Time Kinematic) solution is needed. This can come from a farm or community base station or some form of networked RTK solution distributed via Internet or mobile phone.

Since its introduction to agriculture in the late 90s, GPS based machine guidance has been rapidly adopted by Australian farmers (45% use GRDC survey, 2004) In the ten years from 1997 to now prices have fallen 60%. There are huge variations in features, accuracy levels, capabilities and opportunities to upgrade in the product lines available in this area. Quite often there are serious discrepancies between what the salesperson claims, what the farmer expects and unit capability. To avoid frustration and wasted expenditure it is wise to invest in independent advice and support as an aid to the purchase decision.

SYSTEMS USES

The following matrix identifies the major types and usage potentials of the various systems on the market.

Accuracy level	Usage	Handheld	Lightbar	AutoSteer
Uncorrected – 5-10m	Recreational, P.Ag. applications, farm mapping	✓	✓	**X**
Differential – sub metre	Recreational, P.Ag. applications, farm mapping, random traffic systems	✓	✓	**X**
Differential – 50cm	As with sub-metre	**N/A**	✓	**X**
Differential – 30cm	As with sub-metre	**N/A**	**X**	✓
Local Base Station - 10cm or Differential – with Omnistar correction signal	Low intensity CT systems	**N/A**	**XX**	✓✓
2cm RTK with local or networked solution	High intensity CTF systems, surveying, engineering	**N/A**	**XXX**	✓✓✓

DEFINING THE USE

Failure to adequately identify current and future requirements for guidance is a certain path to disillusionment with the technology. Some growers' expectation of system capacity may be unrealistic given their budget or current equipment. Rather than be stampeded into to a hasty purchase by enthusiastic sales talk, growers should evaluate their requirements thoroughly before purchasing. For instance, buying dual frequency 2cm RTK with a light bar would be poor economics for a contractor whose sole use was spreading manure over pasture while an organic small crop producer with irrigation could easily justify the expense of a steering kit as well.

UNDERSTANDING ACCURACY MEASUREMENT

System accuracy

Understanding system accuracy is crucial to making a sound investment in guidance technology. While there are many mathematical methods for determining accuracy, marketing has distilled these to two key indicators. These are "Pass to Pass" and "Repeatability", sometimes called "Return to Path".

Most advertising and sales material quote accuracies which reflect most favourably on the product promoted, hence many sub meter systems will be promoted as "achieving 100mm (4") accuracy". This can be defined as "pass to pass within 10 min timeframe" within the document; however many times the definition is absent.

To avoid disappointment system performance should be compared using the repeatable accuracy which should be quoted over a reasonable period of time = > 24hrs and 95% confidence interval. There are now many independent tests that allow these figures to be accurately represented.

Operational accuracy

The accuracy figures discussed above are derived under lab type conditions; actual operational attainment may be considerably different. Software set-up, steering linkage wear, operator error, surface conditions, base station set-up, implement set-up, trailed or mounted equipment and side slopes all degrade steering performance in the field. Recently there have been several 2cm systems that have not performed to that level 'repeatably'.

APPLICATIONS

Benefits and uses of guidance equipment have been widely reported. (**www.grdc.com.au**) A summary for RTK 2cm systems would include the following.

Labour management
Skill level,
Availability,
Shift length.

Precise Operations
Side dressing,
Shielded Spraying,
Banding fertiliser and pesticides,
Inter-row sowing,
Relay cropping,
Targeted amelioration,
Residue manipulation,
Operational advantages,
Night spraying,
Dusty conditions,
Disc seeding,
Accurate guess rows (no misses or overlaps).

INTEGRATION TO FARMING SYSTEM

Guidance equipment should value add to the whole farm system, rather than be a means to an end. 2 cm RTK systems should operate in conjunction with matched widths and wheels, sound agronomy and natural resource management, extensive on farm research and spatial data management. We have seen many farmers purchase 2cm systems without considering the huge value adding potential by matching machinery widths and tyres. Guidance becomes a lever to achieve greater operational and management efficiencies just as much as improved workplace conditions and straighter driving.

OPERATIONAL BASICS

Base station setup

Probably the biggest reason for poor auto-steer performance is quick and nasty base station setups by companies/farmers. You need to realise that if your base moves a couple of centimetres, then your lines will also move this amount. We have even seen base stations set up on dam walls on a star picket. This is not acceptable as a permanent base station location. Even shed mounting has caused some problems due to heating/cooling of steel. Sheds also pose particular problems with ‘multipathing’. This is where the base station receives a secondary ‘bounced’ signal from the same satellites from a reflective surface, such as a roof. Some GPS manufacturers have written ‘smart’ software to overcome this problem, but there are some manufacturers who cannot deal with this effect. It may also be a good idea to get you base station locations properly surveyed in, and the settings saved securely.

Tuning a machine

Properly set up auto-steer systems should never "hunt" for the line for more than a few metres at the start of a run or vary more than 1-2cm off the line. Failure to achieve this indicates component or tuning problems, extremely harsh conditions or implement effects. Steering movements should be smooth, not jerky although cold oil can cause some jerkiness early. We have witnessed several poorly set up tractors where it won't be too long before the hydraulic or steering system fails due to very aggressive steering settings. Contact your manufacturer if you are having these problems.

Data backup

Auto steer systems rely on computers and as such are prone to the same pitfalls as your desktop or laptop. Always back up your important information and carry a notebook with basic tuning settings, (gain, valve and steering values) and the co-ordinates of the A/B lines for each field. Ensure you backup your data card once you have captured all boundary files and A/B lines; once they are lost from the card, it is very difficult to get the machine in exactly the same place again. If you are steering more than 1 machine (i.e. you have more than 1 PC/rover unit) copy all the files across to each machine so that all operations occur on the same tracks. Modifying the A/B lines or adding 'nudge' factors while working in a paddock; unless absolutely necessary, merely creates headaches for every operation after that.

Operator training

We have seen guidance companies blamed for poor systems, when in fact the problem has been operator error. When purchasing you need to consider the ability to lock away important settings in the system. All too often we hear where un-trained operators have adjusted important settings in the machine or base station. This has led to disastrous consequences for all operations thereafter – especially in irrigated bed systems.

Get good training with your system, train all new operators well and make sure you pick a manufacturer with a good reputation for support – as you WILL need it. Be aware that some manufacturers charge for all support while others offer free phone support.

FUTURE TRENDS

Driverless tractors

While it can safely be assumed that there are several autonomous vehicles under development around the world, on board operators are going to be required for some years yet.

Automatic operational recording

While second party monitoring of spraying and sowing operations and equipment can be carried out remotely using existing technology and software, operational logging in real time for management is still in its infancy. Based on the adage, "You can't manage what you don't measure" there is a need for providers of guidance equipment to ensure their products can do more than just steer tractors. For the intensity of management to increase, spatial data (time and position) is required. From managing Integrated Weed Management strategies to on farm research trials, recording applications by time and field position is mandatory. Things the pocket notebook just wasn't designed to handle. Our travels through Australia have also highlighted how poor farmers are at record keeping. With the advent of QA and other regulatory systems, the time has come to record all operations. The advantage of linking GPS to a controller/recoding device will enable automated, spatial record keeping.

Fortunately, a growing list of companies is addressing these issues although linkages between guidance companies and farm management software developers are tenuous and rare. Examples include JD Apex and AGCO's GTA range of software.

Networked solutions

The authors estimate Australian growers have purchased enough RTK base stations to provide a networked solution to an area 3.5 times the area of Australia. How? Local base stations are limited by radio output power and atmospheric conditions from providing accurate data to a rover once past a certain distance known as the baseline. Depending on terrain, manufacturer, firmware, radio type, and frequency the baseline is limited to between 10 km and 25km.

If base stations are arranged in a grid, (75km) networked, data processed by a central processor and then retransmitted as a 'correction' signal, rovers can operate without loss of accuracy anywhere within the grid, provided they can access the 'correction' signal from the network providers. Companies such as Leica and Trimble (and soon TopCon) offer full-networked RTK solutions, but their use in Australia is limited to capital cities at present. There are moves to network many cropping areas of Australia in years to come.

Community base stations are local solutions to similar problems. It is inefficient for twenty farmers in an area to buy twenty base stations when four would do. All reputable GPS providers can offer multi base capacity for their rover systems. Some GPS manufacturers are promoting themselves as having 'networked' RTK solutions, but the current networks operating are merely a smarter extension of shared base stations. The future should be in fully networked RTK solutions.

CONCLUSION

Guidance equipment is part of Australia's contribution to global agriculture. Its use offers growers a range of benefits limited only by their imagination. Many products are marketed beyond their designed applications and careful research and independent advice avoids many of the pitfalls.

Wheeltracks and Widths

Wayne Chapman, CTF Solutions

ABSTRACT

Modular widths for all CTF machinery would minimise costs and maximise profits but is it practical? Expected outputs for a range of operating widths for seeding and harvest will be presented as well as some of the difficulties encountered when matching machinery. Issues arising from including the harvester in the CTF system are examined and possible solutions outlined.

INTRODUCTION

Machinery is the largest capital investment a farmer makes after land, yet many times this equipment is bought without due diligence. As with most capital purchases the service life exceeds the economic life of the investment and growers can become locked in to an inferior farming system for significant lengths of time by inappropriate equipment. Advice costs are much lower than the ongoing impact of a sub standard system.

Machinery issues often constrain farming system choices. The inability of many planting machines to handle significant levels of residue continues to hamper the adoption of full stubble retention in eastern states. The purchase of a larger tractor to get a tax deduction or better interest rate defies logic if it can only be used to do more of the same, faster.

Growers moving to Controlled Traffic Farming often stumble at the first hurdle of deciding what operating width and wheel track spacing they should use. This paper draws on the author's twelve years experience across Australia in assisting growers with these and other decisions.

In the past spacings and widths were *ad hoc* although Chapman (CTF 98) identified three common wheeltrack spacings, based on the spraying equipment used at the time of moving to controlled traffic.

- 1.5-1.8m **-** spraying with utility or tractor,
- 2m **-** tractor or truck and
- 3m with modified tractor or SP sprayer)

The narrower systems were unable to accommodate the grain harvesting operation, although some hay production systems were working successfully.

Sowing widths were not related to the width of other equipment and ranged from 6m to 32m; needless to say the grain harvester was seldom included. Spraying was carried out at 1:1, 2:1 or 3:1 ratios to planter width.

Since then, equipment has changed dramatically; in 1995 there was no CTF Ready equipment, now most companies offer something. The advent of 12m harvester fronts was the single biggest change, allowing larger acreages to move easily to fully matched systems.

SYSTEM REQUIREMENTS

By definition controlled traffic has ALL load bearing wheels operating on permanent tracks, because the goal is to minimise the area compacted. With random traffic and unmatched machinery regimes, compacted areas range from 80-100% for tillage based systems to 40-50% with zero till. Adopting precision guidance (2cm) and matching operating widths reduces this dramatically. See Table 1 for more detail.

In the high rainfall zone some growers have developed dual 2m/4m raised bed systems, which involve 2m centres for the tractor and 4m centres for harvest and sometimes spraying. As can be seen from Table 1 these systems are at best a compromise, resulting in a larger proportion of crop suffering wheel induced compaction. Configuring raised beds to suit a 3m system would provide benefits in terms of limiting wheel traffic, reducing capital costs by alleviating the need for both bed and flat equipment and drainage capacity could be improved, if necessary, by installing minor furrows at 1.5m intervals in the wetter areas.

Table 1. Common systems - %wheeled

System	% wheeled
2m centres, single tyres, 15m planter, Auto steer, 30m sprayer, random harvest 11m	29%
2m centres 8m planter, Auto steer, 24m sprayer, 10m harvest 3m centres harvester on 800mm tyres	22%
As above but all 500mm tyres and harvester on 4m centres	16%
9m CTF	12%
12m CTF	11%
2m CTF cane 800mm twin rows	50%
3m CTF cane 1.5m rows	33%
Horticulture 2m CTF	25%

Only 3 m systems enable growers to progress and include all heavy wheels operating in their paddocks. All current model harvesters can be optioned to a 3m setting and narrower tyres of sufficient capacity are available.

Operating width

This is best described by the narrowest practical width operating in the system.
It should:

- match the width of the harvester fronts available
- be a multiple of the wheeltrack width
- suit the majority of situations across Australia
- be simple and concise.

This paper suggests that 9m and 12m fulfil all the above conditions. These systems offer the lowest % of wheeled soil, the widest range of planting and spraying capacity and the easiest harvesting solutions.

Choice of the best width for an individual's farming system should be based on a comprehensive review. CTF Solutions take clients through a process, which looks at, but is not limited to:

- Farm size
- Existing machinery
- Timeliness of all operations
- Labour
- Budget
- Goals

Operational capacity

Can two module widths satisfy the differing conditions, variation in climate and crops occurring across Australia? Successful farming systems based on these widths already exist in all states. Planter sizes from 9 to 24 metres are possible as multiples of either 9 or 12 metres. Sprayers up to 36 metres are in use. 12 metre fronts allow modern Class 7 and 8 harvesters to be operated efficiently in lower yielding crops.

Timeliness of operations is an integral part of the CTF system and growers should consider all facets of the system before deciding on operating width. Managing system change is not a new exercise for most growers, but many new issues need to be considered in the move to CTF.

Depending on speed, planters working at high field efficiency in controlled traffic systems are capable of sowing between 48 to 200 ha per 12 hour shift. (See Table 3) Spraying capacity is a function of the crop value, climate and the area to be covered, northern farms may be expected to have more spray capacity due to less favourable climatic conditions during the fallow period. Windows of operation are still a matter for judgment, but it is not unreasonable to assume that high value crops require more machine capacity than low value crops.

Table 3. Planting capacity by width and speed at a field efficiency of 65%

	Field Efficency	65%			
Sowing		Area per	12	hr shift	
Width		7km/hr		11km/hr	
		ha	ac	ha	ac
9		49	121	77	191
12		66	162	103	254
18		98	243	154	381
24		131	324	206	509

Chaser bins, drying, windrowing or simply bringing additional harvesters in for the large crops, can all increase harvest capacity. Some clients have been able to reduce capital expenditure on harvesters. The choice of front size can impact harvester capacity particularly in light crops. (Table 4)

Table 4. Theoretical Harvester capacities based on 100% field efficiency

Width	t/hr [1]	t/hr [2]	t/hr [3]
9	37	27	15
12	50	36	20

[1] Wheat - 6t/ha and 7km/hr
[2] Wheat - 3t/ha and 10km/hr
[3] Wheat - 1.2t/ha and 14km/hr

Matching equipment

It should be noted that it is not harvesting per se which is difficult to achieve under a CTF system but rather the unloading of the harvester *on the go*, which requires the most effort. This requires the transfer of grain from the harvester bin to a chaser bin running on the adjacent set of wheeltracks.

Some machines, at either 9m or 12m, require modification to both unloading auger and chaser bin. Table 5 provides details of some models and the extent of modifications required.

Table 5. Harvesters, 3m compatibility, auger length and distance to adjacent track

Make	Model	Auger length Std. (m.)	Gap to 9m centre (m.)	Gap to 12m centre (m.)	3m centres
CaseIH	1688	5.28	2.64	5.7	Yes
	2188	5.28	2.8	5.86	Yes
John Deere	9610	6.1	1.8	4.86	No

Why?

In many situations the harvest is the heaviest operation in the paddock. Past experience with clients who matched operating widths but not harvester wheel tracks soon found the deleterious and expensive effects of harvest traffic on the following crops. You cannot make further enhancements to the farming system until these factors are right.

The charts below show individual row yields from a property before and after matching harvester traffic. You can clearly see the reduced variability in crop yield as a result.

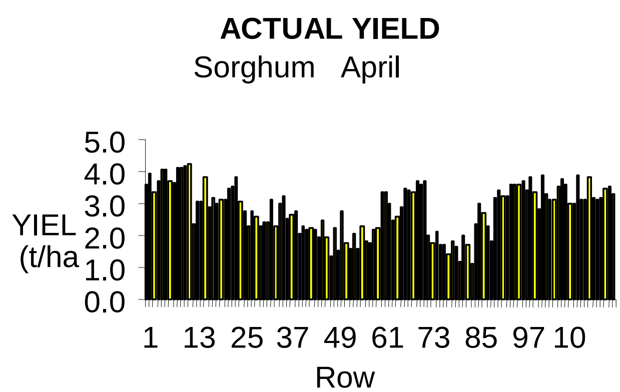

Figure 1. Individual Row Yields across paddock 1998

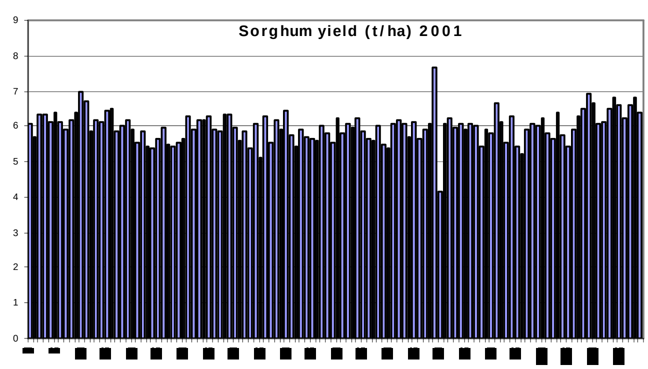

Figure 2. Individual Row Yields across paddock 2001

Another consideration is the soils ability to repair. Highly mobile vertisols repair very quickly, (1-3 years, although some data suggests it could take 2 – 7 years) while others may take much longer. Axle loading is the key determinant of compaction at depth and modern harvesters have very high axle loads. (12-23 ton on front axle) It stands to reason that the aftermath of one wet harvest is going to last a long time and would effect between 15-18 % of the paddock. In central Queensland one grower lost $70/ha as a result of harvester damage in the previous crop.

Another reason for matching the header to the system, is the affect harvest traffic can have on sowing the following crop. In some cases, growers have not been able to successfully plant where harvest traffic has formed deep wheel ruts and un-even seeding conditions. Matched CTF systems never miss these opportunites, and in fact, it is in these practical advantages of CTF where many of the gains are to be made. CTF farmers have control over their farming system.

Attitude or dollars and sense

There is ample evidence from worldwide research that compaction is bad for crop production. It makes no rational or economic sense to leave the heaviest machine in the paddock on random traffic, yet sadly this is the situation of many farmers who claim to be doing CTF. Rather than acknowledge wet harvests are a long-term feature of Australian grain growing, growers are in denial requesting more research into this area. While some prominent consultants can jump on the media bandwagon as grower champions by questioning the validity of a fully matched CTF systems, the reality is that the harvester should, and can be managed in a CTF system for a fraction of the cost of one missed planting opportunity.

CONCLUSION

In 1995 there was not the equipment available to encourage growers to adopt a fully matched CTF system. At CTF 07 we are able to say “Do it now, get some advice and do it properly”.

Controlled Traffic Farming in Central Queensland

Colin Dunne, Sorrell Hills Cattle, Duaringa Qld

INTRODUCTION

We've all heard about Controlled Traffic Farming Systems and how well they work so I'm not here to try to convince anyone just how good it is, but just to share my story and the experiences I have had along the way.

I'm not necessarily a good farmer and what I do is not necessarily right, but what I do is working extremely well for me, putting more grain in the bin and more money in the bank.

FARM PROFILE

My family history on the land dates back to the 1800s, Cattleman until the 1960s when Dad started farming. I have always enjoyed this rural business and today my wife and four children, are all involved in the family business.

I own a mixed cattle and cropping enterprise based near Duaringa, in Central Queensland, 120 km west of Rockhampton. Although we produce both beef and grain the two are kept very separate with no cattle ever allowed on the farming country.

I farm 2200ha of heavy black cracking clay soils which goes under four metres of water in flood times. The cropping program includes wheat, sorghum, mung beans, chichpeas and corn. No cattle fodder is grown at all. We don't have any problem with weeds that are hard to kill and don't use any fertiliser at all.

Our average rainfall is approximately 675mm or 27in.

INITIAL STEPS

I started planting up and back in rows in the 1980s and was using some minimum till practices. I realised I had a problem with soil compaction. The four wheel drive tractor was leaving big tracks, then I started to put the implement deeper which made it harder to pull and caused more wear and tear. I woke up one day and suddenly realised "this is bloody ridiculous".

In 1998 I stopped ploughing, bought a spray rig and within twelve months, had totally adopted a zero till and a Controlled Traffic Farming System.

PLANNING

Sound professional advice is readily available so took advantage of it. When you think that its too difficult, just remember that its all been done before. You do not need to spend a lot of money to change old habits successfully.

I modified the spray rig tractor, spreading both front and back wheels to 3 metre centres. Then I bought a spray rig with 21.5 metre boom with 3 metre wheel centres. The harvester front is 10.75

metres. I regard the harvester as the most important link in the chain. The four wheel drive tractor I use was converted from dual wheels to single wheels on 3 metre centres.

I made marker arms for the planter to mark the initial lines and only needed to use these for one season.

My planter width is 21.3 metres and for the past nine years I have used only one implement to plant five different crops. This year I made a precision planter for summer crops. I still use the same air seeder for winter crops. The planter wheels are purposely not matched to the tractor wheels.

Where I had previously planted 105 rows of summer crop I now plant 12 rows 180cm apart and plant my winter crop 46 rows 46cm apart. I have noticed significant yield increases. There are two narrower rows in the centre of summer crop to define the wheel tracks. The winter crop is planted with wider rows in the wheel tracks to define the wheel tracks. I double the seed population in the rows each side of the wheel tracks by putting two planter hoses to one tine. This prevents green strips in these rows come harvest time.

MACHINERY

I don't believe that you need to spend a lot of money on tractors and machinery to get started. My tractor and two planters are both well over 20yrs old. My tractor does approximately 250 hours per year.

The chaser bin and tractor are both on 3 metre centres and but are not used in the paddock, only on the headlands. The larger capacity header works well for longer runs and higher yields. I have fitted larger nozzles behind the wheel tracks of the spray rig to better target damaged weeks.

AUTO STEER AND TECHNOLOGY

Self steer systems are very good but not essential. I feel that Controlled Traffic Farming is the most important system.

The 400hp tractor is fitted with a 2cm self steer guidance system. The self propelled spray rig is fitted with the same system and has direct injection. Both of these have variable rate technology if I choose to use it.

Satellite imagery is very useful but very expensive. Contour mapping is useful for farm layouts. Using this technology, I have been able to drain the wetter areas in the paddock to the well drained areas not necessarily off the paddock. I have also put roads in for better access, using this information.

BENEFITS

With the use of Controlled Traffic Farming I have much more family time and far less stress.
The reduction of fuel use from 60 litres per hour to 30 litres per hour. The tractor now runs on 4 tyres instead of 8 tyres. The shift work has stopped and so has the banging and clanging in the shed at all hours. No overlap means there are the big savings on chemical, seed and other inputs.

Because some of the changes are so great some people in the area may think you've lost the plot. They soon look over the fence and start asking questions and say things like "you must have had more rain" when really it's the improved farming methods, improving the soils, etc that makes the difference.

WHAT'S NEXT?

- The use of volunteer sorghum as ground cover and spraying out later than previously done.
- Automatic data collection to download data from the computer in the tractor and sprayer to the computer in the office.
- More efficient use of chemicals by band spraying over plants or between plants.
- Greater water use efficiency by increasing ground cover, altering row configuration, populations and other agronomical issues.
- Return of average rainfall years and higher grain prices.

Variable Rate Application and Controlled Traffic at Cunderdin, Western Australia

David Fulwood, Cunderdin, Western Australia

INDRODUCTION

Our family business is located between Cunderdin and Meckering, Western Australia. We produce grain under a dry land, no-till, controlled traffic system. Our average annual growing season (April to October) rainfall is 295 mm (274mm last 10 years, and 168mm in 2006).

In 2007 we have sown all our property to crop, with the exception of one pasture paddock. We don't plan to have any established pasture in our rotation. Parts of our farm have been continuously cropped for over 20 years. This year we planted 5500+ hectares to wheat, barley, canola, lupins and oats intended for export hay. We also include field peas in our rotation. Our rotational plan is 60% cereals, 20% legume and 20% canola, but subject to change with prices and seasonal conditions.

CHALLENGES

The biggest challenges for the production side of our farming system are nutrient management, in-crop disease control and herbicide resistance. Like all primary producers the real challenge is to profitably produce commodities long term under a sustainable production system.

OUR CONTROLLED TRAFFIC SYSTEM

Our complete CTF system in now in its third year of operation. We operate on a 9.144m (30ft) system with centre to centre wheel spacing at 3 metres.

The main equipment in our system is made up of two seeding rigs 9.144m (30ft) & 18.288m (60ft), one boom sprayer 36.576m (120ft) and one harvester 9.144m (30ft).

Other equipment includes a liquid cart, multi-spreader and chaser bin all with 3m wheel widths and a hooded/shielded sprayer with a working width of 9.144m.

Two tractors, the SP sprayer and harvester are all equipped with factory fitted auto-steer hardware. A shared screen and software is moved annually between the sprayer and harvester. The GPS receivers are interchangeable between machines and typically the tractors and header operates on an RTK signal (+/-2cm), while the sprayer operates on the RTG signal (+/-10cm).

We have three surveyed fixed base station sites where our base station is positioned as required.

Both seeding rigs and a multi-spreader are able to apply inputs at variable rate, using Zynx controllers. Tractor operation is kept simple with the use of a factory fitted guidance screen to control all auto steer functions and a separate Zynx screen to control all seeding, spreading or shielded spraying functions.

HOW WE STARTED WITH PRECISION AGRICULTURE

With the increased level of herbicide resistance, particularly to grass selective herbicides, Greg Fulwood had a shielded sprayer built and also an aftermarket RTK auto-steer system fitted in 2003. The idea was to grow wide-row lupins and spray the resistance ryegrass with non-selective herbicides using a hooded sprayer, once the lupin crop was well established. This was successful however the aftermarket auto-steer system did not steer the machine accurately enough at seeding or when shielded spraying and crops suffered significant crop damage.

In 2005 we used factory fitted auto-steer and were successful in accurately sowing and shielded spraying, with minimal crop damage.

As soon as we saw auto steer in operation we realised the potential of such technology and during 2004 we planned out and purchased the equipment required to have a complete system including variable rate application in place for the 2005 season.

PADDOCK LAYOUT

We have not taken any technical approach to setting up run lines. Most paddocks are set up using the longest straight fence to determine the heading of the main run line. For each paddock the “Point A and Heading” method is used to set up the run line, using whole numbers for the headings. This allows the run line to be accurately entered and used by controllers in other machinery. When choosing an auto-steer system I believe that this method of setting up run lines is an essential feature. An added beneficial feature is being able to name the run lines, rather than just numbering each run line. This allows headlands and other minor run lines to be selected easily and accurately by the operator.

One recommendation is to have a common run line for the whole property where possible to keep the system simple for all operators.

It is important to ensure headlands provide access for filling equipment at seeding and for harvest paddock storage equipment.

Our longest run is around 2.5km and shortest less than a few hundred metres. The ideal run line length is difficult to nominate as it depends on machinery capacity and actual crop yields. The limiting factor is usually the header grain tank capacity and efficient distance for the chaser bin to travel between header and paddock storage.

VARIABLE RATE APPLICATION

In 2005, 2006 and 2007 we applied compound fertiliser and nitrogen on all cereal crops and canola crops using variable rate prescriptions. Prescription zones are created biomass using analysis carried out by Silverfox, and also take into consideration results from soil testing of these zones plus overlaying of previous years yield maps as well as input from our knowledge of paddock performance. Rates are decided for each zone paddock by paddock and are often altered just prior to seeding depending on moisture conditions and crop condition in the case of top up nitrogen.

We apply compound fertilizer and urea at seeding and spread urea post seeding using a multi-spreader. Test strips for each prescribed rate of fertilizer input are run in the direction of traffic across each variable rate zone. This allows accurate analysis and assessment of the economic benefit of varying the rate using yield data collected at harvest.

BENEFITS

Benefits of operating such as system are numerous. Some of the main benefits are:

- Zero overlap resulting in an instant saving on fuel, seed, fertilizer and chemical (7 to 8% saving)
- Inter-row sowing allows tynes to be used for sowing in a stubble retained system
- Potential fuel savings with machinery operating with less wheel slip.
- Long term improvement is soil structure in zero traffic areas.
- Reduction in operator fatigue and ease of operation.
- Increased header capacity (100% full header front).
- Inter row spraying options.

ECONOMIC BENEFITS

Analysis by Dr Michael Robertson of CSIRO shows variable rate application of fertilizer increased gross margin of between $4 and $23 per hectare (average $13/ha) in the 2005 season. In the same year approximately $13/ha was saved on reduced inputs from zero overlap.

Michael's final analysis showed an annual gross margin increase of around $130,000 for our cropping enterprise.

ALTERNATIVES

An alternative system is to have all machinery operating at 12 metres (40 foot) widths. This system has some advantages over the 9 metre system, including increased harvest capacity and the convenience and simplicity of having seeding and harvesting equipment operating on the same tramlines. This system is something we are still considering, although we wanted to have the seeding capacity of 18m seeding equipment at the time of implementation.

FUTURE IMPROVEMENTS

Areas of improvement in the future may include:

- Higher accuracy shielded spraying
- Larger harvest capacity (60 foot front?)
- Change to a 40 or 45 foot system for increased harvest capacity
- Complete removal or destruction of weed seeds at harvest
- Faster/simpler seeder filling
- GM technology to assist with herbicide resistance weed control
- High accuracy seed and fertilizer placement at sowing & disc seeding equipment
- Rear discharge of grain from harvester to chaser bin
- Remote sensing of plant nutrition requirement
- Remote sensing of plant disease and weed burden

- Remote sensing of soil nutrition & variable rate application of lime etc
- Precise variable rate application of separate N P K and trace elements
- Real time communication of machine activities and yield results to each other and to management.

CONCLUSION

- Large productivity/ profitability gains can be made with a relatively small initial capital outlay
- CTF systems can be continuously improved or added
- Plan out your "dream" system and then start by implementing it in order of what will give you the best return on capital
- Don't ever buy a new tractor without ticking the box for factory fitted auto-steer!

Impact of Controlled Traffic Raised Beds on our Property: "STRUAN" - in High Rainfall South West Victoria

Cam Gibson, camandcara@hotmail.com

Our farm is located in the south west of Victoria which for the last 50 years has predominately been a grazing area. The only cropping done in the area was done conventionally and primarily to provide grain and forage for stock feed. Where we are situated in the southwest has an annual average rainfall of 550-600mm.

Being at the higher end of rainfall occurrence, has made cropping difficult to sustain a viable income from crop production. Crops were sown and then waterlogged or even washed away in the winter, therefore giving the farmer no option but to sow crops in the spring, which would greatly reduce yield.

In the last 10 years things have changed dramatically with the introduction of raised beds for broad acre crop production. When we introduced raised beds to our business we did not expect the introduction of everything that an intensified cropping program would include. We were now given a chance to sow a range of crops that we had not previously been able to grow. Our rotation is generally a canola-wheat-barley continuously, and has proven viable and productive. We have not reduced our sheep numbers but have expanded our cropping enterprise because of the confidence we have in raised beds. We call them our insurance policy and we sleep a lot better at night if a large rain event occurs. With the introduction of raised beds to our farm we are now cropping parts of the farm that we never thought to crop before. Producing very productive areas that were not being used to the grounds ability. Without raised beds we could not reliably produce a crop on our farm.

Some of the challenges that we identified with the raised beds was getting the correct depth in the furrows, matching the machinery so that the wheels were running in the furrows. Also using a dump level to obtain the highest and lowest points in the paddock to determine the most efficient way to run the beds and the water run off.

WATER LOGGING

Our top soil depth is around 10-20cm, followed by a heavy impervious blue-black sodic clay. After consistent rainfall of 30-50mm a water logging situation occurs because the water builds up in the top soil above the slow draining subsoil. In the long term this drastically reduces crop yield and in the worst case, kills the plants.

The introduction of raised beds to our cropping practices has reduced this problem by at least 80%. We first put in some beds in 2001 in a 90ha paddock, 44ha was put into beds and the rest was left as flat ground. The entire paddock was sown with barley and the result was better than expected. The 44ha of beds yielded 4.8ton/ha while the flat area yielded 2.5ton/ha. So with that, we then started to bed the rest of the farm's ground that was susceptible to these water logging issues. Since 2001 dryer conditions have developed but with 02 and 03 being wet winters the beds still proved their viability.

Since 03, with the dryer conditions we have experienced in south west Victoria, raised beds have not had an effect on yield loss on our farm.

CONTROLLED TRAFFIC

Controlled traffic did not exist on our farm until we started using raised beds. We began constructing beds conventionally and sowing with a combine, sowing three beds at a time but the wheel marks where not in the ideal position.

We then moved into getting our paddocks marked out with 2cm auto steer. We would then bed the paddocks using a centre to centre bed width of 2 metres, and this would be successful. We moved to a 10m seeder which fitted compatibly over five, 2-metre beds with no overlapping and wheel placement was a lot better.

Our 18m boom spray tank runs with its wheels in the furrows of the 2 metre beds and covers 9 beds without overlapping. Since marking out our paddocks overlapping has been eliminated and running the machinery wheels in the furrows has greatly reduced compaction. For example pulling out a plant on top of the bed can be done with ease, while previously you would snap the plant in half while trying to pull it out.

Our soil textures consist of a brown light/medium clay loam, with our pH ranging from 5-7.

The clay component of our soil impacts greatly on structure, and compaction can occur very easily.

Before raised beds the ground would become hard and crusted making it difficult for plant roots to descend.

Porosity in the soil was limited and it showed with plant growth being quite slow. Forming beds would aerate extra top soil, making a friendly environment for plant growth without the clay present until deeper down.

The soil structure in the bedded paddocks has now changed dramatically, going from hard to penetrate, to being able to stick a screwdriver into the soil down to the top of the handle. It would also appear that after a while, the heavy clay subsoil that was very close to the surface becomes less dense, perhaps due to some sort of breakdown occurring with improved drainage and the absence of compaction.

With less machinery disturbing plant growth, the soil and all wheels confined to the furrows between the beds, compaction is virtually eliminated from most of the soil in the paddock. The well structured soil in the raised beds promotes rapid plant growth, and makes it considerably easier for plants to access nutrients.

Drainage plays an important factor in beds as well, because of the intense amount of run off. The end drains have to be able to handle a high volume of water. With the limited amount of rainfall in the past, water catching from these beds has been particularly valuable. Catching the water and running it to dams for storage which has been able to be used for stock during the drought.

CONCLUSION

Moving forward using innovative, diverse and new technology is the future of our farm.
As a young farmer it is incredibly exciting to be able to enter the future, and what it has to offer in this particular area of agriculture.

Being able to use controlled traffic/raised beds on our farm is a big step into refining our cropping enterprise and the whole farm, year after year. Using water more efficiently is what we intend to do in the future, with the previous years being dry it makes you more aware of how important it is to utilise water saving procedures. So every little aspect on our farm has to incorparate water saving as its number one priority.

Controlled traffic is one of these procedures and so the task is there for myself to introduce it to the farm more intensively and effectively.

In the future I hope to have created a cost effective, productive cropping program using relevant information and the best technology available.

Variable Rate Technology

Points to Consider in the Workshop in Data Collection, Interpretation and Translation to Practices

David Hall, Senior Research Officer, DAFWA, Esperance, WA

- Potential returns to VRT range from <$5 to > $40 /ha. An increase in profitability of $10 /ha will invariably pay for the costs of applying VRT .

- Zone areas need to be seasonally consistent 70 % of the time for VRT to be effective and profitable.

- Defining zones can be done using yield, near infra-red (NDVI), soil, electromagnetic induction (EM), elevation and ‘ mud’ maps.

- Often a combination of techniques is used to ‘fine tune’ zones. Different maps may also be used to apply differing products. Where as yield and NDVI maps are often used to zone paddocks for nutrients, EM can be used to zone paddocks for gypsum applications where subsoil sodicity/boron are affecting crop yields.

- There is currently no one universal zoning technique.

- Zoning is best applied where farmers are confident that their ‘higher’ yielding areas are performing near their water limited potential and that the marginal return from investing in VRT is higher than rectifying the limitations in ‘poorer’ yielding areas.

- Technical support and compatibility between products has hindered VRT adoption. However, with increased demand this should be a short term issue.

Using Controlled Traffic to Engineer Seedbeds for Increased Water Conservation, Crop Production and Profit

Greg Hamilton[1], Jessica Sheppard[2] and Rod Bowey[1], [1]Department of Agriculture and Food and [2]Avon Catchment Council

INTRODUCTION

The effects of compact soil on the growth and development of plants has been well known in the scientific literature for at least 50 years. These effects are:

- Physical impairment of emergence
- Restriction on the growth and proliferation of roots
- Reduction in the amount and availability of water to roots
- Reduction in the amount and availability of oxygen and the heightened probability of waterlogging.

Equally well known are the phenomena that cause soil to be compacted:

- Farm machinery - their weight, tyre width and diameter, track width, and tyre pressure
- The number of machinery passes and the lack of alignment of their tracks
- The points of tillage implements
- Excessive soil wetness
- Soil condition (undisturbed and loose)
- Grazing - the type and weight of animals, the number of grazings the and soil moisture when grazed
- Overburden pressure of soil as depth and water content increase
- Rain drop impact, which compacts the surface soil, causing it to form a thin seal.

Farmers have long been aware of most of these causes, but have not been able to assess their impact because they had no way of comparing the productivity of compacted versus loose soil, side by side on a field scale. With the advent of precision guidance and steering systems such comparisons are now possible, because the capability now exists of precisely controlling the location and number of tracks on which their machinery operates. This capability creates the opportunity for farmers to engineer seedbeds with near ideal physical, biological and chemical conditions and to compare the productivity of engineered seedbeds with that of 'normal' seedbeds.

This paper describes one means of deliberately engineering improved root-zone soil conditions in a controlled traffic regime and presents results that illustrate the levels of improved soil conditions and increased productivity that result from its application. This information provides insights that will enable farmers to make more-informed and better management decisions on how to gain substantial productivity improvements - improvements that cannot be maximised without controlled traffic (CT) operations.

The information provides a means of grasping an opportunity that is only available with precise control of farm traffic, because only under CT conditions can traffic compaction be reduced from about 52% of a paddock (with completely unaligned tracking) to around 15% (with even multiples of machine width, aligned tracks, trackwidths and narrow tyres). Readers should note however, that the practices described will produce their largest benefits where soils have compact layers within the top 25cm depth of soil.

HOW TO CREATE A NEAR-PERMANENT DEEP, LOOSE SEEDBED

To improve soil conditions of the root zone there are clear-cut management objectives that have to be achieved. These are:

- Increase the amount of soil organic matter
- Maintain good surface cover
- Reduce the density of the soil

If these objectives are met the soil will be:

- more stable to wetting and drying
- more permeable to water and air
- contain more plant available water and have
- a larger population of soil organisms and
- a larger soil nitrogen content.

The challenge is therefore to create a seedbed that is deeper, looser (rather than compact) with increased organic matter without

- inverting the soil, to minimise the loss of organic matter and soil nitrogen
- disrupting and exposing the roots of previous crops or pasture, to maximise the retention of a food source for soil organisms and to ensure the roots are present to act as reinforcing rods and minimise re-consolidation
- burying plant matter, to ensure plant tops and litter remain on the surface, to maintain a mulch to protect the soil against rain, wind, high temperatures and excessive evaporation
- incurring too much fuel, time and cost.

When assembling this technology the authors were aware that the chosen means of creating and maintaining a deep loose seedbed needed to be as practical and economic as possible, and so the decision was made to:

- limit the depth of disturbance to around 20-25cm., to constrain the cost and time required, and
- create a depth of about 30cm of loosened soil, a depth over which 90-95% of plant roots reside and from which 90-95% of water and nutrients are drawn.

The means chosen to create these conditions was to:

- rip the soil with a conventional ripper with tines spaced 30cm apart
- undertake the ripping when the soil moisture was moderately moist at 20-25cm depth (This moisture content is called the lower plastic limit (LPL) and can be judged by being able to roll a handful of soil into a rod that breaks up when it has a diameter of about 1cm. If the rod can be rolled into a smaller diameter it is too wet; if it can be rolled into a larger diameter, it is drier than optimum. Drier is better than wetter. When soil is disturbed at the LPL moisture content it breaks into a tilth rather than large clods (if too dry) or smeared grooves (if too wet.)

Once ripped, the loose tilth is maintained by using a modified ripper with fewer narrow tines (spaced ~ 70cm apart) and flat, wide blades mounted at the base of the tines (Figure 1). This machine:

- has substantially less draft than a conventional ripper
- causes near-zero soil inversion
- cuts and retains roots in a near-undisturbed state
- retains surface plant cover
- provides a near ideal tilth that is 25-30cm deep.

Figure 1. Ripper with narrow, widely spaced tines and wide blades that is used to maintain deepened loose seedbeds with near-ideal physical conditions in soils with shallow, dense ploughpans or B-horizons.

RESULTS

This form of soil management has been used on large scale field sites (from 1ha to 200ha 'plots') in the Great Southern District of Western Australia (rainfed grain crops), and in Pakistan (irrigated maize and wheat crops). The soil types at the Western Australian sites are shallow duplex soils with very dense ploughpans and B-horizons at depths of 10-15cm. The soil types in Pakistan are deep silty loams with dense ploughpans at 10-15cm depth.

Penetration resistance profiles

Average penetration resistance profiles monitored monthly at Mindarabin WA throughout a dry season in 2002 and a wet one in 2003 show the deepened seedbeds maintain a soil environment that does not limit root proliferation. Deepened seedbed data are less than the limiting value of 2000kPa (Taylor, 1971), which contrasts markedly with the normal seedbed.

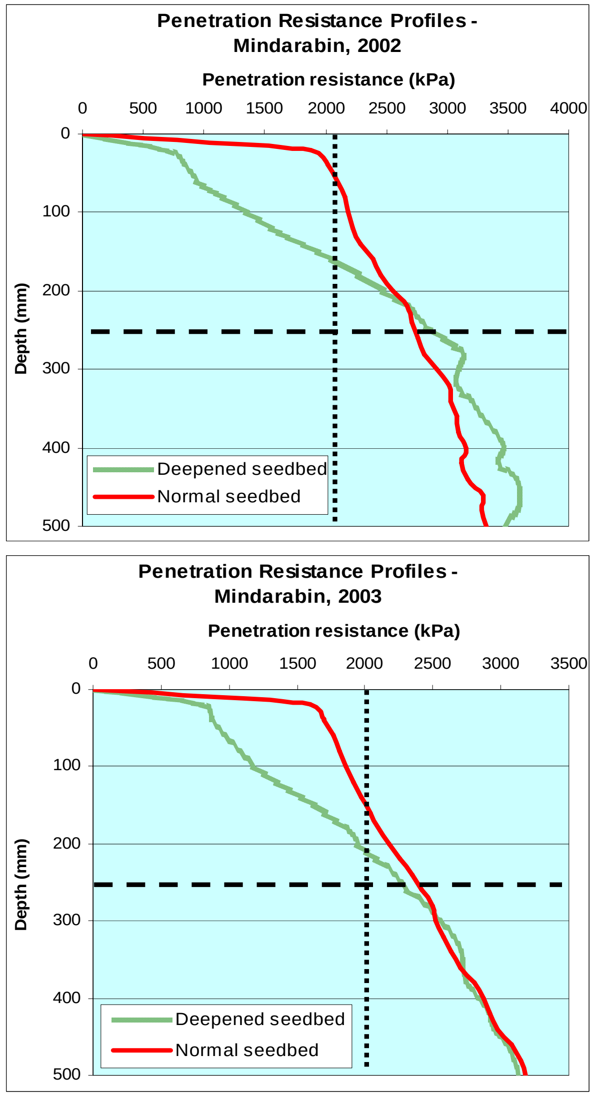

Figure 2. Average penetration resistance profiles for a grey clay at Mindarabin WA for 2002 (a very dry season) and 2003 (a wet season). The depth of the loosening is shown (horizontal dashed line), as is the penetration resistance that limits roots proliferation (2000kPa) (dashed vertical line).

Root mass and distribution

Root weights and distributions in normal and deepened seedbeds in Pakistan and WA (Figure 3) showed there was respectively 27% and 14% more root matter in the deepened seedbeds, most of which was in the 15-30cm depth layer, where the roots in a normal seedbed were very much less, as illustrated by Barnes (1971).

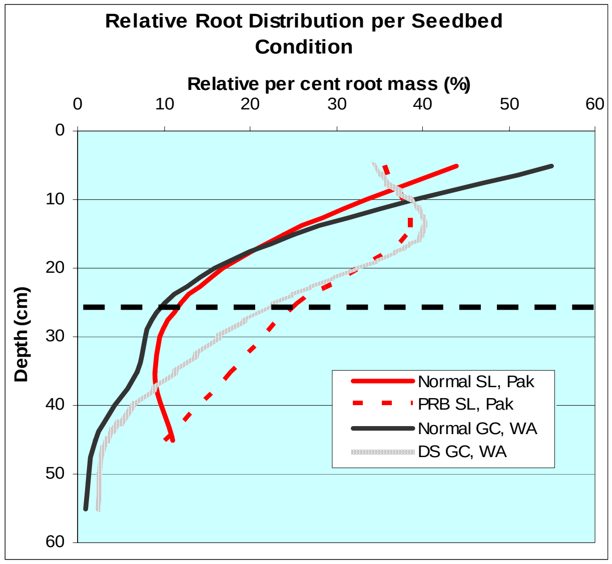

Figure 3. Contrasting relative root distributions and amounts in normal and deepened seedbeds in a silty loam soil (SL) in Pakistan and a grey clay soil (GC) in Western Australia.

Organic carbon and nitrogen content and distribution

Data from Pakistan and Woodanilling, another WA site where this form of soil management is applied (Figure 4) show that wherever root growth and depth is greater, so too is the amount and distribution of soil organic carbon. This soil constituent relates directly to soil nitrogen and the rate of mineralisation of this nitrogen is greater in loose soils compared to compact soil (Kemper et al. 1971; Parish 1971).

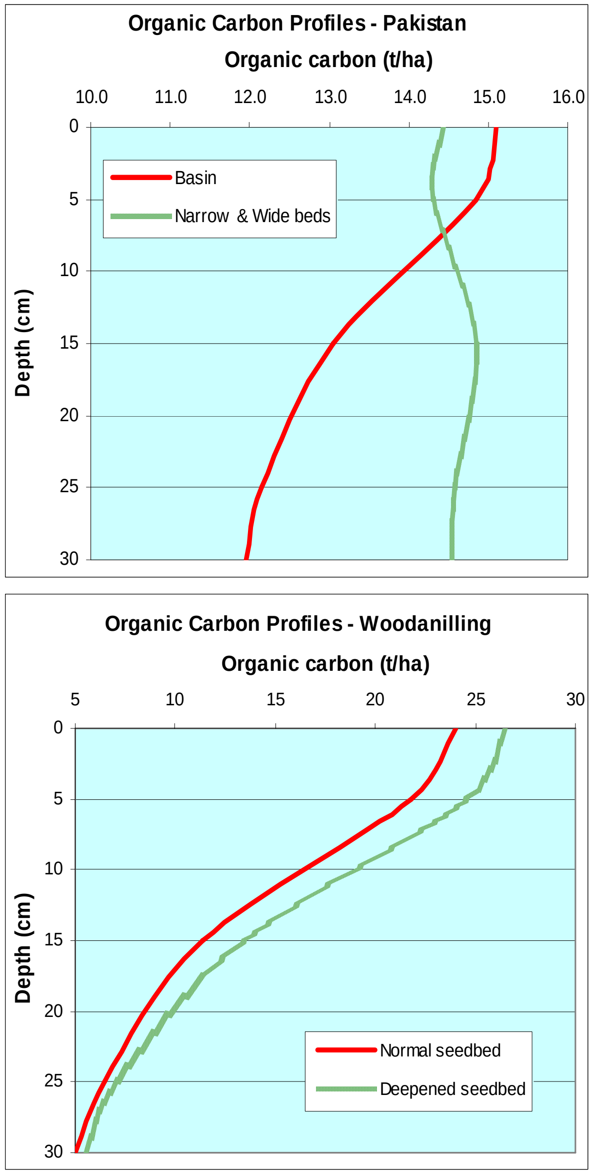

Figure 4. Organic carbon profiles in "normal" and loosened seedbeds in Pakistan and Woodanilling WA showing the increase that results from increased root growth in the top 30cm of deepened seedbeds.

Hydraulic conductivity and infiltration

Roots and the soil organisms that live in proximity with them soil create a more porous and stable soil, with enhanced water and air movement. Conversely, waterlogging susceptibility and poor oxygen supply characterise compact soil (Grable, 1971). Figure 5 illustrates the substantially improved infiltration of rainfall that occurs in the root zone of plants. Water that penetrates deeply is conserved for longer and if this is still within the root zone it will be largely used by plants rather than lost to the atmosphere as evaporation.

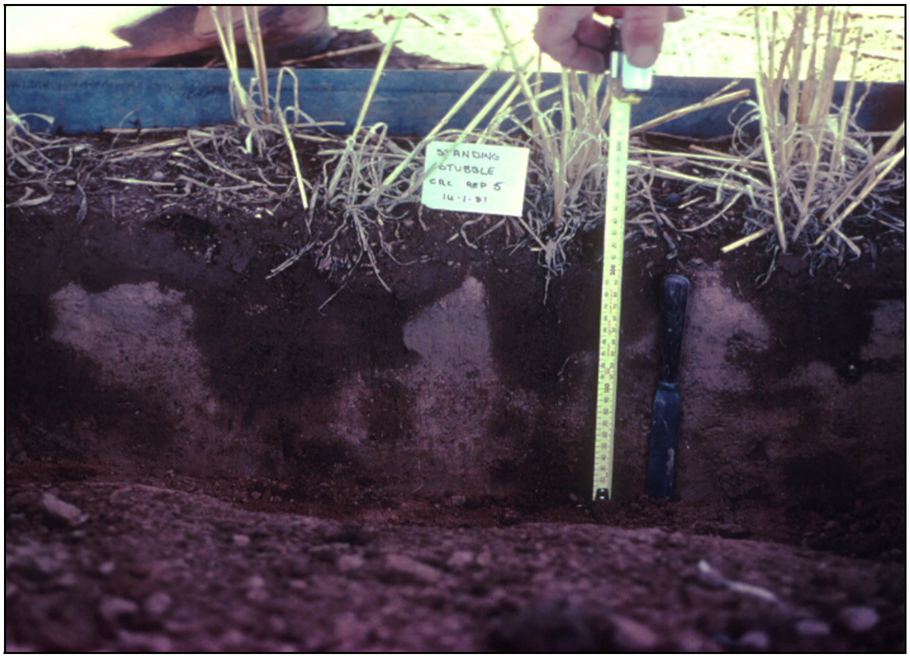

Figure 5. A profile showing enhanced rainfall infiltration in the root zones of a wheat crop.

Plant water use and average soil moisture profiles

Average soil water content profiles of regularly monitored root zones of crops grown on normal seedbeds and deepened seedbeds at Mindarabin in the wet season of 2003 show distinct differences that infer greater plant water use by the crops grown on the deepened seedbeds (Figure 6 left hand graph). When the effects of contrasting soil densities in these seedbeds are taken into account, by expressing the data as percentage of the total pore space in each, the interpretation is confirmed with extra insight. The “normal” seedbed is shown to have effectively waterlogged conditions below 15cm depth, which would limit root growth on its own, irrespective of the root limiting density of this layer.

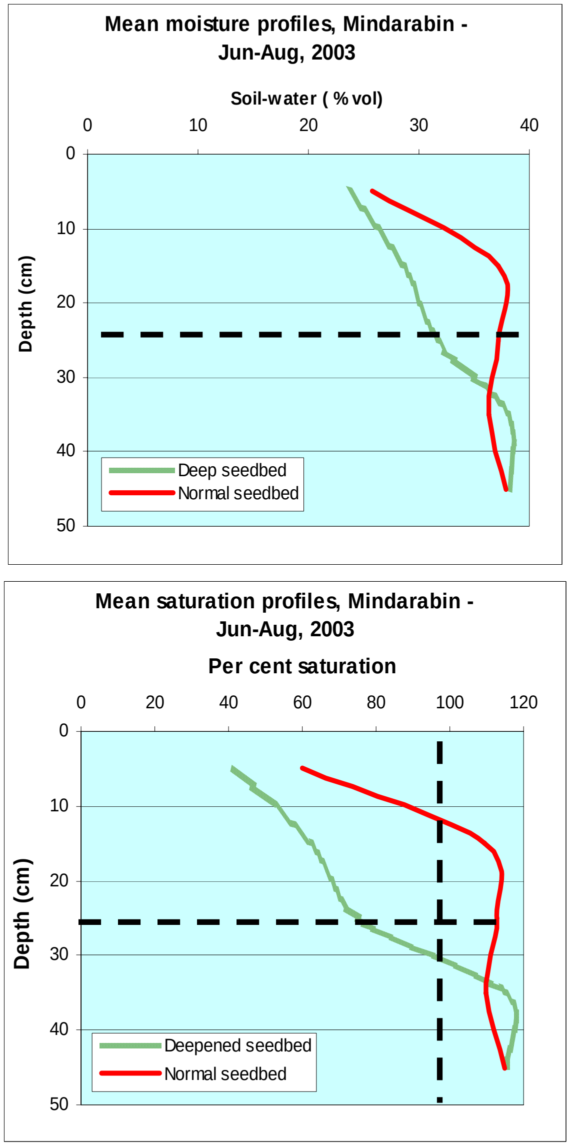

Figure 6. Average soil moisture profiles in a deepened seedbed and normal seedbed in a grey clay soil at Mindarabin WA

Production

All locations where this form of soil management has been practised have produced substantial yield increases. In Figure 7 yield data are presented for the Mindarabin grey clay soil in WA for 2001, 2002 and 2003. All of these seasons experienced abnormal distributions and amounts of rainfall: 2001 was dry early and wet late; 2002 was dry early and sparingly moist late; 2003 had above average rainfall all season. The deepened seedbeds easily performed better in all seasonal conditions, confirming their ability to conserve and enhance the availability of water to plants in all conditions.

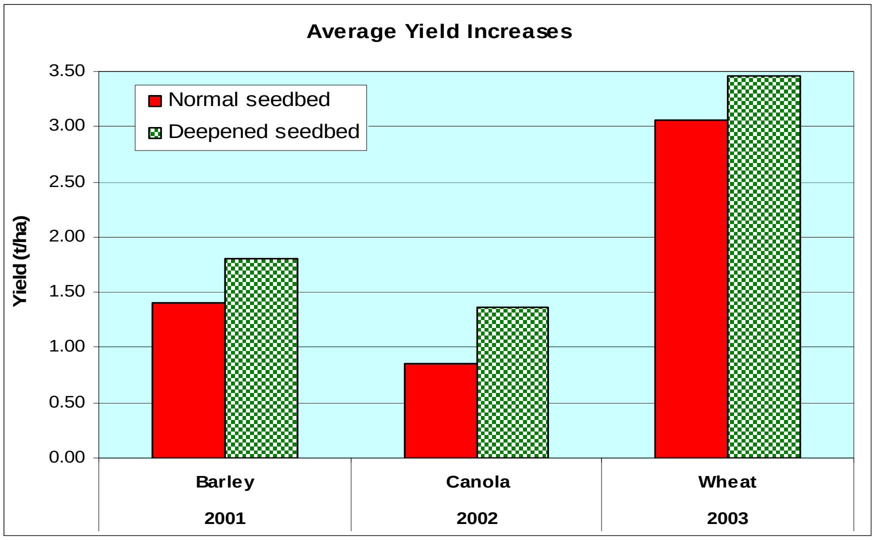

Figure 7. Average production data from tri-replicated 1ha plots at Mindarabin WA. The average yield increases, 29% in 2001, 63% in 2002 and 13% in 2003 are highly significant.

Costs and benefits

Gross margin analyses of no-tillage crop establishment on a normal seedbed and a deepened seedbed illustrated the benefits of using deepened seedbeds easily exceed the extra costs involved. These used the 3-year average yield increases over a 5-year rotation of wheat, barley, canola, peas and wheat, and 2003 on-farm commodity prices for the grains and crop inputs. This produced a conservative 5-year average increase in gross margin profit of $85/ha or 28%.

This result is deliberately conservative because: (a) the analysis included the cost an annual renovation of the deepened seedbed (at $50/ha), which is probably too frequent; and (b) it did not include an off-setting reduction in the operating cost of this practice in a CT environment, i.e. improved trafficability of permanent tracks and the substantially reduced draft of seeding into a loose seedbed. For example, observations from the broad-acre practice of seeding 200ha of deepened seedbed indicate a substantial reduction fuel in fuel usage, from 6-7 l/ha on a settled, compact no-tillage seedbed to 2-3 l/ha on a deepened seedbed.

DISCUSSION AND CONCLUSIONS

This form of soil management was deliberately formulated to build on the soil improvements that accompanied the no-tillage crop establishment revolution – increased soil organic matter and soil nitrogen, improved water conservation and efficient seeding and in-crop operations. It has been demonstrably successful in this respect, as all these attributes have been improved, with no loss in accessibility.

It also sought to seize the opportunities of provided by CT - operational precision - to raise the condition of root zone soil to levels that approach theoretical limits. Whilst these maximum limits may still be a little way off, the root zone environment for crops has been improved to a point where the level and reliability of its productivity over highly varying seasons is beyond those currently existing and well beyond those existing when the land was first cropped.

How often does one need to renovate?? There is no universal answer for this management question. The need or benefits of renovating will be determined by the rate and extent to which the soil of a deepened seedbed reconsolidates. Seasonal conditions and traffic control will determine this need and frequency. Wet seasonal conditions and compaction caused by farm traffic and stock will increase the need for and frequency of renovation. Dry seasonal conditions and good traffic control will decrease the need and frequency of renovation. Experience and field testing will reveal when a renovation will be worthwhile.

Although not deliberately included in the objectives of this work, the beneficial environmental aspects of deepened seedbeds should be realised and appreciated. Clearly, in times of climate change with fewer, more erratic rainfall events, improvements in water conservation, waterlog prevention and increased plant availability of soil water make this form of soil management much more robust than existing forms of management. Also, its ability to reduce emissions of the greenhouse gases carbon dioxide and nitrous oxide whilst using less fuel should be recognised as progress toward a more sustainable environment.

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Leighview

Stewart Hamilton

Leighview is a family farm in central southern Victoria. Stewart is currently the sixth generation farmer to come home to the farm. The property over the last 35 years has changed is focus from self replacing merino enterprise with little cropping to mainly broad acre cropping with a few weed eaters on the stony country.

Realising the yield potential of the 510mm of average rainfall each year better farming systems were sort after.

BIT OF HISTORY

- 1987

Started trialling direct drilling with airseeder but unhappy with tine breakout.

- 1990

511 combine with direct drilling under carriage for better seed placement.

- 1995

First of the raised bed trials went in 1.95m. 511 28 run combine. 27.5m sprayer on 3-4m centres.

- 1997

480Ha of raised beds in place

- 2002

Prototype 6m air seeder developed. Hydro tines and press wheels. 27.5m sprayer on 3-4m centres.

- 2004

IPM integrated pest management.

- 2007

Prototype 10m airseeder developed on 2m centres. 275Hp articulated tractor on 2m centres. GPS Ag auto farm 2cm accuracy. 30m Spreader on 2m centres. 28m sprayer on 3-4m centres. Header still on factory settings (too hard).

At present 2500 Ha are cropped with a Canola, Wheat, Barley. Rotation

Also grown are Linseed and Field peas.

The raised beds were intended to minimise yield loss rather than increase yield. Having beds has given us the confidence to keep inputs up at the level needed to match the available moisture without worrying about plants shutting down due to water logging.

In the past 12 years the beds have run water only once and have had no nutrient run off. The beds result in a perfect seed bed not being compacted.

Fuel usage on flat 80 -100% horsepower from a New Holland TJ275 around 5-6 litres per Ha
Fuel usage in raised beds 50- 60% horse power around 3 litres per Ha.

FUTURE PROBLEMS

Header is the biggest problem facing us at the moment with a 36f offset front and wheel centres at 3.6m. It will not fit into the controlled traffic system. Also the sprayer will be next on the list looking for a 30m boom on a 2 meter centre.

A New Farming System for the Sugar Industry

Brad Hussey, BSES Limited, Mackay

INTRODUCTION

In recent years, the Australian sugar industry has embraced a range of new technologies to aid in the management of the farm business. These technologies include yield mapping, soil mapping, EM maps, GPS auto steer on tractors and community GPS base stations.
These technologies, when combined with a move to controlled-traffic, reduced tillage and fallow legumes, form the new farming system.

THE NEW FARMING SYSTEM

The move to this new farming system has been necessary as sugarcane grown on the traditional system is planted on 1.5 m row spacing. Cane is harvested one row at a time with all harvesting equipment passing over each row. Harvesting equipment has a wheel or track spacing of 1.83 m to 1.88 m which is not matched to the row spacing.

This mis-match of wheel to row spacing leads to a large area of the field being compacted during the harvesting operation by heavy harvesting equipment. Due to the high summer rainfall, fields are often wet when harvested leading to perfect conditions for soil compaction.

Sugarcane yields are also considerably higher than many other crops with district average yields in the 80 to 100 t/ha range. Individual blocks can have yields in excess of 150 t/ha. To remove these high yields from the field requires a large amount of infield traffic.

This traffic is mostly unconstrained and almost never guided with GPS guidance. This mis-match of wheel spacing and unconstrained traffic often results in 80% of the field being trafficked.

The move to a controlled-traffic farming system has been a part of a larger change to a New Farming System. The new system is based on controlled-traffic system at 1.8 m with permanent beds. Soybeans are grown in the beds to break the sugarcane monoculture and cane is then direct-drilled into the beds using dual-row double-disc-opener planters to reduce the amount of tillage required. These planters plant 2 rows of cane at 500 mm apart into the bed which is about 1 m wide. Many of the machines working in the new system now have GPS guidance to limit the compacted area.

Soil and yield maps are interpreted and used to from the basis of a nutrient management plan. Yield maps are used to schedule the cane harvests.

BENEFIT OF THE NEW SYSTEM

- The sugarcane monoculture has been broken by the fallow legume.
- The amount of tillage required has been significantly reduced.
- The amount for fuel used has been reduced.
- The compacted area has been reduced from 80% to 30%.
- Inputs managed based on yield and soil type.

SUMMARY

The use of new technology in the sugar industry is leading to reduced input costs, while maintaining yield leading to increased profitability and sustainability of the industry. The main challenge for the industry going forward is for a great proportion of growers to adopt the farming system/s. There is still work to be done to integrate all of the technologies to make the system complete.

Accurate Data Management for Precision Agriculture

Doug Jeans, Rinex Technology

ABSTRACT

The advent of precision agriculture has highlighted the requirement for accurate data management. Furthermore the amount of both spatial and temporal information that is required to be updated on a continual basis is beyond the means of traditional data management practices. The Saturn HR guidance system provides a seamless path between the office and field machinery for planning, product application, and data archival of all seed, chemical and fertiliser applications. The data management system is embedded within the HR guidance system which can also be equipped with AutoSTEER and AutoSPRAY for a comprehensive precision agriculture management system.

INTRODUCTION

Precision agriculture is still very much in its infancy and today is still an emerging technology that is widely misconstrued. Earlier misconceptions were that precision agriculture was specifically the use of GPS with a yield monitor, or in more recent times the use of guidance or automated steering system. However these thoughts are merely some of the tools that are used within the precision agricultural solution. Hence it is first necessary to define what is meant by precision agriculture. Numerous organisations throughout educational and government institutions have defined precision agriculture, however for the purpose of this presentation the following definition from the US house of Representatives (US House of Representatives 1997) is considered.

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 minimizing unintended impacts on wildlife and the environment".*

This definition recognises that site-specific product information is required across the whole farm, over a long term period. Hence traditional information recording techniques, such as a small notepad which may be transcribed to a computerised farm management package, is now being challenged. In order to adopt accurate data management for precision agriculture it is essential that the techniques for recording field data are improved. This field data will form the backbone of the spatial and temporal information in the farm management system.

The Saturn HR system (HR), from Rinex Technology, is an integrated GPS guidance and field data recording system designed specifically for accurate data collection for precision agriculture. Furthermore the HR allows the user to seamlessly transfer information between farm management systems and the vehicle as production based information is designed, applied and archived.

THE PLAN CENTRIC CONCEPT

The typical crop production cycle for any particular field commences at the completion of the harvest operation from the previous season. From this point in time forward, any activity or treatment that is performed in the field is recorded, the final activity being the seasonal harvest. This cycle has been described as plan centric as the whole growing season is centred around a plan for the field. This plan will detail such activities as, the crop type and variety, seeding and fertiliser rate, insecticide and herbicide treatments throughout the growing season. The planning stage will commence in the farm office when a decision is made as to which crop is planted in the field. This decision will be made based upon historical records for the field. The plan centric concept is illustrated in Figure 1.

Figure 1. Plan Centric Concept

Once the plan has been devised in the office it is then necessary to implement this plan in the field. In the case of spraying a herbicide, the plan will detail such information as individual chemicals with any relevant attributes and their individual application rates, and the water delivery rate from the boom. However it is likely that from the time the treatment plan was conceived and when it is applied in the field, prevailing atmospheric conditions or crop growth stages may influence the final mix. Accordingly it is necessary to record the actual application information as opposed to the designed application. These actual records are those to be recorded for the particular field. This information is then transferred back to the farm management system in the office and will form the basis of management decisions in the future, hence the plan centric concept.

MAPS AND PLANS

In order to visualise the whole farm, with individual fields and their respective attributes, a scaled map provides the necessary detail in an intuitive format. However progressing forward from this point a geo-referenced map in a digital format is an integral component to record spatial data from field treatments. Furthermore digital maps may then also make use of remotely captured data such as aerial photographs or satellite images for underlays on the farm map for visual referencing.

Farm maps can be created using PlanIT, the back office management package from Rinex Technology. The farm map can be enhanced with mapping layers to show attributes such as arable areas, waterways, bush areas, roads or any necessary linear or area features. A fundamental feature which is recorded is the field boundary which defines the perimeter of individual fields. It is the field boundary which is used in the HR to automate the data collection when farm machinery is working within the respective field. A typical farm map derived from PlanIT is shown in Figure 2.

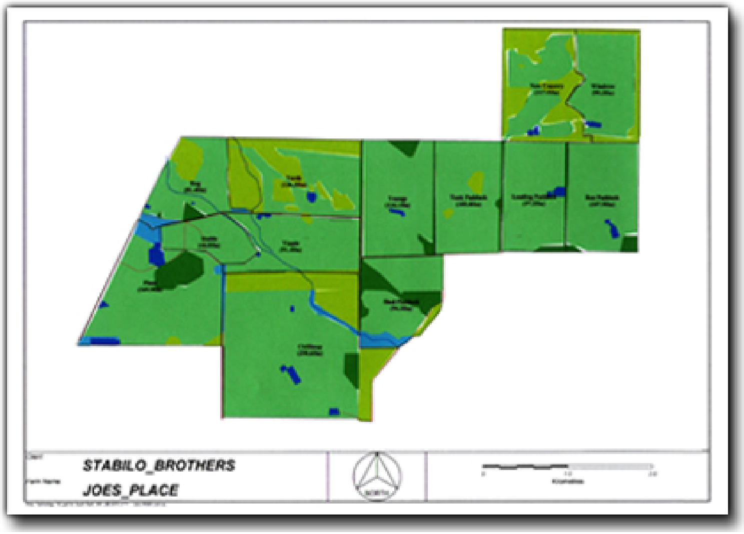

Figure 2. Sample Farm Map

Furthermore the use of the farm map provides a simple interface when developing an application plan for the farm. Recognition of individual fields displayed on a map is far easier than a tabular list of field names. Hence when selecting fields for inclusion in a plan the farm map is more instinctive to the human operator.

The design of any application plan for treatment of a field all have the same basic constituents, the product, its attributes and the application rate, and the field where it is to be applied. As previously indicated an application plan with chemicals will be more complex as there will most likely be several chemicals in the “cocktail mix”. By using PlanIT a field and product matrix is generated where Chemicals are added in the columns and Fields are added in the rows. For each field in the application plan the intersecting cell for the applicable chemical will record the application rate. A typical application plan from PlanIT with the linked farm map is shown in Figure 3.

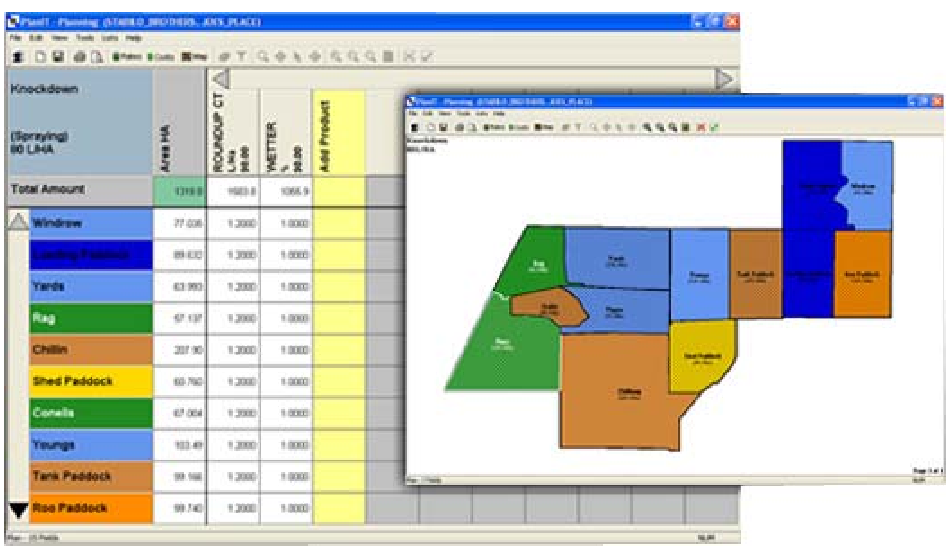

Figure 3. Application plan with linked farm map

THE SATURN HR

The Saturn HR is a combined GPS guidance and data management system produced by Rinex Technology. The user interface is a 22cm colour touch screen which allows the operator to control guidance and automated boom section functions, as well as import application plans from PlanIT and record relevant data on field treatments. The recorded data may be exported back to PlanIT. The Saturn HR touch screen is shown in Figure 4.

Figure 4. Saturn HR user interface

The HR will import plans designed in PlanIT, as well as other farm management systems such as PAM, for automated data management in the tractor. The application plan includes the necessary products and the fields where the products are to be applied. The overall integrity of the entire data management system is protected by the HR when using geo-referenced farm maps with individual field boundaries and the applications plans. As previously stated the application plan can be amended in the field prior to application to allow for prevailing conditions. Furthermore the HR can be interface to a number of flow controllers to record actual application rates. The overall functionality of the HR allows the applied products to be recorded with spatial and temporal attributes in an automated structure which can then be transferred the relevant farm management system.

TANK MANAGEMENT FOR PRODUCTS

The application plan which is imported to the HR details the products and fields which are to be treated using the respective plan. The operator of the tractor which will be applying the treatment is required to fill the tank with the appropriate products. For any product the HR tank is defined as a container which is used to hold seed (air seeder) chemicals (sprayers) or fertilisers (super spreaders). In the case of a chemical application the tank of a sprayer will be required to hold the applicable chemicals and water. The HR tank calculates the amount of product required to be placed in the tank to achieve the target rate in the application plan. This is shown in Figure 5.

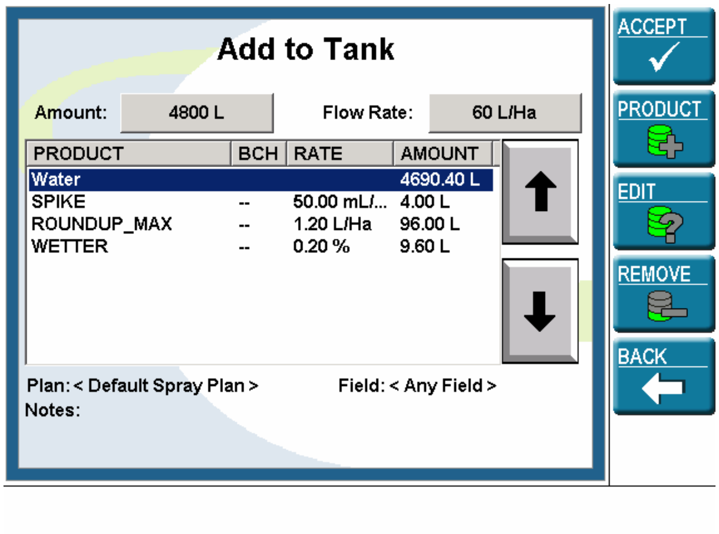

Figure 4. Saturn HR tank

The HR tank can calculate virtually any combination of rate, area or amount so that the operator is not required to do this task and minimises the errors from human operators. All products can be recorded with their respective attributes including the withholding period, chemical group and type, mixing configuration and batch numbers.

AUTOFIELD – AUTOMATED FIELD DATABASE RECOGNITION

An integral component of the HR is the automatic field recognition, AutoFIELD. As all data is spatially recorded it could be argued that it is not necessary to have defined fields with names. However with farm management the recognition of these fields is still an important aspect of day to day management. From the development phase of a plan to the treatment application in the field, it is the "field-name" that the owner and operator will refer to for the field in question.

Accordingly it is imperative that the treatment information is recorded within the correct field and this is the power of AutoFIELD function in the HR. This is intrinsically linked to the digital farm map in the farm management software which ensures that the treatment data is associated with the correct field.

Once an application plan has been loaded into the HR and the tractor commences work in the field the HR automatically checks the field is included for the applicable plan. The HR can not stop application of the treatment, however it does alarm the operator that they are working in the wrong field.

GUIDANCE FUNCTIONS ON THE HR

As previously stated the HR is a combined guidance and data management system. By incorporating the two functions it is possible to provide additional benefits to the operator for controlled traffic applications. The field database on the HR is also used to store and retrieve A-B points for each individual field, however when incorporating the AutoFIELD function it automatically selects the A-B points for the relevant field, minimising human error once again.

A relatively new guidance function offered on the HR is the RePLAY guidance. This allows a tractor to follow the same path from a previous treatment, hence if the field is not worked with parallel runs for whatever reasons it is still possible to apply controlled traffic guidance in the field in which ever formation is required.

Finally the HR will interface with several automated steering systems for controlled traffic operations. The guidance functions available on the HR can all be used with AutoSTEER. Hence whether the system is used for straight parallel swaths using A-B guide points, or contour guidance around irregular shaped fields, the HR AutoSTEER can be invoked.

FIELDNET ON THE HR

Another new feature which has been released on the HR is for real time multiple vehicle guidance and data management. FieldNET distributes information pertaining to the vehicle between other vehicles in the same field using a wireless network. FieldNET allows guidance information to be transmitted between vehicles as well as farm data. The network synchronises data sets between the vehicles when the systems are connected for the same field.

CONCLUSION

The Saturn HR provides an easy to use interface for accurate data recording and vehicle guidance. The HR can be used extensively for controlled traffic and precision agriculture applications where meticulous data recording is required due to its unique functions including tank management and AutoFIELD. Furthermore the recorded information can be easily transferred to office management systems for further data management and archiving to improve whole farm production. The HR forms an integral component of automating the plan centric concept which is fundamental building block in precision agriculture.

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The Journey is Great, but does PA Pay?

Garren Knell, ConsultAg, Alison Slade, DAFWA, CFIG

KEY MESSAGES

Variable results were achieved in 2006 when matching fertiliser inputs to productivity zones. Results ranged from an increase in paddock returns of $2700 to a loss of $4500 compared to a blanket application of fertiliser.

After 8 trials over 4 years it remains unclear if the adoption VRT and applying fertiliser according to the performance of each productivity zone is likely to generate significant profits when compared to blanket applications of fertiliser in the Corrigin district. The information gathered in the process does however allow farmers to better understand their paddocks and their crops fertiliser requirements to assist in making profitable fertiliser decisions.

Where soils have a high nutrition status (N, P, K, S) and low reactive iron there is scope for farmers to significantly reduce fertiliser inputs in the short term and still achieve profitable grain yields.

AIMS

To better match fertiliser inputs to productivity zones to increase whole paddock profitability.

To document and evaluate a practical procedure utilising tools and services that are readily available for zoning paddocks and matching fertiliser inputs to productivity zones.

Key words

Zone management, Precision Agriculture, VRT, Nutrition, Profitability

METHOD

Zoning paddocks and estimating crop nutrition requirements

The Corrigin Farm Improvement Group in conjunction with ConsultAg and DAFWA conducted 5 trials looking at Precision Agriculture and Variable Rate Technology. Summarised within this paper are 2 trials from 2006. The rest of the trials performed in a similar manner. Paddocks were zoned using Silverfox's biomass imagery analysis. The analysis incorporated biomass data from 5 seasons of crop performance. This produces a biomass stability map. The biomass stability map identifies zones in the paddock that consistently show poor, average or good performance. This is a useful tool in precision agriculture because it also helps to identify those areas which are unstable in their performance through time.

Target yields for each productivity zone were set using the biomass images and farmer experience. Soil testing was undertaken in each zone at a depth of 0-10cm and 10-20cm. The Nulogic crop nutrition model was used to generate the fertiliser requirements to achieve the target yield in each productivity zone. Target yields were reviewed post emergence due to the late break to the season and low rainfall. Where target yields were lowered the nitrogen requirements were amended to reflect the change in target yields.

The sites were tissue tested in August to evaluate nutrient uptake and to ensure that there were no trace element deficiencies that would influence the trial results. The paddocks were also flown by Air Agronomics to assess crop biomass in response to the nutrition treatments.

Trial designs

The paddocks were sown with the farmer's air seeder so that a seeding run would pass through at least two of the productivity zones but usually through all three. The plots were a full air seeder width wide and yield was measured with a weigh trailer from a minimum plot length of 100m in each zone.
Trial designs were a fully randomised design with 3 replications. In paddocks where the zone size was not large enough for 3 replications, 2 replications were used but 2 header cuts were taken down the length of each plot to provide 4 data points for each treatment.

Economic calculations

All financial calculations used 2006 list fertiliser prices. The grain prices were calculated individually for each treatment using the December 2006 AWB golden rewards premiums and discounts. The prices were then converted back to a farm gate price. The calculated returns for each treatment represent gross income minus fertiliser and application cost.

RESULTS

Example 1 – N and G Turner, Corrigin 2006

The trial paddock is a sandplain soil type ranging from loamy sand to deep white sand and was located high in the landscape. The paddock grew lupins in 2004 and Calingiri wheat in 2005 and 2006.

The paddock was un-grazed over summer and the stubble was burnt in late autumn prior to sowing. The paddock received *266mm* of rain during January, February and March. It was a dry winter and the crop received *180mm* of growing season rainfall.

Soil tests indicated that the site had relatively high phosphate levels and low to ideal reactive iron levels (See table 1). This meant that the site was unlikely to be responsive to phosphate. The soil nitrogen levels were low and the paddock was wheat on wheat and the site was expected to be responsive to nitrogen. Table 2 shows the target yield for each productivity zone and the recommended rate of nitrogen and phosphate to achieve the target yield.

Table1. Soil test results.

Productivity Zone	pH (CaCl)	Organic Carbon	Nitrate Nitrogen	Ammonium Nitrogen	Phosphorus (Colwell)	Reactive Iron	Potassium (Colwell)
Poor	4.8	0.46	8	1	21	127	34
Average	5.2	1.76	8	2	33	682	102
Good	5.5	1.37	17	1	23	488	81

***Note** – Sub soil data not included.*

Table 2. Fertiliser recommendation to achieve target yield.

Fertiliser Treatment	Target Yield $t.ha^{-1}$	Phosphate Kg/Ha	Nitrogen Kg/Ha	Potassium Kg/Ha	Cost $/Ha
Low	1	5	11	3.5	$27
Medium	2	10	30	6.7	$59
High	3	10	65	6.7	$96

Grain yield and economics

All 3 productivity zones yielded very well, exceeding target yields by between 0.5-1t.ha^{-1} (Table 3). The zones performed as expected with the highest yield in the good, average and poor zones 3.65, 2.89 and 2.2t.ha^{-1} respectively.

The highest yield and returns in the poor productivity zone were achieved with the medium fertiliser input. This is not surprising given the grain yields were at least 1t.ha^{-1} greater than the target yield.
In the average productivity zone the medium and high input treatments achieved similar yields and grain quality, however the additional costs of the high input treatment meant that it generated lower returns (Figure 1). All 3 treatments failed to make ASWN quality because of low protein.

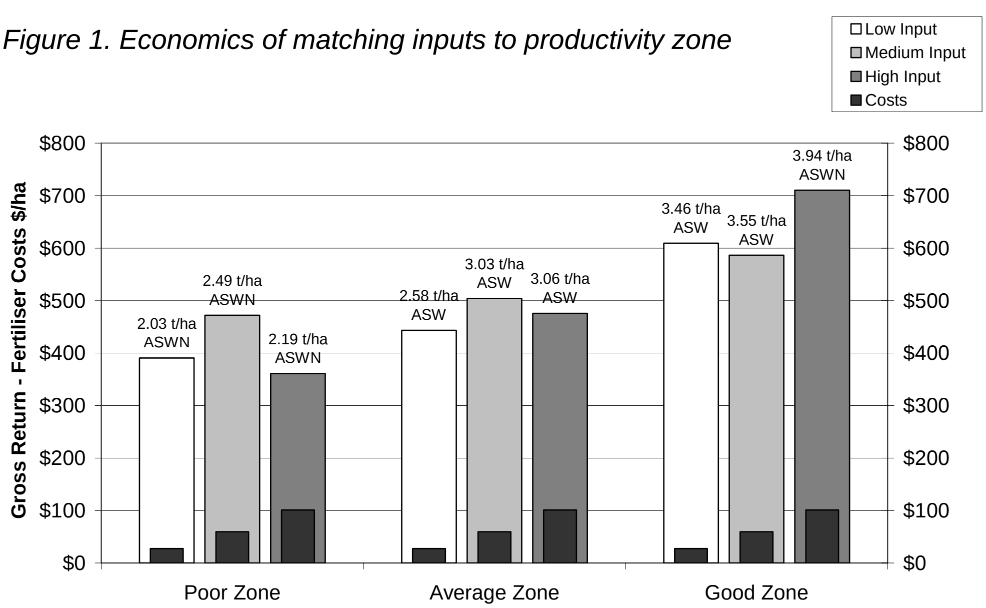
Table 3. Grain yield, quality and price of each fertiliser treatment in poor, average and good productivity zones.

	Input	**Yield** t.ha	**Hect wt**	**Screenings**	**Protein**	**Moisture**	**Pay Grade**	**Price $/T**
Poor Zone	Low	2.03	82.1	3.2%	9.5%	10.0%	ASWN	$206.0
	Medium	2.49	81.5	3.2%	10.1%	10.0%	ASWN	$213.5
	High	2.19	81.5	3.0%	9.8%	10.0%	ASWN	$211.0
Average Zone	Low	2.58	81.5	1.8%	8.9%	10.0%	ASW	$182.5
	Medium	3.03	82.1	1.7%	9.1%	9.9%	ASW	$186.0
	High	3.06	81.6	2.5%	9.4%	9.9%	ASW	$188.5
Good Zone	Low	3.46	80	3.2%	9.2%	9.9%	ASW	$184.0
	Medium	3.55	81	2.2%	8.9%	9.9%	ASW	$182.0
	High	3.94	80	3.2%	9.5%	9.8%	ASWN	$206.0

In the good productivity zone the high input treatment achieved the highest yield and returns (Figure 3). The returns were further improved by the high input treatment achieving ASWN where as the medium and low inputs were down graded to ASW because of low protein.

Figure 1 shows the gross return minus fertiliser cost for the low, medium and high inputs in the good, average and poor productivity zones. The black bars represent fertiliser expenditure.

Figure 1. Economics of matching inputs to productivity zone



Zone management *vs* blanket treatment

To calculate the benefit or cost of managing this paddock according to productivity zone we extrapolated the findings across the whole paddock according to the areas of each zone in the paddock (Table 4). In this example VRT assumes fertiliser rates based on target yield in a zone; good (high), average (medium) and poor (low). The unstable areas of the paddock that fluctuate in performance from year to year were included in the average productivity zone.

This shows that in 2006, there would have been a net benefit of $2693 in this paddock from matching fertiliser inputs to productivity zones (VRT) compared to applying the medium treatment as a blanket across the whole paddock. While this additional income is a step in the right direction it only represents a 5% increase in returns. Given the financial and time costs involved in setting up a VRT system many farmers would want a substantially greater increase in returns than 5% to warrant adoption.

If the whole paddock was blanketed with the high input treatments there would only be a $740 benefit compared to the medium input in 2006. This is a small additional return given the extra financial risk associated with spending an extra $37/Ha on fertiliser. In an average or poor season the high input treatment would be highly unprofitable.

Table 4. Cost or benefit of matching fertiliser inputs to productivity zones

	Ha	Low	Medium	High	VRT
Poor	10	$3910	$4720	$3610	$3910
Average	59	$26137	$29736	$28084	$29736
Good	31	$18879	$18197	$21700	$21700
Total		**$48926**	**$52653**	**$53394**	**$55346**
Difference from Medium input		-$3727	$0	$741	$2693

Example 2 – P and A Groves, Yotting 2006

The paddock was sown to lupins in 2005 and Calingiri wheat in 2006.

The paddock received around *260mm* of rain during January, February and March. It was a dry winter and short spring and the crop received approximately *180mm* of growing season rainfall.

Soil tests indicated that the site had high phosphate levels and low to ideal reactive iron levels (See table 5). This means that the site was unlikely to be very responsive to phosphate. The soil nitrogen levels were not high. This was surprising considering the previous legume crop and mineralisation from summer rain. There may have been some leaching of nitrate from the soil surface.

Table 5. Soil test results

Productivity Zone	pH (CaCl)	Organic Carbon	Nitrate Nitrogen	Ammonium Nitrogen	Phosphorus (Colwell)	Reactive Iron	Potassium (Colwell)
Poor	4.9	0.74	36	5	31	326	87
Good	4.6	0.4	11	1	27	451	87

***Note** – Sub soil data not included.*

Table 6 shows the target yield for each productivity zone and the recommended rate of nitrogen and phosphate to achieve the target yield. The soil tests indicated that there was no additional phosphate or nitrogen required to achieve the 2T target yield in the low zone.

Table 6. Fertiliser recommendation to achieve target yield.

Fertiliser Treatment	Target Yield $t.ha^{-1}$	Phosphate Kg/Ha	Nitrogen Kg/Ha	Cost $/Ha
Low	2	0	0	0
Medium	3	5	15	$30
High	4	10	55	$91

Grain yield and economics

The paddock was high yielding, especially given the dry season, however the zones did not perform as predicted. The poor performing zone was the highest yielding with an average yield of 3.06 t/ha (Table 7, Figure 2). It is not clear why this occurred and will require further investigation. The average production zone achieved the lowest yield (2.6 t/ha) and the good zone achieved the median yield (2.87 t.ha).

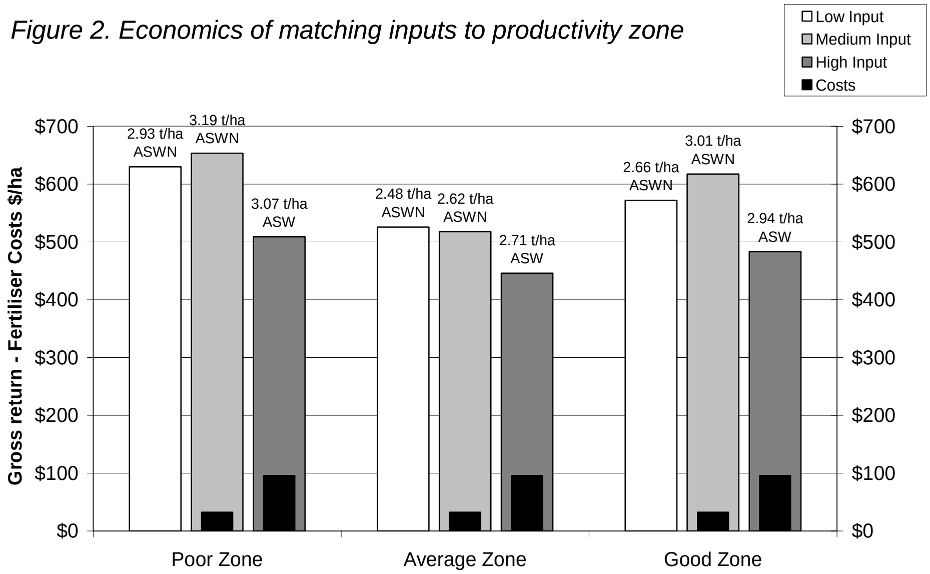
Table 7. Grain yield, quality and price of each fertiliser treatment in poor, average and good productivity zones

	Input	**Yield** t.ha	**Hect wt**	**Screenings**	**Protein**	**Moisture**	**Pay Grade**	**Price $/t**
Poor Zone	Low	2.93	80.9	2.4%	10.2%	10.1%	ASWN	$215
	Medium	3.19	81.2	2.1%	10.1%	10.1%	ASWN	$215
	High	3.07	78.0	5.0%	11.9%	10.1%	ASW	$197
Average Zone	Low	2.48	80.6	2.7%	11.0%	10.3%	ASWN	$212
	Medium	2.62	80.6	2.9%	11.4%	10.2%	ASWN	$210
	High	2.71	79.0	3.8%	12.2%	10.2%	ASW	$200
Good Zone	Low	2.66	81.2	2.4%	10.4%	10.3%	ASWN	$215
	Medium	3.01	81.1	2.1%	10.4%	10.2%	ASWN	$216
	High	2.94	78.1	4.5%	11.8%	10.2%	ASW	$197

Across all zones the medium input treatment achieved the greatest returns except in the average zone where it had equivalent returns to the low input treatment (Figure 2). The low and medium input treatments were able to achieve ASWN quality in all zones, however the high input treatment was discounted to ASW due to high protein. This is not surprising given the high nitrogen supply and sharp finish to the season. If a AH or APW variety had been grown the high input treatments would have received a protein premium rather than a discount and would have increased the returns. The grain yield failed to respond to the additional nitrogen and phosphate applied in the high input treatments and in most cases it suffered a yield penalty as well as grain quality discounts (Table 7).

The low input treatment exceeded the target yield (2T/ha) in all productivity zones (average yield 2.69T/Ha). This is an exceptional yield to achieve across all 3 zones given there was no applied fertiliser.

Figure 2. Economics of matching inputs to productivity zone



***Note** – no costs associated with low input as no fertiliser used.*

Zone management *vs* blanket treatment

To calculate the benefit or cost of managing this paddock according to productivity zones we extrapolated the findings across the whole paddock according to the areas of each zone in the paddock (Table 8).

If the paddock was sown using VRT and nutrition was applied according to predicted zone performance there would have been a net loss of $4494 (8%) in this 105Ha paddock compared to a blanked application of the medium input (Table 8).

The most profitable management option for this paddock would have been a blanket application of medium inputs (fertiliser cost $30/Ha). The blanked application of low input treatment (nil fertiliser) generated the next best returns which were only $1186 less or a 2% reduction in income for nil fertiliser expenditure. This is a surprising result and it is pleasing to know that fertiliser inputs can be reduced (in the short term) without significantly compromising yield where soil nutrition levels are high (N, P,K,S) and reactive iron levels are low.

Results would have been different if there had been a better finish to the season; however the site still achieved above 5 and 10yr average yield for the district.

Table 8. Cost or benefit of matching fertiliser inputs to productivity zones

	Ha	Low	Medium	High	VRT
Poor	10.5	$6615	$6857	$5345	$6615
Average	63	$33138	$32634	$28098	$32634
Good	31.5	$18018	$19467	$15215	$15215
Total	**105**	**$57771**	**$58958**	**$48657**	**$54464**
Difference from medium		-$1186	$0	-$10300	-$4494

CONCLUSION

The Corrigin Farm Improvement Group (CFIG) has replicated these types of trials more than 8 times over 4 years with similar results and as yet it is unclear if the adoption of VRT and applying fertiliser according to the performance of each productivity zone is likely to generate significant profits when compared to blanket applications of fertiliser in the Corrigin district.

The information gathered in the process does however allow farmers a better understanding of their paddocks and the crops fertiliser requirements to assist in making profitable fertiliser decisions.
In most situations there are trends or small increases in profit that suggest that zone management may have merits, however the seasonal variability in yields (Wet, dry, drought, frost) seems to prevent the treatments achieving their full response.

Our previous trials have indicated that zone management to ameliorate soils and correcting potassium deficiencies can be highly profitable.

It would appear logical to use VRT to assist growers to play the season with post emergent applications of nitrogen. The paddock could be sown with blanket nutrition and if there is an above average season addition nitrogen could be applied to the higher yielding zones in the paddock. CFIG will focus on this in the final year of the project.

ACKNOWLEDGMENTS

Corrigin Farm Improvement Group and participating farmers, GRDC, James Easton CSBP.

Electromagnetic Soil Mapping – Implementing the Outcomes

Quenten Knight, Consulting Agronomist, Precision Agronomics Australia, Esperance WA

INTRODUCTION

An increasing range of technologies that allow farmers to compile very detailed information about their paddocks is becoming available. It can be a challenge to organise this information so it makes sense and has some real use. Precision Agronomics Aust, supported by Precision Cropping Technologies are working closely with farmers to introduce these new technologies to aid management and agronomic decision making. The principal focus is to build a sound knowledge of the major factors influencing production and to generate practical outcomes that can be implemented by the farmer. Projects have commenced in the Esperance region and this is a brief discussion on some initial outcomes.

METHODS

The first stages involve mapping and analysing the topography and soil variability. Electro Magnetic Induction technology coupled with an RTK GPS has been used to conduct an EM Survey. The DualEM is towed behind a vehicle and measures the apparent electrical conductivity (ECa) of the profile at two depths 0 to 0.5mt and 0 to 1.5mt. It senses changes in soil conditions by how well it conducts an electrical current. Various soil properties can influence the DualEM response including soil texture, electrolytes (salts) and moisture. The DualEM map is a guide to soil profile change but requires interpreting starting with soil-testing. PAA have established a service dedicated to this task and collect soil cores at targeted locations over the survey area. The soil-test results are then subject to detailed statistical analysis generating knowledge of where soil properties of agronomic importance are varying over the survey area. These can include soil texture, potential water holding capacity, CEC, Sodicity, boron, Aluminium and depth to clay etc.

RESULTS

The 260 hectare paddock in the following example clearly demonstrates variability in soil type and topography that are having a big influence on final yield. The information gained from conducting an EM survey with RTK elevation data have provided us with the ability to identify the soil properties that were causing yield variation and some of the outcomes implemented to overcome this variation. Figure 1 below shows the relationship between EM and Yield where the canola yield is reduced at the low EM reading and also at the highest EM readings, whilst table 1 shows the implications to gross returns. The variations in yield and gross returns are best explained by the various graphs below where figure 2 represents the relationship between EM and clay %, strong correlations between constituents of soil particles or soil texture and EM were evident (clay r^2 0.81, sand r^2 -0.72). As the EM value increases, the soil profile 0-60cm has more clay and less sand with potential to hold more water (Figure 3) to support higher yields, providing that other sub soil constraints do not limit crop root growth.

Figure 4 shows that EM and cation exchange capacity (CEC) at 0-60cm were strongly correlated (r^2 0.76), generally the CEC is a measure of a soils overall fertility and ability to hold onto applied nutrients.

Therefore the lower yields at the low EM values represented by zone 1 in Table 1 can largely be explained by the low clay % which results in the soils ability to hold less plant available water exposing crops to periodic drought when rainfall events are infrequent. CEC is also poor resulting in poor nutrient availability especially after heavy leaching rains.

Figure 5 shows a positive relationship between EM and exchangeable sodium percentage (ESP) over 0-30cm (r^2 0.83) and 0-60cm (r^2 0.83). This data when used in conjunction with the strong correlation 0-60cm (r^2 0.85) between EM and the Calcium/Magnesium ratio (Ca:Mg) in Figure 6, demonstrate that the trend to lower yields at the high EM values in Zones 4,5,6 and 7 are largely due to the sub soil constraints caused by high levels of sodicity and magnesium.

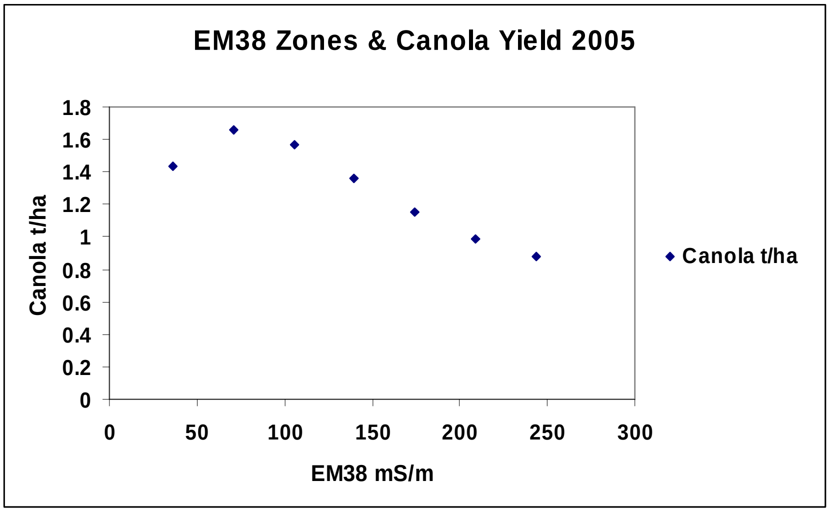


Figure 1

Table 1. EM Zones and canola gross returns

EM Zone	Ave EM Value	Ha	Ave t/ha	Gross $ @ $400/t	$/ha @ $400/t
1	36.6	37.1	1.44	$21,341.33	$574.97
2	71.0	64.7	1.66	$42,850.13	$662.38
3	105.5	114.3	1.57	$71,698.38	$627.04
4	140.0	33.2	1.36	$18,048.21	$543.08
5	174.4	9.3	1.15	$4,285.44	$460.15
6	208.9	1.4	0.98	$539.37	$393.93
7	243.3	0.4	0.88	$137.97	$350.90

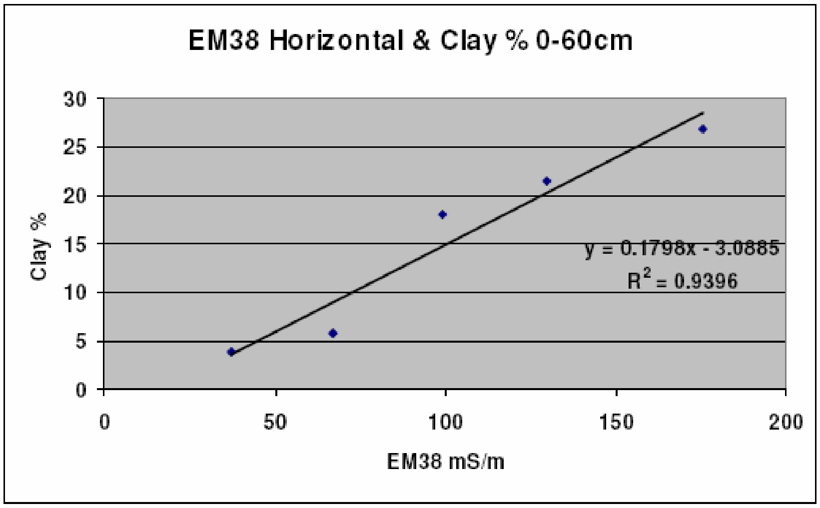


Figure 2

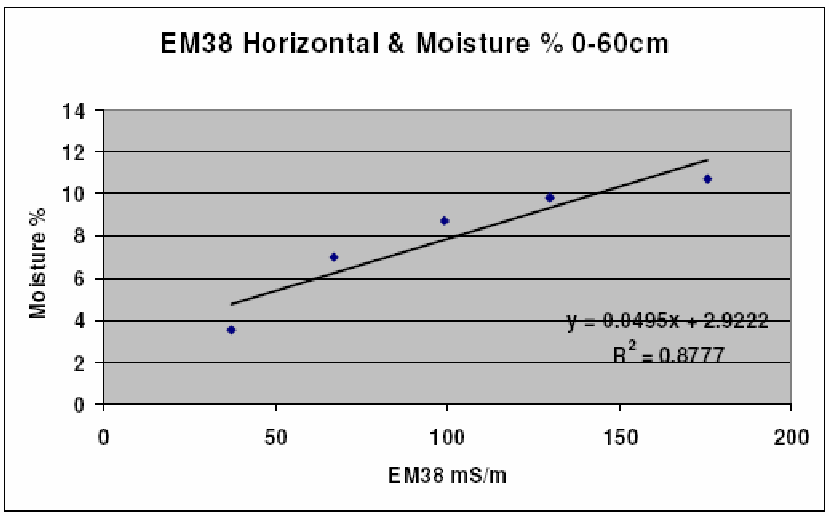


Figure 3

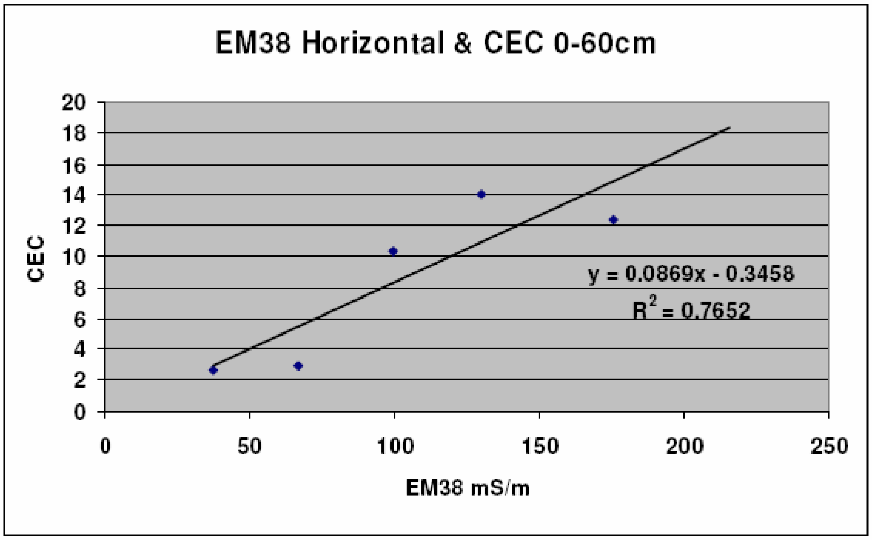
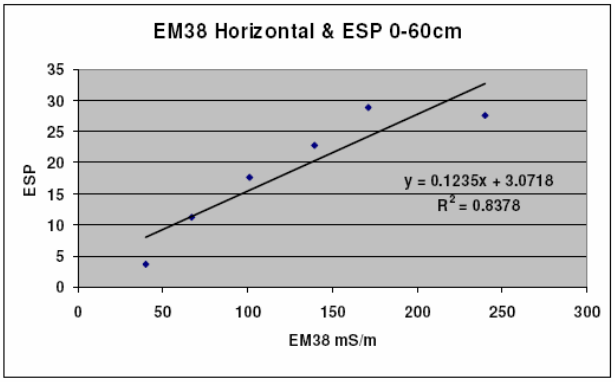


Figure 4



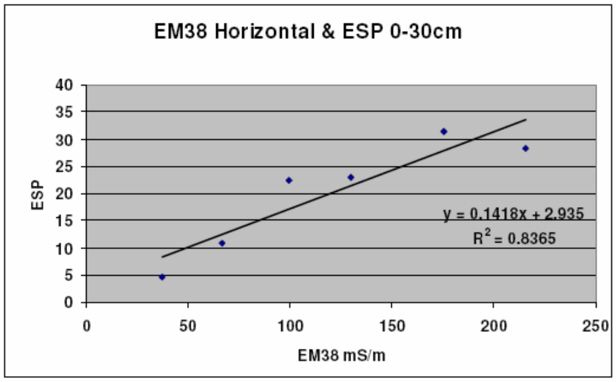


Figure 5

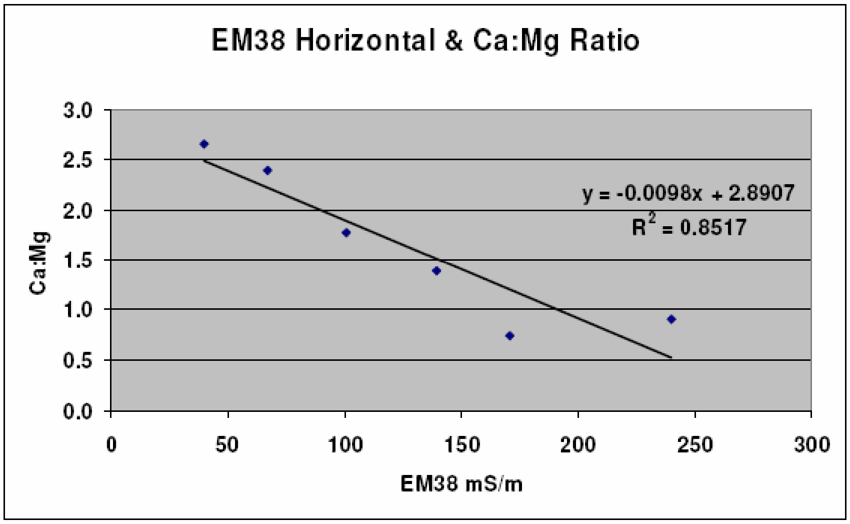


Figure 6

DISCUSSION

It is now apparent that lower yields and gross returns are occurring in this paddock where EM values are low but also where they are high. We also now know through targeted soil testing and analysis what is causing these yield losses and are now in a position to implement some management changes aiming to improve yield and gross returns in these lower yielding areas.

Figure 7 shows a map of the 260 hectare paddock representing three different zones in which different management practices will be undertaken. Zone 1 represents 60 hectares of the paddock where low yields were occurring due to low clay %, Moisture %, CEC, average pH levels (0-10cm) of 4.5 and potassium levels (0-10cm) ranging between 25-47 ppm. The management strategy employed in Zone 1 include lime application at 1.5T/ha, Muriate of Potash at 50Kg/ha and split applications of Nitrogen and Sulfur to improve efficiency of these nutrients by avoiding excessive loss by leaching.

Zone 2 represents 133 hectares where standard management practices will be continued as the soil analysis has not revealed any chemical or physical constraints that are restricting yield.

Zone 3 represents 67 hectares, in this zone we know that the soil has the ability to hold more water and nutrients, however plants have difficulty in accessing this due to the sub soil constraints associated with high sodicity and magnesium. The management strategy to be employed in this zone is the application of Gypsum at 3.5 T/ha to improve water infiltration and avoid the previous periodic water logging and the subsequent hard setting of the soil within these areas. RTK elevation data from the paddock also revealed that areas in Zone 3 also require minor surface drainage to drain water from some low lying areas.

Zones 1 and 3 were spread individually with each fertiliser or soil ameliorant with a Marshall multi spreader using farmlap guidance.

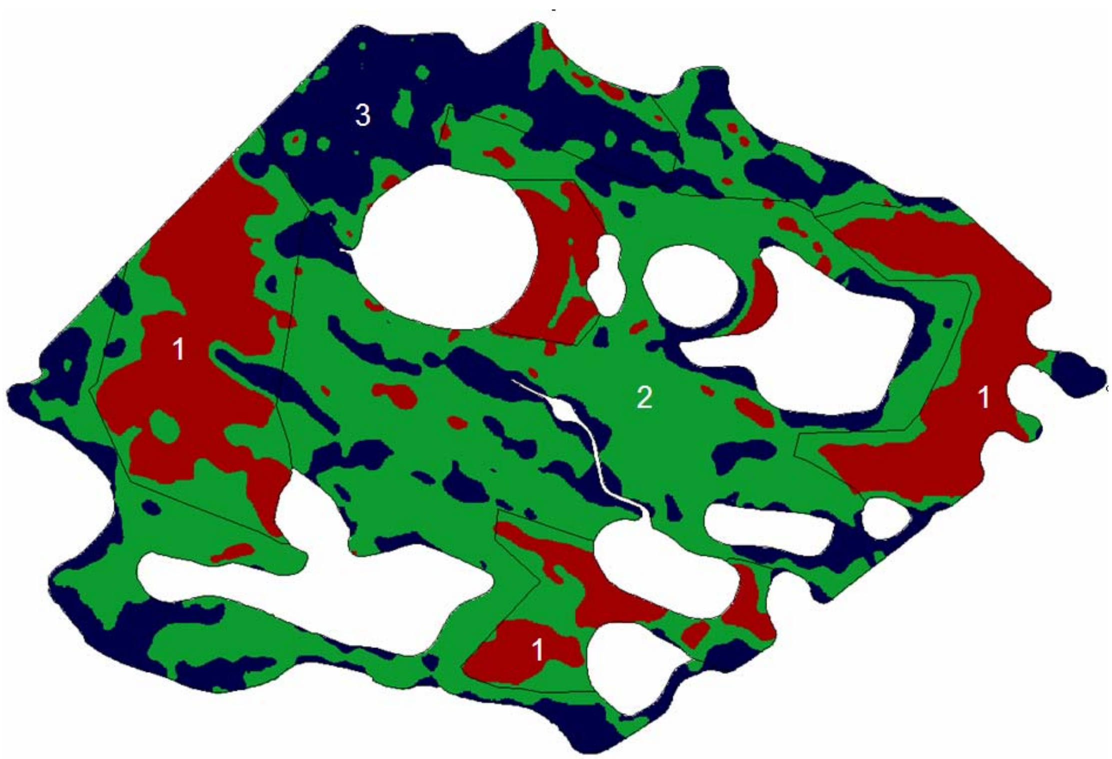


Figure 7

CONCLUSION

EM soil mapping is providing us with a guide to soil profile change, this information when coupled with strategic soil sampling to depth is allowing farmers and advisors to make informed decisions on the management of soil properties both physical and chemical which are having either a positive or negative effect on yield.

EM coupled with GPS allows us to easily create separate management zones that can be treated individually from the remainder of the paddock allowing us to be more targeted with expensive farming inputs.

- PAA have found many agronomic benefits from EM mapping other than the example above, other outcomes that have been implemented include;
- Depth to clay maps for clay delving boundaries.
- Variable rate herbicide maps for soil types where ryegrass/weed numbers are consistently high.
- Variable rate gypsum and lime maps.
- Variable rate nitrogen maps for either Urea or boom applied UAN.
- Areas of future high salinity risk.

ACKNOWLEDGEMENTS

Michael Wells – Precision Cropping Technologies SA.

Precision Farming with Machinery and in the Farm Office

James Lang, AGCO

INTRODUCTION

The ISOBUS communication standard is widely known for its ‘Virtual Terminal’ aspects enabling end users to plug and play implements into a tractor and operate multiple functions from one terminal in the cab. The ISOBUS standard also comprises protocols for recording and storing data which offer opportunities for precision management of farm machinery and farm business costs – the next step for precision farming after crop management.

Chapter 10 of the ISO11783 standard identifies the “Task Controller and management information system data interchange” describing data exchange to and from sensors, the Task Controller, Virtual Terminal and Farm Management information Systems.

The scope of this chapter basically identifies two objectives:

- Transfer data to and from devices
- Management and transfer of data to and from Farm Management Information systems. (FMIS) or PC office packages.

Some additional components of an ISOBUS system other than a Virtual Terminal is a ‘Task Controller’ and also a ‘TECU’ (Tractor Electronic Control Unit). These items can work together to provide a valuable management tool. TECU’s can come in different varieties but the basic concept is that they provide an interface for the tractor control systems (such as engine, transmission, general tractor performance data) and share sensor information across the ISOBUS network.
The ‘Task Controller’ can then record this information as a task or job.
This highlights the need for following ISO standards when data logging as the machine will log raw sensor data such as fuel flow rate, mechanical wheel rotation, GPS distance and or radar distance. If this information is recorded in standard formats then any Farm Management system (Office PC package) can use the raw data to calculate meaningful parameters such as wheel slip.

Job information can consist of:
Tractors:

- Fuel Burn
- Wheel Slip
- Ground Speed
- Draft control
- Trans/Engine temperatures

Harvesting:

- Traditional yield & related data
- Ground speed
- Concave settings, combine setting
- Grain Loss
- Some harvesting information may just be a record of a mechanical setting as there may not always be a sensor to measure from.

Why is this additional recorded data important?

INTERPRETING YIELD MAPS

It has often been stated that a major difficulty in precision farming and the adoption of VRT is the difficulty in interpreting yield maps. Providing more history on a particular crop can certainly help
For instance:

Ground speed

Most thoughts of precision agriculture revolve around lateral precision attained from Steering systems, not must discussion revolves around ground speed precision.

- Could a map of ground speed when seeding overlayed over a yield map show a correlation between speed and seeder performance, to help explain an area of poor yield that was uncharacteristic and previously unexplained?
- Could a map of wheel slip during seeding or tillage operation highlight hard spots within management zones that may need further analysis?
- Are there optimum efficiencies to be gained in operating machines within certain parameters to balance work rates, fuel usage, crop production? Could you know what these operating parameters are unless you record and analyse the information?

ANALYSING MACHINE COSTS

Most Farming businesses can accurately allocate crop related costs (seed, fertiliser, spray) to paddocks or farm business units- what about machine costs?

- Could accurately allocating machine costs to marginal areas influence a decision as to the particular areas viability?
- Should accurately allocating a machines maintenance/operating costs to a given area be included in the enterprise profit/loss analysis?

BUSINESS EFFICIENCIES

Job recording can also provide precise labour analysis. Are all machine operators equal? Job recording can allocate machine performance data to operators- Analysis of machine performance data may highlight that three operators on the same machine doing the same operation may vary in performance. For example wheel slip: Two operators may average 5% wheel slip seeding whereas the third may average 15% wheel slip This would scenario would obviously represent an obvious setup/ operator training issue that needs addressing which wouldn't have been picked up if it wasn't for job recording from 'Task Controller'.

TRACEABILITY

Few people argue that traceability requirements are increasing and will continue to increase, representing a real cost to Farm Businesses. ISOBUS through Task Controller and data logging can help make these mundane tasks efficient by recording all job information from 'as applied' maps to the machine performance data all in the one spot, no need for putting memory cards separately into implement terminals for as applied maps and tractor terminals for machine data.

INVOICING

Many Farm business are turning towards contracting to supplement income and increase utilisation of expensive machinery investments. Any contracting job requires generating an invoice, which can be an arduous office task. Job Recording with an ISOBUS 'Task Controller' can efficiently and equally importantly accurately provide machine performance data required to invoice the job. For example, fuel burn from the Machine, a coverage map from an ISO Guidance system showing accurate area, as applied information from an ISO Implement such as sprayer, spreader.

IN SUMMARY

Task Controller and ISOBUS provide an easy way for machinery operators to record all relevant data required by Farm Businesses to improve efficiencies in their business. As Precision Farming is about finding efficiencies in inputs, the next step after crop inputs is to run precise farming operations right the way through from machinery operation, machinery maintenance, farm bookwork and labour inputs. As Data logging crop information such as yield maps is the tool for efficiency using VRT, Data logging machine performance is the tool for looking more efficiency in other areas of the farm business.

ISO11783 EXTRACT:

Part 10
Task Controller and management information system data interchange

Scope
This standard specifies a serial data network for control and communications on forestry or agricultural tractors, mounted, semi-mounted, towed or self propelled implements. Its purpose is to standardise the method and format of transfer of data between sensor, actuators, control elements, information storage and display units whether mounted or part of the tractor, or any implements. This particular standard, describes the Task Controller Applications Layer which defines the 1) requirements and services needed for communicating between the Task Controller and electronic control units. 2) The data format to communicate with the farm management computer, 3) the calculations required for control and 4) the message format sent to the ECU are defined in this document.

How Responsive is my Paddock?

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INTRODUCTION

One of the pervading questions challenging farmers when managing a paddock is; will this paddock respond to a favourable season and crop inputs? For example, a responsive paddock will produce higher yields in years of above average rainfall and poorer yields in seasons with below average rainfall. In a responsive paddock these yields would be similar to those predicted by a French-Shultz equation, where yield would increase in accordance with rainfall. In contrast, an unresponsive paddock might produce a low yield in a poor season and in an above average season produce only marginally more grain. This may be a result of an ameliorable constraint, such as a nutrient limitation or weed problem, or a more serious subsoil constraint that cannot be managed. Examples may include a strongly acid soil profile or shallow gravel close to the surface.

Unfortunately responsive and unresponsive patches are unlikely to be confined to paddock boundaries. In reality part of the paddock may be unresponsive and part may be responsive. In these situations farmers need to consider managing parts of their paddock differently, using modern precision agriculture technologies, such as yield maps and Landsat images that can be used to predict spatial variations in biomass. Traditional approaches to zone management in precision agriculture involve identifying and managing zones in a paddock that are consistently low, medium and high yielding. However, the challenge in dryland crop production is to manage inputs in a variable climate where the yield potential at a given location changes with respect to season.

We suggest the spatial variations in yield can be interpreted from a different perspective. These spatial variations imply some parts of the paddock respond favourably to the season (the above average zones) and some parts respond poorly (the below average zones). If the paddock is managed uniformly, and obvious agronomic issues, such as weeds and nutrition are already accounted for, then the spatial variations in yield give the grower an insight into how every location in the paddock responds to the season, or cropping environment.

One yield map on its own will provide growers with some insight into the spatial variation of yield, but historical studies have shown this variation may be unstable. It can fluctuate from one year to the next, causing confusion, particularly when one part of the paddock previously performed poorly, but yields well in the following year. This can occur when the seasonal distribution of rainfall is such that a subsoil constraint that limits yield, such as a shallow duplex soil that limits root growth, has no impact. Farmers may be interested in these unstable, but potentially productive components of the paddock and manage them differently from other low yielding zones in the paddock.

We therefore develop a simple method that can be applied to consecutive yield maps to determine whether a part of the paddock is responsive or unresponsive. We discuss different management options for various portions of the paddock, given the historical yield map data.

METHODS

Site description and history

Winter wheat, *Triticum aestivum* cv Calingiri was grown in 1999, 2001, 2003 and 2005 on a 190 ha paddock (116˚ 24' S and -29˚ 53' E), near Buntine in Western Australia. Lupins, *Lupinus angustifolius*, were sown in 2000. A volunteer pasture was brown manured in 2002 and canola, *Brassica napus*, was grown in 2004. Management and rainfall varied from one season to the next, but within a season, management, including the variety, time of sowing, time and amount of fertiliser and herbicide application were uniform (table 1). Soil types in the paddock ranged from a deep yellow sand, to a sandy loam and loamy clay.

Table 1. Season and management of the wheat crop in the study paddock

Year	Annual rain (mm)	May – October rain (mm)	Date of Sowing	Fertiliser N,P,K,S (kg/ha)	Seeding Rate (kg/ha)
1999	609	389	Not recorded	60,14,0,9	Not recorded
2001	283	201	19-May	65,18,0,12	90
2003	298	257	20-May	15,14,0,9	90
2005	298	245	18-May	48,12,12,5	80

Data processing

In every year, point data were logged and recorded using a commercial Case AFS yield monitor attached to a Case combine harvester. Data were post processed in ARC GIS 9.2. Data extremes (± 3 standard deviations from the mean) were removed. Yield data were interpolated onto a 25 m raster grid using global kriging to enable analyses to be carried out between years and minimise the influence of local outliers on the analysis.

Index development, yield threshold and zone creation

Three indices were calculated at every location in the paddock using four years of yield map data. These comprised the mean yield, the maximum yield and the difference between the mean and maximum yield.

We subdivide the paddock into 3 zones, poor yielding and unresponsive, acceptable yielding and unresponsive and acceptable yielding and responsive. Acceptable yield was defined by nominating a yield threshold, or yield where they are unsatisfied with the result. In this study we suggest a nominal yield of 1.6 t/ha, based on historical yield data from the paddock, but a farmer can nominate an appropriate value for their circumstances, eg a break even yield.

Poor yielding and unresponsive zones have a low mean yield and in four seasons of cropping failed to achieve the threshold yield (<1.6t/ha).
Acceptable but unresponsive zones produce, on average more than the threshold yield (>1.6 t/ha), but have a small difference between mean and maximum yield often less than 0.3 t/ha. These are consistent, economic, performing zones but unresponsive to season type.
Acceptable and responsive zones also have an acceptable mean yield, with a high difference, often approaching 1 t/ha, between the mean yield and maximum yield. In these zones, favourable seasons

often result in greatly enhanced yields. These zones are economic and, on occasion, highly productive. These zones are candidates for additional inputs in favourable seasons.

RESULTS

Whole paddock

Paddock mean wheat yields ranged from 1.89 ± 0.42 t/ha in 2003 to 2.56 ± 0.65 t/ha in 2001. 1999 was the most variable year, averaging 1.92 ± 0.73 t/ha. Wheat yield averaged 2.46 ± 0.44 t/ha in 2005. Yields from 2003 and 2005 were normally distributed, with low standard deviation. In contrast 2001 and 1999 were highly skewed, suggesting the different year 'types' generate different yield distributions (data not shown).

Spatial variation of yield

The first index, which captured the spatial variation of mean yield, ranged from 1.02 t/ha to 3.4 t/ha (Figure 1). There was a strong correlation between mean yield and maximum yield (r^2 = 0.79), but there were outliers, with many low yielding zones performing well in one of the four years. Therefore when conditions were favourable, many poor performing sites responded well. This is partially explained by the poor relationship between the difference of mean and maximum yield and mean yield (r^2 = 0.13).

The paddock was divided into the three zones, poor yielding and unresponsive, acceptable but unresponsive and acceptable and responsive. These occupied 14%, 32% and 53% of the paddock respectively. A map of the spatial variation of mean yield is presented in Figure 1. The difference between mean yield and maximum yield is presented in figure 2 and the location of the three zones is presented in Figure 3. It was noticeable that the highest yielding areas (Figure 1), weren't necessarily the most responsive (Fig.ure 3). In contrast some low yielding zones did respond and may justify higher levels of inputs in favourable seasons.

DISCUSSION

The three zones defined using the above approaches have several advantages over existing, statistically intensive approaches that farmers may have become familiar with. Firstly, the calculations can be performed easily using existing software, as complex pre-processing and data transformations are not required. These calculations could even be performed in Microsoft Excel. Thus, the biological meaning of the critical value, yield, is retained and the resultant maps can be viewed in terms of their productive capacity, rather than a transformed variable.

The difference between the mean value and the maximum value obtained at a location provide a grower with valuable information on the yield potential of the location in an ideal season. This approach treats every location as unique; the maximum yield achieved at one location might be achieved in a different season to a nearby location in the paddock. This problem has confounded the adoption of PA technologies, but we argue it does not matter what year a point in a paddock performs well, as long as it has the capacity to do so. Acceptable and responsive zones have, by definition, a large difference between mean and maximum yield and should be managed accordingly, particularly in favourable years.

The poor yielding and unresponsive zones, with a small difference between mean and maximum yield are candidates for alternative crops, revegetation or low inputs. Generally their yield can not be corrected through nutrition or weed management as they possess a yield limiting constraint that limits crop growth and yield in every season.

The outcome derived from the application of these indices is highly dependent on the threshold yield. The farmer must nominate this yield, based on their own understanding of the paddock and the yields they are satisfied with. Higher thresholds will increase the area of marginal yield and the amount of paddock classified as poor yielding and unresponsive, while lowering it will reduce the area in this zone.

Once the farmer is happy these zones mean something to them from a management perspective, variable management strategies may be employed on each of the three zones.

CONCLUSION

We have developed an index that enables farmers to zone paddocks based on the paddocks ability to respond to favourable conditions. These zones must be created with the farmer's involvement where the farmer nominates a threshold yield based on their knowledge of the paddock.

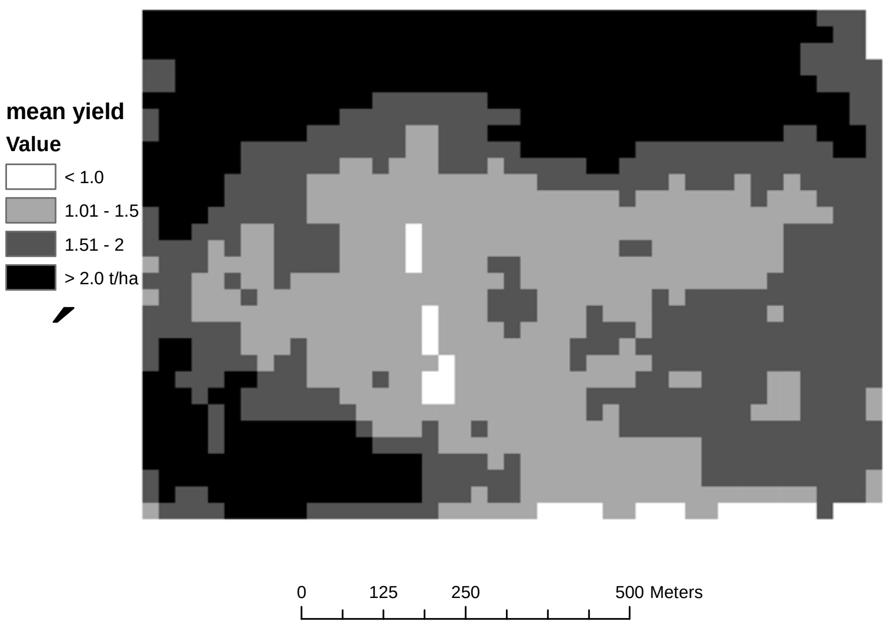

Figure 1. Mean wheat yield derived from 4 crops sown in 1999, 2001, 2003 and 2005.

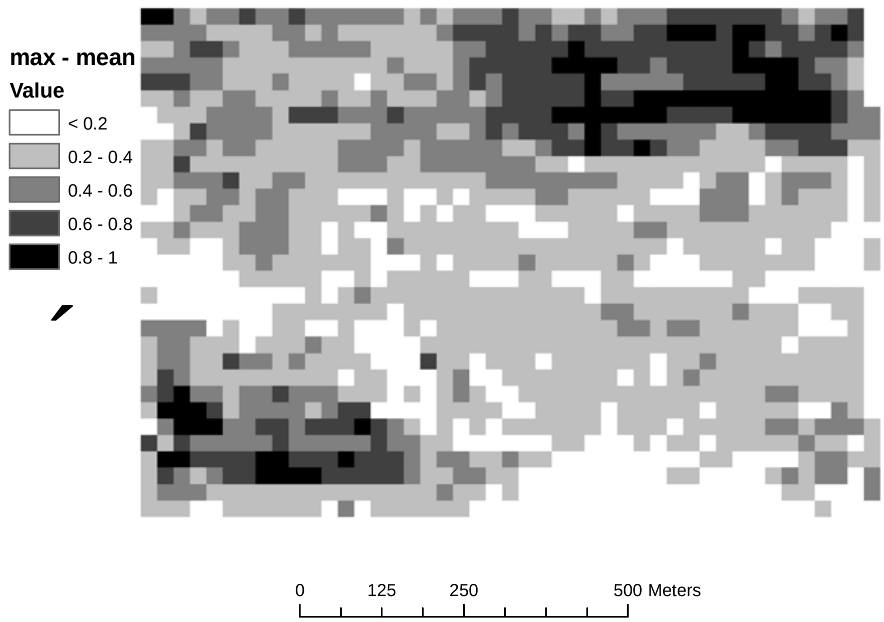

Figure 2. The difference between mean and maximum wheat yield, derived from 4 crops sown in 1999, 2001, 2003 and 2005.

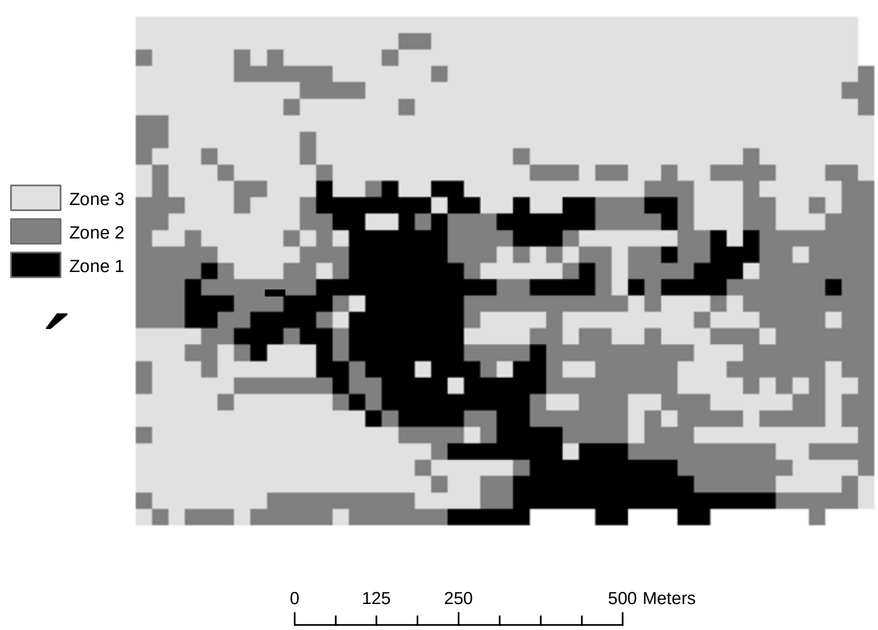

Figure 3. Three management zones, derived from 4 years of data. Zone 3 produces acceptable yields and is responsive to favourable seasons; Zone 2 produces acceptable yields but is unresponsive to favourable seasons, Zone 1 produces poor yields and is unresponsive to favourable seasons.

Yield Maps - More than just Pretty Pictures? Does Soil Depth Explain Spatial Variability of Yield on a Central Queensland Black Vertisol?

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ABSTRACT

Yield mapping is increasingly being adopted by central Queensland grain growers to measure the extent and magnitude of spatial yield variability within paddocks, based on the premise that *"you can't manage it, if you don't measure it"*. Often growers do not get past the initial recording process, as identifying the cause of yield variability can be time consuming and complicated. This paper presents the results of a study that investigated the impact of soil depth on the spatial variability of yield, measured with a yield monitor for a summer sorghum crop planted in December 2005. Prior to this study, soil depth and the corresponding plant available water capacity (PAWC) were anecdotally considered the leading cause of yield variability on an Open Downs soil (black vertisol) in central Queensland. Results showed the variability of crop yield was not correlated with soil depth. Importantly, identifying other parameters that may have impacted on yield variability was difficult, as these were measured at a much broader scale, which complicated analysis. From a research and adoption perspective this has important implications. If yield mapping is to be adopted and utilised effectively, tools and techniques that improve the identification of yield variability drivers are necessary. It is likely that this will require an increase in the spatial sampling of parameters, which is simple and cost effective.

Key Words: Farming systems, yield mapping, Open Downs soil, precision agriculture.

INTRODUCTION

Yield mapping is an excellent tool to assist with identifying and quantifying variability within a paddock. However, to measure the spatial extent and magnitude of yield variability is only the first step; what is more difficult is to identify the underlying causes of this variability and then develop and implement management options that maximise profitability and sustainability. In central Queensland, the adoption of yield mapping technology and the consequent implementation of alternate management options in dryland agriculture has been very low. Anecdotally, one of the foremost reasons given by growers for this low uptake is that many feel little can be done practically to manage the variability occurring within their paddocks.

One of the major land systems used for cropping in central Queensland is the Oxford land system. This system predominantly consists of basaltic clay soils. One of the soil types located within this system is as an Open Downs soil (black vertisol). A feature of this soil is the highly variable soil depth and the consequent variable PAWC. Webb & Dowling (1990) found that the position on the slope had the biggest influence on soil depth, with areas in the upper and mid-slope generally being shallower (<0.9m) than areas in the mid-lower and foot slopes. Their work also indicated that although position on the slope was influential, it was by no means an accurate predictor of effective soil depth as both shallow and deep soils had occurred at all areas within the landscape. From a farming systems perspective, variable soil depth could be driver for yield variability; however, within central Queensland few intensive sampling surveys have been undertaken to assess soil depth variability in a precision agriculture context.

In a dryland production system, especially in the northern grain belt, crop production relies heavily on stored soil moisture; hence PAWC is an important driver of production and is inextricably linked with the depth of the soil. For the Open Downs soil, a commonly held view within the central Queensland farming community was that although yield wasn't being measured spatially, anecdotal observations by growers assumed that poor performing areas in a paddock in most years was due predominantly to soil depth. Exactly how growers knew the soil was shallow and what growers define as shallow is in itself an interesting research question. Furthermore, it was believed soil depth changed so much and so randomly that very little could be done practically, unless the paddock performance was extremely poor, in which case the most appropriate land use may be to convert the whole paddock back to pasture.

This paper investigates in field variability of soil depth and assesses whether there was a relationship between soil depth and yield (as measured by a yield monitor) and whether soil depth was the leading cause of yield variability within the study area for the season.

MATERIALS AND METHODS

An on-farm trial was undertaken 40km north of Emerald in central Queensland at the property Moonggoo (S23.15763^0, E148.05545^0). The data presented is from yield mapping in 2006.

The trial area was a 77 hectare paddock with the soil being a self mulching black vertisol (Isbell, 1996). This soil is known locally as an Open Downs soil, with some typical properties shown in Table 1.

Table 1. Typical soil properties for the trial area (after Irvine 1998).

Parameter	**Surface**	**Subsurface**
pH	8.0	8.4
Exchangeable Na (%)	0.6	1.7
Electrical conductivity (mS/cm)	0.06	0.1
Clay content (%)	67	74

The PAWC (15cm intervals) for the trial site for 0-90cm soil depth are given in table 2. This data was derived using the "trickle irrigation" method (Dalgliesh and Foale. 1998).

Table 2. PAWC for the trial area (Buck and Grundy, 2004, P. 101)

Depth (cm)	**PAWC (mm)**	**PAWC Cumulative (mm)**
0-15	31.1	31.1
15-30	30.2	61.3
30-45	30.2	91.5
45-60	26.9	118.4
60-75	27.5	145.9
75-90	25.5	171.4
Total 0-90	**171.4**	

A 1m single skip sorghum crop was planted on 30/12/05 using a zero till, opportunity cropping farming system. It was double cropped following a wheat crop that was harvested 84 days prior on 7/10/2005. Grain yield, grain protein, plant available water (PAW) and soil N levels at planting and harvest were measured; and in-crop rain was recorded.

Prior to harvest 21/04/06, grain yield and moisture monitors onboard the harvester were calibrated. Following harvest, yield data was edited with the removal from the harvest log of yield points within 10m of the centre of contour banks, 27m from paddock edges and erroneous yield points lower than 750kg/ha and greater than 4500kg/ha. The yield data was then processed using ArcView GIS software. After an initial assessment, areas of greatest yield variability (both high and low yields) on the yield map were identified to be sampled for soil depth. On 17/01/07, 141 soil cores were taken throughout the paddock, with each site spatially referenced with a handheld GPS device (+/-5m accuracy). Soil depth was recorded for each core at the depth of intersection with the underlying parent material (basalt). Soil depth data was then mapped using ArcView to assess how much of the yield variability occurring within the trial area was explained by the relationship between yield and soil depth.

To assess the relationship between yield and soil depth two spatial scales were examined, using 4.5m and 27m radii around each soil core location. Yield points from the yield log occurring within these radii were averaged and plotted against the associated soil depth for that point. The 27m radius was chosen to assess whether there were broad trends associated with soil depth that were at a scale at which some form of management decision or strategy could be implemented. The 4.5m radius was used to investigate if a direct relationship between the soil depth sample point and the recorded yield could be identified at a micro scale.

Finally, the decision support tool *HOWOFTEN* was used to characterise the rainfall experienced during the fallow and in-crop for the study area from a historical perspective. The rainfall records used for the simulation were from the Capella Post Office, which is located 10km north of the trial area and has rainfall records going back to 1890.

RESULTS AND DISCUSSION

Edited yields from the harvest log clearly demonstrate that yield was highly variable across the study area. The average yield was 2.72t/ha, however, the yield ranged greatly from 750kg/ha up to 4313kg/ha, with the most frequently recorded yield (4209 log readings) ranging from 2750-3000kg/ha (Figure 1).

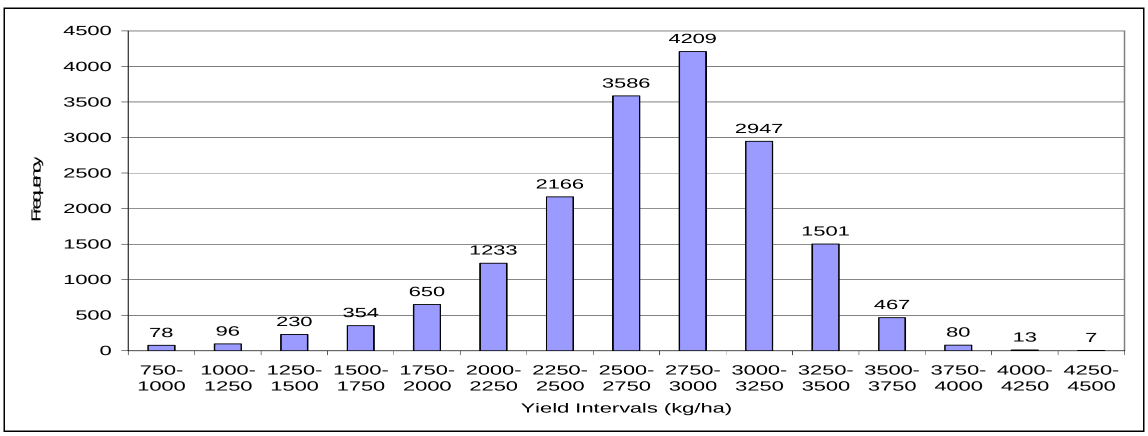

Figure1. Yield variability across the study area.

Soil depth and (it is speculated) the subsequent PAWC across the study area was highly variable as soil depth ranged from less than 45cm to over 150cm (Figure 2). The most frequently measured soil depth interval was 75-90cm (35 cores), which represents 24.8% of the sampled cores. From Table 2, the PAWC to a depth of 45cm equals 91.5mm, whilst to 90cm the PAWC equals 171.4mm, thus demonstrating that soil depth has the potential to be a cause of yield variability in this paddock and more broadly on Open Downs soils across central Queensland.

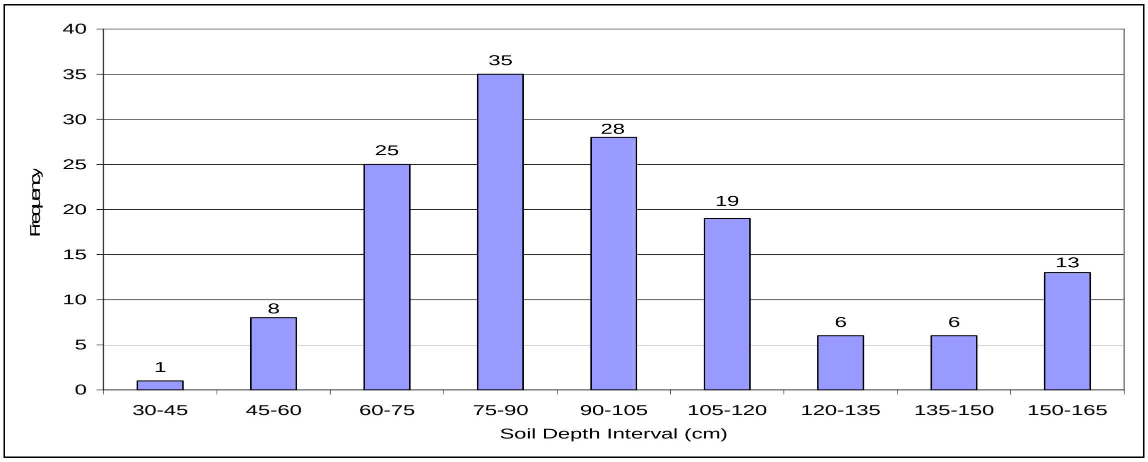

Figure 2: Soil Depth versus Soil Core Frequency per Interval Range

Figures 1 and 2 above clearly demonstrate that there is large yield and soil depth variability across the study area. However there was no significant relationship found between yield and soil depth in the study area for this season that could explain the measured yield variability (see figures 3 and 4). Neither the macro (27m radius) nor the micro (4.5m radius) spatial scale showed a strong relationship between soil depth and yield. It should be noted that yield data does have significant limitations when it comes to micro scale paddock assessment of variability, as the spatial scale of yield data is very course and thus has the potential to mask variability at a fine spatial scale.

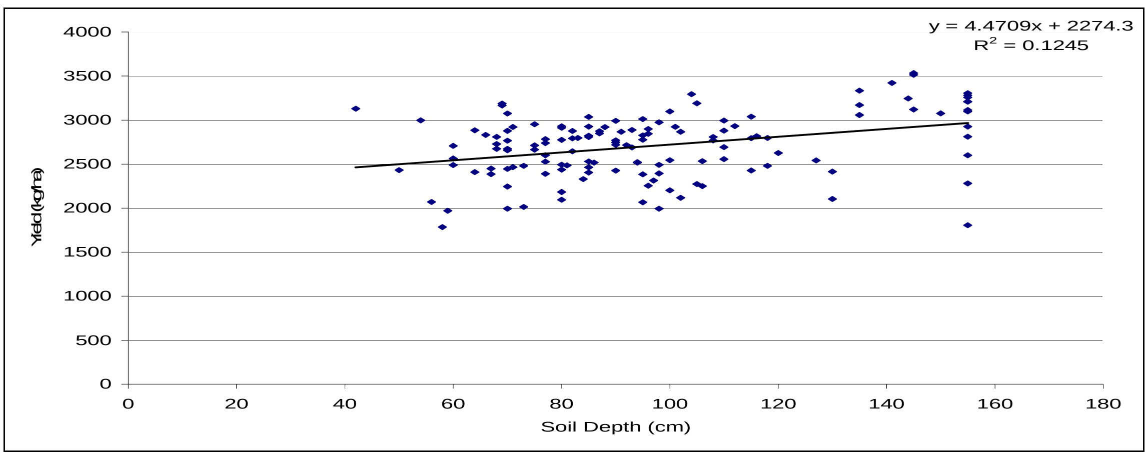

Figure 3: Average yield of yield points within a 27m radius of soil sampling points versus soil depth.

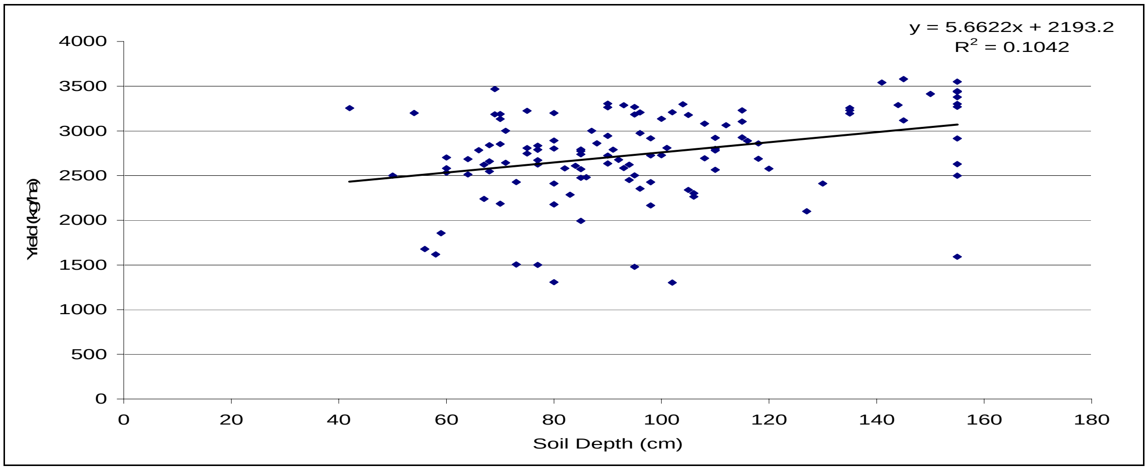

Figure 4: Average yield of yield points within a 4.5m radius of soil sampling points versus soil depth.

If soil depth is believed to be one of the biggest drivers of spatial yield variability on an Open Downs soil, why hasn't it occurred in this study? In what situations is soil depth likely to be a driver of yield variability across a paddock? The primary situation would be for example if a paddock of the same soil type had an area with 45cm soil depth and a PAWC of 91.5mm and another area with 75cm soil depth and a PAWC of 145.9mm. If fallow rainfall was sufficient to fill the soil profile to 75cm, then at planting the 75cm soil would have 54.4mm more plant available water then the 45cm area. Potentially this moisture limitation can be made up with in-crop rainfall if the season permits. Hence soil depth will most likely have the greatest impact as a driver of yield variability across a paddock when there are significant differences in soil water at planting, during seasons with low levels of in-crop rain.

The above pre-conditions for soil depth to be a driver of yield variability also need to be put in a management context. Under an opportunity cropping farming system (as practiced in the study area) cropping intensity is usually higher, planting decisions are frequently made with lower starting soil water levels and there is a greater reliance on in-crop rainfall to produce yield. Hence given the opportunity cropping management practice, the variable soil depth and corresponding PAWC of the study area are less likely to be a cause of yield variability.

So why wasn't soil depth a driver of yield variability in this case study? Rainfall during the fallow and in-crop for the study area are displayed in figure 5. Fallow rainfall equalled 359.5mm (figure includes 29.5mm of rainfall that occurred post-planting, but prior to soil sampling). A *HOWOFTEN* simulation of the fallow indicated that the amount of rainfall during the fallow ranked it in the top 14% of years. In-crop rainfall equalled 126mm. A *HOWOFTEN* simulation of in-crop rainfall indicated that the season studied ranked it in the bottom 25% of years. From this scenario it would appear that the season experienced had the potential to have yield variation as a result of soil depth.

Fallow efficiencies in central Queensland typically range between 15-20%, although they can vary greatly depending on the conditions and length of the fallow, with values being greater than 30% in some instances (Agnew and Huf, 1994). Given the previous crop was a wheat crop (harvested 84 days prior to planting) and the paddock was managed using zero till; cover levels would typically be expected to exceed 50%, which would assist with maximising infiltration in the fallow. With these pre-conditions plus the fact that the fallow ranked in the top 14% of years it was speculated that the fallow efficiency would be high, which would maximise the potential for differences in starting soil moisture due to soil depth. Soil water at planting was measured at 91mm, which was less than expected and resulted in a fallow efficiency of 15.5% (soil water at the start of the fallow was 49.3mm). This suggests that a large amount of rainfall was lost via runoff during intense rainfall events. From the PAWC values in Table 2, 91mm of stored soil water for this soil is equivalent to a fully wet profile to 45cm. As displayed in Figure 2, all but 1 of the 141 soil cores was greater than 45cm in depth suggesting that soil depth would not be a major driver of yield variability for this crop.

Another consideration is the water requirement of a sorghum crop. Based on our sampling of starting soil water, the average WUE of the sorghum crop was 12.5kg/ha/mm, which is within the range outlined by Dalgliesh and Foale (1998) for a *good* sorghum crop of 12-15kg/ha/mm (WUE = crop yield kg/ha/(in-crop rainfall + planting soil water). However in actual fact water-use efficiency varied across the study area, for example an area that yielded 1000kg/ha had a WUE of 4.6kg/ha/mm whilst an area which yielded 4000kg/ha had a WUE of 18.4kg/ha. This suggests that a factor other than soil water was driving yield variability across the study area.

If soil water was not a driver for yield variability for this crop, then what was causing the yield variability? The next logical driver is soil nutrition and in particular soil nitrogen. However measured starting soil nitrogen levels (109.7kg/ha) and sorghum grain protein levels (average 11.6%) indicate that nitrogen levels were not limiting crop production. Admittedly, soil nitrogen and grain protein levels were not captured spatially across the paddock and this highlights the fact that although yield is being intensively sampled spatially, other parameters which impact on yield like starting soil water and nitrogen levels are not. This makes identifying the causes of variability and developing and implementing appropriate management strategies inherently complex.

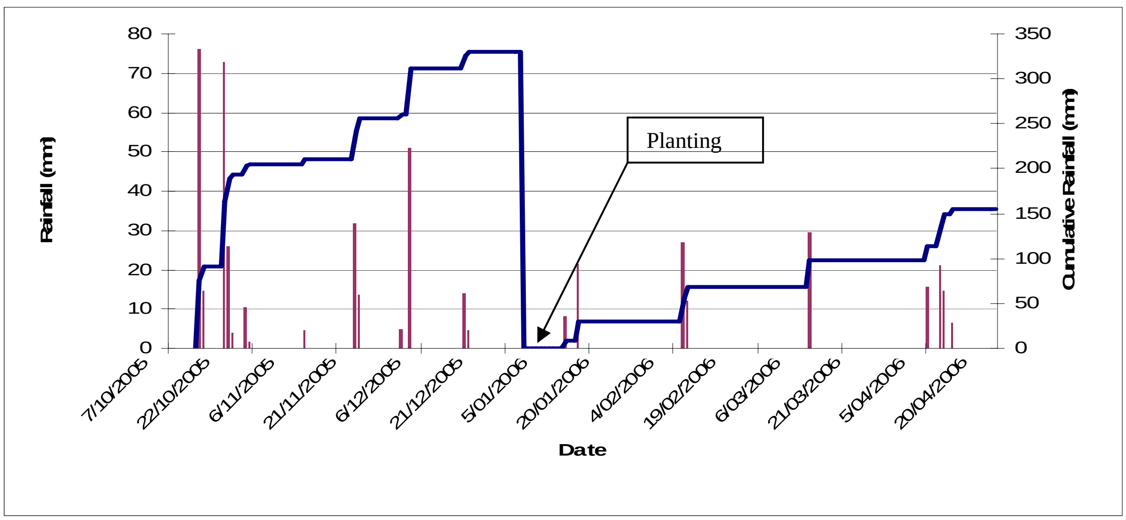

Figure 5: Cumulative and event rainfall during both the fallow and in-crop

From this study extensive yield and soil depth variability was found, however the cause of the spatial yield variability for this sorghum crop could not be identified. Although this research has not identified the cause of yield variability in this instance, it has questioned the previous assumption that soil depth and corresponding PAWC was the greatest driver of yield variability on an Open Downs soil in central Queensland. Furthermore, other parameters that may have impacted on yield variability like, starting soil water and soil nitrogen, were measured at a much broader scale than yield data, which complicated analysis and made identifying drivers of yield variability difficult. From a research and adoption perspective this has important implications. If yield mapping is to be adopted and utilised effectively, tools and techniques that improve the identification of yield variability drivers are necessary. It is likely that this will require an increase in the spatial sampling of parameters, which is simple and cost effective.

ACKNOWLEDGMENTS

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Farmer Trials and Experience Prove the Adoption of Precision Agriculture Technologies is Profitable in Western Australia (WA)

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ABSTRACT

The marked increase during the last two years, in costs of fuel (30%) and fertiliser (18%) has contributed to increasing uptake of precision agriculture (PA) technologies in Western Australia. The on-farm trials and farmer observations reported in this paper indicate, in most cases, that the contributing farmers are obtaining a return on investment in the order of 300% over three years. Payback generally occurs within the first year, except at the upper end of investment (A$120,000). Their results are supported by economic modelling. For those farmers yet to take up this technology, cost, lack of compatibility of equipment, data collation and analysis are still perceived as barriers to adoption.

Keywords: profitability, adoption, Western Australia, farm results

INTRODUCTION

The South-West of Western Australia has a total agricultural area of 16 million hectares, of which 6.7million hectares is cropped in any year. The landscape is ancient, hundreds of millions of years old, highly weathered, leached and in its natural state, very infertile. The soils are predominantly acidic sands and sandy loams of granitic origin, (many of our pasture species have been selected from the acid soils of the Greek islands). The climate encountered by the contributing farmers is Mediterranean with between 200mm – 400mm of average annual growing season rainfall, falling between April and October each year (i.e. during winter).

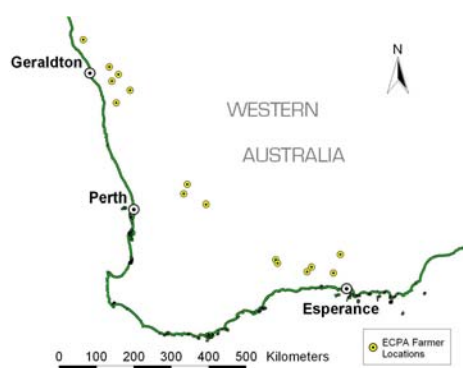

Figure 1. Location of contributing farming families in Western Australia

The 14 farming families contributing data to the paper, located as in Figure 1, farm a total of 70,700 hectares (174,500 acres) or about 1% of the cropping area in South-West of WA. The working unit is often a father and son with one or two staff, working an average farm size of 5,000 ha with about 4,000 ha in crop. Field sizes are typically 100 ha. Tractors are commonly 450 hp with triple wheel 4wd or track systems. Boom widths are approximately 45 m. Seeders are approximately 15m wide, and are generally attached to 3 bins or 2 bins plus a liquid cart. The principal crops they grow are wheat, barley, oats, lupins, canola and peas. Typically they use a minimal tillage or a one pass approach to sowing, with a resulting increase in reliance on chemicals for weed control and an increase in herbicide resistance. The marked increase in costs in the last two years of fuel (30%) and fertiliser (18%) has contributed to the increasing uptake of precision agriculture (PA) technologies. Urea prices for 2007 have risen from A$450/t I 2006 to A$550/t.

Investment in PA equipment by the growers ranges from A$15,000 to A$120,000 (approximately €9,000-72,000) with accuracy in the GPS signal being the main contributor to increased cost (typically 2-10 cm precision at the top end). Returns to PA investment come from two main areas. Firstly, the reduction in underlap and overlap in application of insecticides/herbicides and fertiliser, enabled by GPS auto steer and auto boom and secondly, from the redistribution of fertiliser based on zones of crop performance (variable rate fertiliser application). Variable rate controllers used by this group of farmers include the Western Australian manufactured range of Farmscan (http://www.farmscan.net) products (6 farmers), the KEE/Zynx (http://www.kee.com.au) products (6 farmers) manufactured in South Australia and one John Deere (http://www.deere.com) and one Flexicoil controller (http://www.flexicoil.com).

This paper will present practical farming examples of the application of PA and its benefits, supported by on farm research results where available and highlight some survey results on factors still limiting adoption of the technology.

INCREASES IN MACHINERY EFFICIENCY AND OTHER BENEFITS AND OPPORTUNITIES FROM USING GPS

The farmers represented in this paper typically reported efficiency gains of 8-10% in chemical usage through the adoption of auto steer and the associated auto boom technology (solenoids on each jet or a segment of the boom can be switched off when the controller senses that the segment of the boom is passing over a previously sprayed area). This equates to a saving of at least A$8/ha or A$32,000/annum for the average sized cropped area noted above. Further fuel efficiencies of about 20% (A$3.60/ha) can be made if they are using a tramline system (all vehicles with the same wheel spacing, generally 3 m) which confines compaction to dedicated wheel tracks that become firm over time requiring less traction and reducing fuel use. Further benefits of 3-15% come from reduced compaction and crop damage on the rest of the paddock (Webb et al. 2004). The efficiency benefits from using GPS technology of varying accuracy, including auto steer/auto boom technology, are widely accepted in WA (There are about 2000 farmers with the property size that warrants this technology at present in WA. The sales manager for Farmscan estimates 400 hydraulic steerage units have been sold in WA and a further 200 visual steerage units in the last three years).

Our reduced tillage systems have lead to an increased use of selective herbicides for weed control and a resulting increase in the herbicide resistance of weeds. Options for controlling multiple herbicide resistant ryegrass are limited and expensive. They include switching to more expensive herbicides, catching the residue coming out of the back of the harvester and dumping it in piles to be burnt, cutting a crop for hay, returning to pasture and grazing and using spray topping to control the grass in the pasture phase. This latter option results in a net loss of A$8-42/ha/annum (Monjardino et al, 2004). On David Fulwood's farm, a 2 cm GPS is used so that he can inter-row spray lupins using a shielded boom with a non selective herbicide (Figure 2). Lupin row spacing is taken out to 75 cm with no yield penalty to the crop. This gives him another tool to fight against ryegrass herbicide resistance whilst maintaining fields in crop. The net result is about A$15/ha more return than the standard management strategy of using more costly selective herbicides. However, it is slow work with the sprayer only moving at between 9-13 km/h compared to 25-35 km/h for traditional broad acre spraying, depending on the water rate required and the terrain.

Figure 2. Wide spaced lupins at 75 cm centres, and shielded boom spraying the crop, 2 cm accuracy guidance (David and Malcolm Fulwood).

VARIABLE FERTILISER RATES

Slow adoption

Variable rate technology (VRT) has been slower in adoption than the auto steer and auto boom. VRT is not purely mechanical in its nature as are auto boom and auto steer. Once management of performance zones are determined and the rates set, then the programming and application are mechanical. However the precursor to the rate map involves understanding the agronomics of a crop and its interaction with its environment over time. Farmers understand how variable seasonal/agronomy interactions can be and the resulting risks they face. Variable rate includes these seasonal and other agronomic risks. Additional reasons for the slower adoption of VRT will be reported in the outcome of two surveys later in this paper.

Forming a performance zone

The approach to performance zoning uses a statistical analysis to reduce the inherent agronomic risk of defining a performance zone (Adams and Maling 2004). Although this analysis can use yield monitor data, NDVI derived from Landsat data has been used by my clients. The NDVI from different seasons is analysed temporally as described in Adams and Maling 2004). A performance zone map is generated which defines three zones: above average, average, and below average with 60% of the area occupying the average zone. Further, each pixel is identified as being consistently high or consistently low performing through time based on a threshold value on the standard deviation of a normalized pixel through time. If a pixel has been highly consistent through time, it is very likely that the pixel will behave the same way next year. Therefore the risk in defining a zone in a field as good, or poor performing is markedly reduced. In practice we have found that if over 60% of a field has performed in a consistent manner through time (either high or low) we can effectively identify the zones; that is, if we classify a zone as high performing, the yield in this zone is nearly always higher than other parts of the same field.

These zones have been verified as accurate in the following season's yield and trial data. Table 1 shows typical results of that approach with the historical mid season NDVI derived zones effectively picking the yield zones. Field characterisations of soils in different performance zones and modelling point to plant available water as the main factor affecting the crop performance between zones in our rain limited environment (Oliver *et al.*, 2006).

Table 1. Yield monitor yields (2005) for barley (fields) and wheat (fields) obtained from zones derived from a historical analysis of NDVI at David Fulwood's farm. The percentage of the field performing consistently (C) i.e a pixel falls within the same performance zone for all the years analysed.

Zone	Field 4, C=75% Yield t/ha	Field 5, C=79% Yield t/ha	Field 10, C=80% Yield t/ha
Good	3.25	2.60	3.13
Average	2.91	2.10	2.78
Poor	2.11	1.95	2.07
	Field 11, C=74% Yield t/ha	Field 18, C=69% Yield t/ha	Field 23, C=83% Yield t/ha
Good	3.27	2.87	3.03
Average	2.90	2.48	2.70
Poor	2.37	1.71	1.77

Turning a performance zone into a fertiliser rate

Forecasting the performance of a zone defines the crop demand for nutrients which must be matched with what the soil and fertiliser can supply. Underestimate the nutrient requirement and the crop performance will be limited. Overestimate nutrient requirement and an excessive amount of fertiliser will be applied. In the Western Australian environment the Department of Agriculture has developed sound relationships between soil tests for N, P and K and the fertiliser needed to meet a target yield (Adams *et al* 2000, Bowden and Bennett 1974, Bowden and Diggle 1996, Bowden and Scanlan 2006).

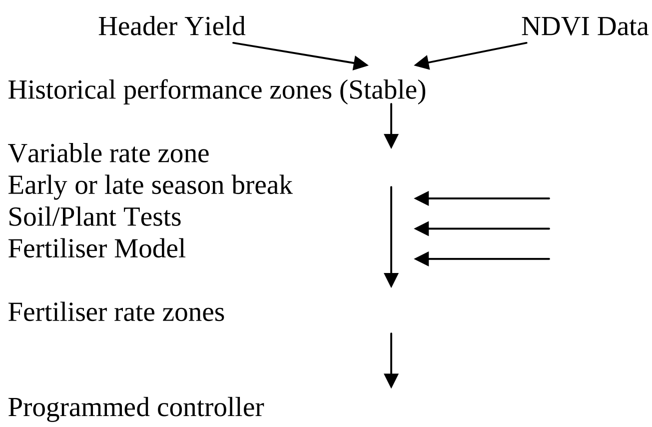

Figure 3. Diagram of the process of taking historical header yield or NDVI data to variable fertiliser rates in Western Australia

Therefore, by estimating the anticipated yield from the performance zones and linking it with a soil test, we can derive the fertiliser rate for that zone. A simplified flow diagram of the process is presented in Figure 3.

In practice, the potential yield zones are further modified up or down based on the timing of the seasonal break (the first large falls of rain in autumn after the hot, dry summer) which in turn provides an indication of likely growing season rainfall. In the wheat belt area we are representing the average break is considered to occur on or about the 15th of May. In an early seasonal break, e.g. about three weeks earlier than average, the productive potential of all zones is raised and the nutrient demand increased. In a late seasonal break, e.g. three weeks later than normal, the productive potential of all zones is depressed and hence, nutrient demand is less than normal. In extreme cases farmers don't sow. Equally, if the season starts average, but performs well early, nitrogen top up fertiliser is applied because of an increased potential for each zone.

Does variable rate fertiliser pay?

David Forrester, who farms in the Geraldton area of WA, has been using zones to apply his variable rates of fertiliser for the last 8 years. He tests the efficacy of his rates and zones by applying low, average and high fertiliser rates in strips across all zones. The Department of Agriculture and Food Western Australia (DAFWA) became involved in 2002 in formalising this process and analysing the data. In 2002 the high rate of fertiliser for "Dam" field was 145 kg/ha of DAPSZC (DAPSZC is the trade name of a compound fertiliser sold in WA containing 16.9% N, 18.2% P, 0.15% Zn and 0.05% Cu based on DAP – diammonium phosphate) plus 220 kg/ha of urea. The average rate was 80 kg DAPSZC with 120kg/ha urea, and the low rate was 20 kg DAPSZC with 0 kg/ha urea. David's target grain quality measures were a grain protein of at least 10.5% and screenings of less than 5%. Tables 2a and 2b show that in 2002 the low fertiliser input gave the best return on the poor performing zone, the average rate the best return on the medium performance zone, and the high rate the best return and grain quality on the good performance zone.

Table 2a. Yield t/ha and A$ Gross Margin/ha by zone and fertiliser input for David Forrester's 'Dam' field in 2002. Same letter following yield indicates no significant difference.
Analysis by DAFWA and adapted from Blake et al. (2003).

Crop Potential/Zone	Poor		Medium		Good	
	t/ha	$GM/ha	t/ha	$GM/ha	t/ha	$GM/ha
Low Fertiliser	1.54 a	105	2.10 b	248	2.45 b	254
Average Fertiliser	1.68 a	38	3.56 c	303	3.62 c	320
High Fertiliser	1.67 a	-26	3.69 c	238	4.26 d	398

Table 2b. Protein % and screenings% by zone and fertiliser input for David Forrester's 'Dam' field in 2002. Adapted from Blake et al. (2003).

Crop Potential/Zone	Poor		Medium		Good	
	Prot %	Scree %	Prot %	Scree %	Prot %	Scree %
Low Fertiliser	9.3	2.3	8.3	1.9	9.2	1.6
Average Fertiliser	9.6	6.1	11.1	3.1	9.8	2.5
High Fertiliser	12.7	9.0	11.3	5.7	12.3	3.4

In 2004 David applied a high rate of fertiliser 145 kg of DAPSZC with 180 kg/ha of urea, an average rate of 80 kg DAPSZC with 120 kg/ha urea, and a low rate of 20 kg DAPSZC with 60 kg/ha urea. The areas associated with each zone in 2004 were 21% poor, 28% medium and 51% good. The results in 2004 showed an average $63/ha benefit by using zoned rates rather than an average rate across the field.

Table 3a. Yield t/ha and $GM/ha by zone and fertiliser input for David Forrester's 'Dam' field in 2004. Same letter following yield indicates no significant difference.

Crop Potential/Zone	Poor		Medium		Good	
	t/ha	$GM/ha	t/ha	$GM/ha	t/ha	$GM/ha
Low Fertiliser	2.20 a	188	2.30 a	209	2.45 b	242
Average Fertiliser	1.95 a	88	2.70 b	223	3.00 c	275
High Fertiliser	2.15 a	60	3.35 c	285	3.80 d	357

Table 3b. Protein % and screenings% by zone and fertiliser input for David Forrester's 'Dam' field in 2004.

Crop Potential/Zone	Poor		Medium		Good	
	Prot %	Scree %	Prot %	Scree %	Prot %	Scree %
Low Fertiliser	10.6	1.3	11.4	1.2	12.3	1.3
Average Fertiliser	11.8	1.5	12.7	1.1	12.9	1.5
High Fertiliser	12.9	1.1	13.5	0.8	13.5	1.5

Given the similarity in outcomes between 2002 and 2004 matching fertiliser rate to productive potential should hold across seasons and this conclusion supports David's experience on farm, however the years had similar growing season rainfall at 328 mm in 2002 and 308 mm in 2004. Unanalysed data from the 2006 drought year indicate a 300 kg/ha response to the higher fertiliser rate on the "good" performing areas of the paddock and a depression in yield on the "poor" areas of 140 and 290 kg for the average and high rates respectively. Average yield on the paddock for 2006 was in general 1 t/ha less than the reported yields in the above table from 160 mm growing season rain. David believes he is getting a $30-$60/ha benefit to the zoned application of fertiliser across the farm which agrees with the measured and analysed results by DAFWA on his 'Dam' field and modelled estimates from nutrient response curves. Farmer observations, field trial results, and economic modelling are in general agreement; variable rate applied over stable performance zones, using fundamental agronomic understanding *is* profitable. This approach is also clearly more environmentally responsible with fertiliser being placed where it is needed and not where it is superfluous.

There is always an exception

The following results (Table 4.) come from typical non replicated farmer trial strips, placed across performance zones which were derived by Silverfox Solutions. The rates were applied by Murray Carson, the owner, using commercial equipment on a farm located approximately 60kms north of Geraldton near Ajana. The rates were recommended by Shane Turner, Summit Fertiliser's local area manager. The yields were measured from a John Deere harvester equipped with a John Deere yield monitor.

The results indicate clearly the interaction that can occur between zone and soil test. In this case there is still a response to the high fertiliser rate above the average trial rate in the poor performing zone due to the soil's inability to match the plant's nutrient demand, even at the lower yield level. The result emphasises the importance of the soil test and modelling input steps indicated in figure 2. The units/ha of N, P, and K applied were 24, 7 ,10 (low); 48, 14, 21 (average); 71, 21, 32 (high) kg/ha fertiliser rates, respectively.

Table 4. Yield (t/ha) and soil test data by zone and fertiliser input for Murray Carson's field number 26 in 2005.

Crop Zone	Poor	Medium	Good
	t/ha wheat	t/ha wheat	t/ha wheat
Low Fertiliser	1.29	1.50	2.21
Average Fertiliser	1.67	2.19	2.71
High Fertiliser	2.10	2.21	3.00
Soil P (ideal 20 ppm +)	10 ppm	16 ppm	15 ppm
Soil K (ideal 60 ppm +)	15 ppm	24 ppm	48 ppm
Organic C	0.45 %	0.82 %	0.93 %

Survey results show perceived impediments to Precision Agriculture adoption

Surveys carried out by the WA Department of Agriculture and Food (DAFWA) (Webb,xxx) and the Grains Research and Development Corporation (GRDC) (Price, 2004) have identified a number of factors that remain as hindrances to widespread adoption of PA by Australian grain growers. The nationwide GRDC survey (n=145) indicated key factors such as lack of confidence about cost, cost/benefit, setting up equipment, matching and understanding data sets and collecting and collating required data. The DAFWA survey of three grower groups (n=45) indicated cost of equipment as the biggest barrier to adoption. Other barriers included the knowledge and skills required in collecting and collating data, poor compatibility of equipment, and time taken to set up equipment to make it fully operational. Cost of the equipment is reducing as the scale of adoption increases. The on farm research contributing to the results noted above is addressing the cost/benefit issue. Setting up equipment remains a problem as a number of the contributing farmers would attest to (even within one make/brand). Private consultants specialising in PA are moving into the area as the volume of farmer's participating in PA provides sufficient income for them to assist in data manipulation and interpretation.

CONCLUSION

Precision Agriculture as practised by the 14 farmers contributing to this paper is profitable and in some cases highly profitable. Returns per hectare range from A$11.60/ha for those using purely mechanical efficiencies to obtain a benefit to over A$60/ha for those using variable rate technologies. Less tangible benefits are obtained from reduced stress and increased working life of some family members. However for those still to take up this technology, cost, lack of compatibility of equipment, and the complexities of data collation and analysis, are still perceived as barriers to widespread adoption of PA.

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Multiple Benefits from Inter-row Sowing with 2cm RTK GPS

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INTRODUCTION

The advent of affordable 2cm autosteer for broadacre farmers is an exciting development in Australian agriculture. It allows farmers to sow crops with a high level of precision never thought possible before GPS. Inter row sowing is rapidly being adopted by no till farmers across Australia. Inter row sowing refers to the sowing of crops precisely (-/+2cm) between the previous years crop rows. Over the last 4 years a number of research trials and farmers have discovered a number of agronomic benefits associated with inter row sowing. This paper highlights these benefits.

METHODS

Replicated experiments were established in wheat stubble that ranged in biomass from 2 to 6 t/ha. The wheat-on-wheat data presented in this paper refers to inter row and in row sowing of crops into standing stubble from the previous year. The lentil, herbicide efficacy and canola trial data also included a slashed stubble treatment. Most of the data is from trials in SA, with one trial included from NSW (DPI project). Row spacings ranged from 225 to 300 mm.

RESULTS AND DISCUSSION

Yield Increases for wheat-on-wheat

Yield increases for wheat-on-wheat sowing into standing stubble were measured on 5 out of 7 sites over 3 years (Table 1). In 3 of the sites less soil-borne disease on the inter row was a significant factor in increasing yields. Better plant establishment and possibly an improved micro-climate for wheat in standing stubble also contributed to a yield improvement for inter row wheat in standing stubble.

Table 1. Wheat-on-wheat yields in inter row sowing experiments 2004 to 2006

Site	Sowing row	Yield t/ha	Yield difference	Disease effect
Sandilands SA 2004	Inter row In row	4.11 3.88	0.23	Take-all
Tammworth NSW 2004	Inter row In row	2.51 2.30	0.21	Crown rot
Sandilands SA 2005	Inter row In row	3.74 3.42	0.32	CCN and Take-all
Hart SA 2005	Inter row In row	2.99 2.77	0.22	None
Buckleboo SA 2005	Inter row In row	2.82 2.79	0.03*	None
Kimba SA 2006	Inter row In row	0.26 0.17	0.09	None
Waikerie SA 2006	Inter row In row	0.83 0.70	0.13*	None
Average all sites	**Inter row In row**	**2.47 2.29**	**0.21**	

* not significant

Farmers adopting inter row sowing are finding the establishment of crops in paddocks with medium to high stubble loads (3 to 10t/ha) are significantly improved with inter row sowing. Inter row sowing virtually eliminates the need to use other machinery for stubble management e.g. off-set discs, prickle chains, slashers and rollers to break stubble down.

Yield increases for canola in wheat stubble

Two experiments in 2006 were established to investigate the benefits of inter row sowing canola into standing wheat stubble. At Sandilands, although not significant, visually the standing and burnt stubble treatments had more even and higher establishment than the slashed treatments. Yields of canola in standing stubble were significantly higher than slashed stubble at Sandilands (Table 2). At Karkoo, inter row canola into standing stubble had both higher establishment and yield than the on row treatment (Table 3).

Table 2. Canola at Sandilands 2006

Stubble treatment	Plant # per m2	Yield t/ha
Burnt	68	0.45
Slashed	47	0.32
Standing	70	0.59
l.s.d	n.s.	0.22

Table 3. Canola at Karkoo 2006

Stubble treatment	Plant # per m2	Yield t/ha
On row	36	0.27
Inter row	47	0.35
l.s.d	10	0.06

Farmers inter row sowing canola into cereal stubbles are also observing improved establishment, early vigour and yield.

Improved herbicide efficacy in stubble retained systems

In 2006, an experiment was established to test the efficacy of Treflan, Dual and Avadex on ryegrass in 3 stubble systems (Burnt, Slashed and Standing). Ryegrass control in standing stubble was significantly better than slashed stubble with all three products used (Table 4). Stubble loads in this trial were 6 t/ha. In the standing treatment, 3 t/ha was actually standing and 3 t/ha was lying on the surface, and in the slashed treatment 6 t/ha was lying on the surface. In 2005 the same trial was established on a site with only 2 t/ha of stubble, and no difference in herbicide products was observed.

Therefore, with stubble loads above 2-3 t/ha we expect better herbicide efficacy when stubble is left standing.

Table 4. Ryegrass control at Sandilands 2006

Stubble treatment	% ryegrass control		
	Treflan	Dual	Avadex
Burnt	89.3	66.7	38.3
Slashed	29.3	37.3	16.3
Standing	84.3	78.3	51.7
l.s.d	17.3	35.3	20.2

In stubble retained no-till systems, the efficacy of soil applied herbicides (Dual, Diuron, Treflan, Avadex etc) on ryegrass is very important given the heavy reliance on these herbicides. Inter row sowing allows no-till farmers to keep stubble standing.

Harvestability benefits for inter row lentils

From trial data, there appears to be significant potential advantages in the harvestability of inter row lentils sown into standing stubble (Table 5). Lentils plants sown into standing stubble were taller by 6-8 cm and the height of the first pods was also greater by 4-5 cm compared to burnt and slashed stubble. Increasing the height to where the first pods develop and by the lentils using the stubble to "lean on" at harvest time will prevent less lentils lying over onto the ground. This can result in less harvest losses by physically being able to pick up more lentils with the harvester front, and also increase harvest speeds by having the harvester front higher from the soil surface. Indeed, farmers are finding they can reduce harvest losses by 0.4 t/ha and one farmer doubled his harvest speed in an on-farm trial of inter row vs. in row lentils.

Table 5. Lentils at Sandilands 2006

Stubble treatment	Plant ht. cm	Ht. to 1st pod cm	Yield t/ha
Burnt	23.8	14.6	0.58
Slashed	25.7	16.1	0.65
Standing	31.4	20.2	0.58
l.s.d	3.3	1.1	n.s.

What GPS accuracy do you need?

If you are serious about inter row sowing, a ±2 cm RTK system with your own base station is the way to go. This is because repeatable accuracy enables your sowing rig to come within ±2 cm of your sowing rows from the previous year and be able to hold a straight line down the length of the field. Sub-metre autosteer (±10-20 cm) does not have this level of repeatable accuracy, but you can re-set your A:B line by eye and attempt to inter row sow the following year. However, this will not be as successful as a ±2 cm system. Also, owners with sub-metre systems will allow for some overlap to compensate for the lower level of accuracy in the system. This results in an uneven row configuration across the field. From farmer experience, an estimated success rate for inter row sowing with various systems is as follows,

Up to 90% for ±2 cm RTK system with your own base station (Fig. 5)
Up to 70% for sub-metre autosteer (±10-20 cm)
Up to 50% by eye using permanent wheel tracks

Some rules to follow for inter row sowing

The base station must remain at the same location for a particular paddock year-in year-out.
Your auto-steer must have the ability to store and recall an A:B line for a particular paddock.
Your auto-steer must have a 'nudge' feature in order to move the required distance to go inter row e.g. nudge over 5" in year 2 if you are on 10" spacings
You must keep the same row spacing year-in year-out
It is preferable to sow in the same direction each year for each run because sowing rigs will crab, but hopefully crab in the same pattern as the previous year.

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Farmer Case Studies on the Economics of PA Technologies

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INTRODUCTION

One of the major goals of the Southern Precision Agriculture Association (SPAA) is to increase the adoption of precision agriculture (PA) across Australia. There has been a rapid adoption of Global Positioning Systems (GPS) guidance and autosteer in South Australia in the last 5 years. It is estimated that 30% of broadacre crops in SA are now sown and/or sprayed using GPS technology. However, other PA technologies such as yield mapping and variable rate is less common with <1% of adoption across cropping regions in SA. One of the major reasons for this is the lack of evidence that the investment in variable rate technology (VRT) can provide sound financial returns to farmers. The aim of this report is to quantify the economic benefits of PA on 6 farms across SA. The PA technology evaluated included yield mapping and VRT, as well as GPS guidance and autosteer. It is hoped this information will provide farmers and advisors valuable background information in deciding whether an investment in PA will improve individual farm profitability.

METHODS

Six farmers were interviewed from different cropping regions of SA and with varying levels of PA experience (Table 1). Information was collected on:

- area of cropping program, crops grown, crop yields, gross margins, rainfall, soil types (Table 2)
- variable input costs (fuel, fertiliser, seed, pesticides, machinery, labour) per ha
- GPS equipment purchases and purpose
- evidence that PA is working on their farm in regard to less overlap, VRT etc
- other benefits of PA e.g. conducting own agronomic experiments

This information was collated, analysed and a case study written on each individual farmer.

Table 1. Name, location, farm operation size and PA experience of farmers

Farmer	Location	Farm operation	Years of PA experience
Allen Buckley	Waikerie	3000 ha	7
Malcolm and Brian Sargent	Crystal Brook	1600 ha	8
Randall, Jordan and Max Wilksch	Yeelanna	2700 ha	2
Richard and Craig Turner	Snowtown	2340 ha	10
Graeme Baldock	Buckleboo	4475 ha	5
Mark Branson	Stockport	1200 ha	10

Table 2. Rainfall and major soil types

Farmer	Annual Rainfall	Soil types
Buckley	250 mm	Dune/swale formation, sandy loams, shallow red loam over limestone
Sargent	400 mm	Clay loam, sandy loam
Wilksch	425 mm	Red brown earths, sandy loams over sodic clay
Turner	400 mm	Red brown earths, sandy loam over clay
Baldock	300 mm	Gently undulating dune/swale formation, sandy loams, red loam over clay
Branson	475 mm	Black cracking clay, red brown earths

Economic analysis

A relatively simple economic approach was used in this study. The total cost and annual benefit of GPS equipment for each farming operation was calculated and expressed as a total and in $/ha. From this, a "payback period" was determined which is the time taken for the equipment to "pay for itself". The payback period is a function of the annual benefit relative to the initial cost of the GPS equipment and the time taken for the benefit to be instigated. After this payback period, income generated from the GPS equipment becomes profit. The quicker the payback period, the better the investment.

The total cost of equipment for each farmer was simply calculated from the original purchase price (gst exclusive).

Savings on input costs were based on reduced overlap using GPS equipment. This was calculated using the farmers' figures on the individual paddock area that was sprayed, fertilised etc before and after GPS equipment was used (example in Table 3).

Table 3. Example of savings in less overlap using GPS

	Area ha	**% overlap**
Actual area of paddock	100	-
Area of paddock sprayed, fertilised etc before GPS	105	5%
Area of paddock sprayed, fertilised etc using GPS	102	2%
Saving on overlap using GPS	**3**	**3%**

Savings using VRT were calculated from comparing variable rate fertiliser application with a previous "blanket" rate of fertiliser used before PA was employed (example in Table 4).

Table 4. Example of savings in fertiliser using VRT

Blanket rate of DAP		**Area (ha)**	**Total (kg)**
Rate (kg/ha)	100	100	10000
VRT rates of DAP		**Area (ha)**	**Total (kg)**
Rate (kg/ha)	100	50	5000
Rate (kg/ha)	80	25	2000
Rate (kg/ha)	50	25	1250
Total			8250
Saving in fertiliser			**1750**

Production increases from VRT were calculated from higher yields achieved by increasing fertiliser rates on low fertility areas of paddocks. On-farm trial data was used for this purpose. Production increases from inter row sowing were estimated using trial data. Actual farmer data on grain prices and input costs was used in the majority of calculations. Estimates were used when this was unavailable. Soil phosphorus (P) in this report refers to Colwell P. P fertiliser is expressed as units of P per ha.

RESULTS AND DISCUSSION

Costs and benefits

The costs and benefits from PA in this study are summarised below. For all cases the annual benefit from cost savings and increased production was enough to cover the cost of guidance and autosteer equipment within 3 years on average (range of 1-5 years). The payback period for yield monitoring and VRT equipment was longer, some 7 years on average (range of 1-10 years). This is mainly because of two reasons. Firstly, the initial high price of yield monitoring in the mid to late 90's before the equipment became standard on most modern harvesters less than 10 years old. Secondly, for most farmers it was some years before a VRT program was implemented because farmers were not confident to go full VRT until they had evidence it would work. The first step in gaining confidence was targeted soil testing which revealed that varying rates of P fertiliser was a viable option because low yielding areas were high in P, and high yielding areas were low or adequate in soil P. Some of the farmers were reducing their overall fertiliser input using VRT, while others were increasing production on low P areas within paddocks e.g. sand dunes. Involvement with organisations such as SPAA and PIRSA were important in verifying potential returns from PA. Farmers looking to adopt PA in the future are better positioned to make VRT pay within 2-3 years because of access to lower cost equipment (yield monitor, VRT equipment) and more information on the likely financial returns.

Table 5. Summary of costs and benefits of GPS equipment

Farmer	Capital invested in PA		Annual benefit		Payback period (years)	
	total	$/ha	total	$/ha	Yield monitor and VRT equipment	Autosteer & guidance
Buckley	$ 68,500	23	$ 32,850	11	1	4-5
Sargent	$ 98,500	62	$ 20,180	13	10	1-5
Wilksch	$ 73,000	27	$ 57,240	21*	-	1-2
Turner	$ 34,432	15	$ 35,100	15	6	1
Baldock	$ 52,000	12	$ 47,842	10*	-	5
Branson	$ 73,800	62	$ 44,880	37	9	3
Average	*$ 66,705*	*$34*	*$ 39,682*	*$18*	*7*	*3*

*estimated potential, not proven

Table 6. Breakdown of GPS benefits

Farmer	Annual benefit $/ha			
	Savings in overlap	Savings using VRT	Increased production using VRT	Other production increases**
Buckley	4		7	
Sargent	5	5		3
Wilksch	3			18*
Turner	5	10		
Baldock	2		8*	
Branson	10	9		18
Average	*$5*	*$8*	*$7*	*$13*

* estimated potential, not proven

** includes reduced soil compaction, inter row sowing etc

Other major benefits of PA

The reduction in fatigue was highly rated as a benefit of guidance and autosteer amongst all 6 farmers. The ability to conduct your own agronomic experiments was an important benefit for 2 farmers, which has the capacity to lead to better whole-paddock or whole-farm decisions that increase profit.

Management time spent by farmers on PA

Most of the farmers interviewed spent 3-7 days per year organising yield and variable rate maps. Most used basic software supplied by manufacturers and machinery dealers. Although the software was basic, it is fair to say the level of computer and GPS literacy amongst these farmers was high. This may be a significant barrier for further adoption of VRT. Some farmers used the advice of a PA or agronomic consultant in preparing variable rate maps. In contrast, guidance and autosteer takes very little training and on-going management.

Evaluating the economics of PA on your farm

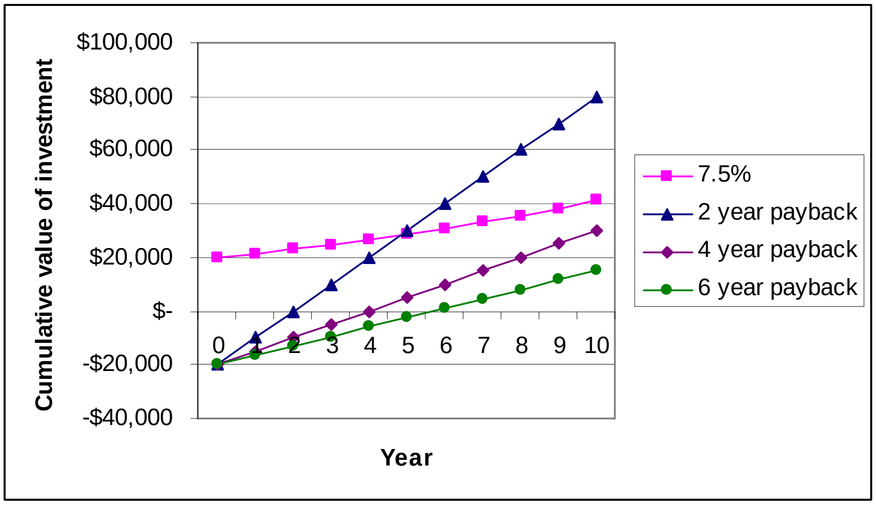
As with any decision to invest capital, farmers need to evaluate the likely returns from PA before investing in equipment. They may engage the services of a PA and/or agronomic consultant to help them with this evaluation. The decision to purchase guidance or autosteer is more straight forward than VRT equipment. An important first step in evaluating the feasibility of VRT will be at least some yield maps and targeted soil testing in different areas of the paddock before purchasing equipment specifically for VRT e.g. electric seed rate controllers. To maximise the return on investment, PA equipment should pay for itself in 2-3 years, particularly given the expected lifespan of PA equipment is likely to be only 5-15 years before it needs replacing. The rapid improvement in “value for money” for new GPS products means that equipment is likely to be worthless after 10 years. The following two examples illustrate the importance of a quick payback period for GPS equipment.

Example A - $20,000 investment in a 10cm autosteer system

Four scenarios are tested in this example,

1. Savings in inputs return $10,000 per year resulting in a payback period of 2 years
Savings in inputs return $5,000 per year resulting in a payback period of 4 years
Savings in inputs return $3,500 per year resulting in a payback period of 6 years
Investing the $20,000 at 7.5% compounding (control)

The cumulative value of the investment is tracked over 10 years. The autosteer after this time is considered to have no value.



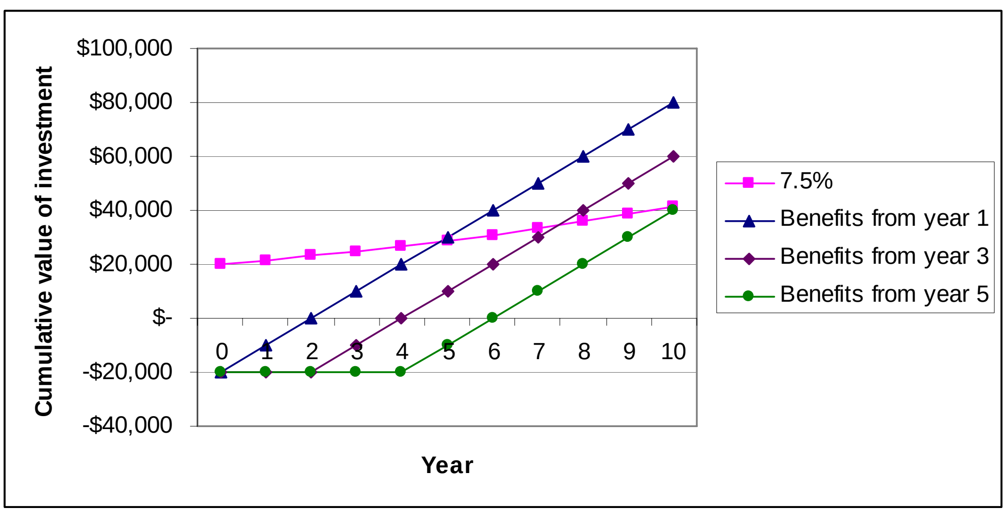
The only scenario to return a greater profit than 7.5% compounding was the first scenario whereby the autosteer returned $10,000 per year in savings on inputs and paid for itself within 2 years.

Example B - $20,000 investment in VRT equipment

Four scenarios are tested in this example,

1. The equipment returns a profit of $10,000 per year, and this profit starts in year 1
The equipment returns a profit of $10,000 per year, and this profit starts in year 3
The equipment returns a profit of $10,000 per year, and this profit starts in year 5
Investing the $20,000 at 7.5% compounding (control)

The cumulative value of the investment is tracked over 10 years, and again the GPS equipment after this time is considered to have no value.



In this example, if the profit generated from the VRT equipment starts in years 1-3 then the investment is reasonably good compared to 7.5% compounding. If the return on investment only starts from year 5 onwards, it is likely to be no better than 7.5% compounding over 10 years.

These examples highlight that the payback period is a function of the annual benefit relative to the initial cost of the GPS equipment and the time taken for the benefit to be instigated. The quicker the payback period, the better the investment. In addition to quick payback periods, other key factors in relation to PA as a good investment are,

Scale of operations. Larger farms can afford to invest more money in PA and will achieve a greater return over time. Smaller farmers should consider syndication or sharing of PA equipment.
Computer literacy. A reasonably high level of GPS knowledge and computer skills are required for successful VRT implementation. This is not the case for autosteer and guidance.
Conduct a feasibility study first to work out a budget, and then shop around the GPS manufacturers for a product that suits your requirements. Consult advisors and other farmers in making this decision.

CONCLUDING REMARKS

PA technology offers farmers opportunities to increase their profitability if they make a sound investment in the equipment required. An initial simple feasibility study is an important first step. In regard to VRT, farmers today are well-placed to take advantage of the knowledge gained from the growers in this study who have been the early adopters of PA technology. Also, the cost of PA equipment has become rapidly more affordable in the last 5 years which will enhance the profitability of adopting PA for many farmers.

ACKNOWLEDGMENTS

Funding provided by SPAA, and the co-operation from the farmers is gratefully acknowledged. Dr Kathryn McCormick provided valuable comments on the report.

Addressing the Challenges of CTF for the Vegetable Industry

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INTRODUCTION

The Australian vegetable industry is a $1.66 billion business (farm gate, 2003/04), with value adding bringing the total to $2.36 billion. The industry is very diverse, with enterprises of every conceivable scale in every state growing a wide range of products. Nationally, the fresh market sector accounts for about 75% of the industry value. The Tasmanian situation is the reverse, being 75% processing based. The Tasmanian vegetable industry is worth $160 million (farm gate) and $360 m packed and processed. Potatoes represent about 50% of the industry value and are the dominant crop (75%) of the processing sector. The Tasmanian industry is contract based in both the processing and fresh sectors. Vegetables grown include potatoes, onions, carrots, brassicas, peas, beans, pumpkins and leafy vegetables. Many farms also grow pyrethrum, opium poppies, cereals, pastures for hay and silage and run livestock.

THE PRODUCTION ENVIRONMENT

Vegetable production occurs across the State, with the main areas in the north-west and north-east hinterland, and in the midlands and north-east coastal belt. There are distinct differences in soil type, topography and farm size between production areas (Table 1).

Table 1. Comparison of the main vegetable cropping regions in Tasmania

North-west/north-east	**Midlands and north-east coast**
Ferrosols (red clay loam on basalt)	Clay loams, sandy and duplex soils
Well drained soils	Well to poorly drained soils
Undulating to steep (10 – 20% common)	Flat to gently undulating
Water run erosion issues	Wind erosion issues
Small holdings (typically 100 – 150 ha)	Larger enterprises (typically about 200 ha)
Expensive land	Cheaper land
Big gun irrigation, pivots and linear increasing	Predominantly pivot irrigation, some big gun
About 75% of vegetable production	About 25% of vegetable production
Greater diversity of crops with some livestock	Smaller range of crops, livestock more likely

Use of leased ground is increasing, particularly for potato production. Contractors are used heavily for harvest, with peas, beans, poppies, pyrethrum, cereals, carrots and onions almost exclusively contract harvested. About 80% of potatoes are contract harvested. Although some crops are planted, grown and harvested year round, most production is based on summer irrigation. Planting intensifies from Sep – Feb, with harvest concentrated in the Jan – Jul period. Harvest often extends into winter, with high soil moisture leading to trafficability and compaction issues. Even in summer, many crops are harvested fresh (eg peas, beans) so pre-harvest irrigation to maintain crop quality results in high soil moisture and similar machine traffic issues.

THE MACHINERY ENVIRONMENT

Achieving equipment track width commonality will be a major challenge in the vegetable industry. The most common tractor track widths used in Tasmania for in-crop work are 1625 mm and 1730 mm (matching 32″ and 34″ potato rows), although some growers have experimented with track widths from 1800 – 2100 mm. Most vegetable crops are grown in rows or beds based on one of those track widths. Larger tractors used for primary tillage and harvest may be on 1830 mm centres. Most tractors in the vegetable industry are 70 – 140 kW, and can attain track centres of 1500 – 2200 mm within manufacturers' standard configurations. For in-crop work, tyre tread widths are 330 – 380 mm, while for primary tillage and harvest work the range is 460 – 600 mm. Equipment used for other crops in the rotation may have other track centre widths and tyre tread widths. As in most cropping industries, the trend in recent years has been to increase work rates with the use of larger, heavier machines, particularly tractors and harvesters. Table 2 shows crops grown on a typical Tasmanian vegetable farm, and relevant equipment track and tread widths.

Table 2. Crops and equipment characteristics typical of the Tasmanian vegetable industry

Dimensions (mm)	**Potatoes, carrots, onions, brassicas**	**Peas, beans**	**Cereals, pyrethrum, poppies**
Tractor track width for in-crop work	1625 or 1730	Generally 1625, 1730 or 1830	Generally 1625, 1730 or 1830
Row crop tractor tyre tread width	330 – 360	na	na
Tractor track width for out of crop work	Generally 1625, 1730 or 1830	Generally 1625, 1730 or 1830	Generally 1625, 1730 or 1830
Non-row crop tractor tyre tread width	460 – 600 530 common	460 – 600 530 common	460 – 600 530 common
Harvester track width	2200 – 2640	2200 – 2600	3000 – 4000
Harvester tyre tread width	300 – 750	400 – 750	700 – 800

BENEFITS OF CTF TO THE VEGETABLE INDUSTRY

The benefits of controlled traffic are well known from the grain industry and include improvements in soil structure and biological activity, infiltration, water holding capacity, yield and operational efficiencies through lower fuel use, lower power requirements, spatial accuracy and timeliness. Additional advantages that could be important for the vegetable industry include:

- potential to achieve more uniform maturity in many vegetable crops, with consequent improvements in harvest and processing efficiencies and product quality
- reduction in clod load to make harvest of root, bulb and tuber crops easier and cheaper
- opportunities for new spatial configurations for many crops, with the possibility of increased plant populations and yields
- elimination of heavy tillage operations and adoption of direct drilling to allow retention of crop residue and cover crops for controlling erosion and weeds
- direct drilling and guidance to allow permanent or semi-permanent drip irrigation systems, with consequent benefits for water use efficiency and foliar disease management
- improved opportunities for mechanical weed control through better guidance, which may become important with the development of herbicide tolerance in weeds, or for organic production

SOME OF THE CHALLENGES IN THE VEGETABLE INDUSTRY

Given the inter-dependence of many operators in the industry, it is not surprising there is debate about the best track width to use for CTF. Many options are discussed, but for the sake of simplicity, the options of 2 m, 2.5 m and 3 m will be covered here. Most potato, carrot and onion harvesters have track widths of 2.2 – 2.4 m, although there are exceptions. Most potato harvesters are bunker equipped single row machines, and track configurations are not symmetrical, with an out-rigger wheel required for stability. While it is possible to side-shift the digging front further than one row from the tractor, tracking and stability on sloping land are major issues. Some USA potato harvesters offer the option of tracking directly behind the tractor with wheels that can straddle the bed, but it means a major change to harvest operations, with the addition of an extra tractor and chaser bin to the system.

Top pull carrot harvesters are another issue. They harvest only one or two rows at a time at row spacings that may be narrower than potatoes. Tricycle-style self-propelled carrot and potato harvesters compound the problem, as these leave tyre tracks over 65% of the width of the machine on a single pass. The entire paddock is subject to multiple wheel passes at harvest.

In short, there is no commonality between tractor and harvester track widths, regardless of the crop.

A consideration in most vegetable growing areas, and particularly in Tasmania, is the width of tractor and machinery combinations for road travel. Vehicles exceeding 3.5 m total width on highways, and 3.2 m on minor roads, require at least one escort vehicle. A significant amount of travel occurs on minor roads. The road transport issue indicates a track width of 3 m maximum, but preferably less.

Soil erosion and drainage

Almost all vegetable cropping in Tasmania occurs on undulating land, particularly in the north-west and north-east. Slopes of 10 – 20% are common, with isolated parts of paddocks up to 35%. Erosion from rainfall or irrigation run-off is evident in current row and bed cropping situations, such as onions, carrots and potatoes. Compacted traffic lanes in a CTF system are seen as an erosion risk. Whether or not this is a justified concern, there are a number of measures that can be used to reduce the risk:

- *Farm layout* – a CTF layout would consider soil erosion risk as one of the primary issues. Key objectives are to ensure drainage down the slope and deal with concentrations of flow through appropriate drainage structures.
- *Run-on and run-off* – overland flow across paddocks could be reduced by construction of appropriate drains to prevent water flowing on to a paddock, and controlling it as it flows off.
- *Infiltration* – with a wide track CTF system, and retention of crop residue, a greater portion of the paddock will have improved infiltration conditions. The wheel track area will result in much less total run-off than current farming systems. It may even be possible to direct run-off from the wheel tracks into the cropping zone, which will have a much greater capacity for infiltration.
- *Irrigation* – the use of drip tape would immediately eliminate irrigation run-off in the wheel tracks, and alternative sprinkler packs on liner move irrigators could be used to reduce the problem. Pivot, solid set and travelling irrigators present issues with no clear resolution at this stage.
- *Straw barriers* – the use of straw barriers in furrows has been shown to reduce the speed of run-off flow and to retain soil on the paddock. Use of a recently developed “straw machine” would assist with erosion control in conjunction with the other methods outlined above.

Many Tasmanian vegetable paddocks have complex slope profiles, so strategic drainage, perhaps with grassed waterways, may be required to ensure traffic lanes remain firm and trafficable when wet.

Farm and operational logistics

Tasmanian vegetable farms tend to grow a very diverse range of crops. Paddocks often have irregular shapes, with many being dissected by drainage lines or having boundaries dictated by dams, creeks or other features. Slope may be an issue for maintaining accuracy of traffic, particularly in wet conditions. GPS will assist directional tracking, but it is still important to maintain traction on the wheel track to keep the equipment on track. The cost of GPS units would also be an issue for many operators on relatively small farms.

Headlands are usually planted across the slope and harvested first to allow room to turn harvesters at the end of the row and for parking trucks. Such an arrangement is inconsistent with the objectives of controlled traffic. Headlands could be grassed, but land is valuable and up to 5% of a paddock area could be devoted to permanent headlands under such a strategy. An alternative would be to crop the headlands anyway, and accept they will not be managed under a controlled traffic system.

THE CURRENT SITUATION

Technical challenges to the introduction of controlled traffic in the vegetable industry are considerable, but all within the bounds of possibility if there is the will to change and the benefits are worth pursuing. The processing vegetable industry is under significant economic pressure due to rising input costs and cheap imports of processed product. There has been a change in the profile of CTF in the last year. A number of growers have joined the conversation, recognising the potential benefits of CTF, but issues of machine configuration and compatibility dominate the discussion. In the grains industry, an independent grower may make a personal decision to convert to CTF and be faced with modifications to maybe five machines. In the vegetable industry, a grower deciding to change track width may need to consider modifying at least six owned machines, and the consequences of that change for up to eight contract harvesters for different crops.

WHAT TRACK WIDTH?

Although there is currently some discussion around appropriate track widths for the vegetable industry, there is no one width that stands out as being obvious. Table 3 outlines track width options and the implications for availability of machinery to suit.

Table 3. Some track width options to consider for a CTF system in vegetables.

Track width centres (mm)	**2000**	**2500**	**3000**
Approx. bed width (mm) [A]	1500	2000	2500
% area wheel tracks [B]	25	20	17
% reduction in number of passes [C]	19	35	46
Equipment availability or opportunity for modification [D]			
Tractor	RA	A	A
Precision seeders	M	M	M
Potato planters	A	A	A
Potato harvester	?	A	A
Onion harvester	A	?	A
Carrot harvester	?	?	?
Bean harvester	NA	M	M
Pea harvester	NA	M	M
Grain/py harvester	NA	NA	RA
Poppy harvester	A	?	A

[A] – calculation of bed width is not exact. The maximum width of a bed is the track width less the section width of the tyre. In reality, it is less than this on account of bed shape (ie raised or flat), the accuracy of steering/guidance and the contact width of the tyre. Bed widths have been calculated as track width minus tyre section width (400 mm in this case) minus 100 mm to allow for other factors, then rounded down to the nearest 100 mm. This leads to wheel tracks around 500 mm. This width could be reduced with narrower section tyres, but is consistent with measurements of current non-CTF bed systems.

[B] – the area of wheel tracks is actually the area that is not the bed. The percentage of wheel track area would be smaller if only the tyre section width was considered in the calculation, but in line with the comment under [A] (above), allowance is made for other factors. Once again, this could be reduced with narrower section tyres.

[C] – as tractor track width increases, so does the working width of implements. It is assumed that the tractor is working the same number of bed widths on each pass, so actual working changes with each option. An example would be a potato planter, which in the 1625 mm system would be planting two rows each pass, giving a working width of 1625 mm. For any other track width, it is assumed that a single pass would plant the width of the bed, but the land area covered is the track width. The % reduction in number of passes is referenced to the current 1625 mm system.

[D] – equipment availability, or opportunity for modification, represents the ease with which equipment can be sourced for each track width option. There are a wide range of machines and designs available from different manufacturers, and a comprehensive survey of all options if far from complete. The code in the table is as follows: RA – readily available from local suppliers; A – available, but needs to be imported, or made to order based on a standard machine; NA – not yet known to be available or existing models cannot be modified to suit; M – should be able to be modified; ? – availability, or suitability for modification, unknown at this stage.

One local corporate agricultural enterprise is currently considering a change to 2 m track centres. The primary motivation is to reduce the area of land used as wheel tracks in crops such as onions and carrots, and hence achieve an immediate productivity gain. While CTF is not the major impetus for this move, the company understands that they could move towards CTF in the future. They are also conscious of the implications for a large number of contracting growers if changes to track width are made that require specialist modifications to tractors and other equipment – eg. beyond 2 m centres.

CURRENT ACTIVITIES

One grower is currently operating under a very simple, small scale CTF system. The crops grown are leeks and bunching carrots for the fresh market, so the large harvest machinery associated with most crops is absent from the system. The guidance system is a straight eye and the paddock layout could be improved. Nevertheless, the site has proved to be a valuable gathering place for others interested in CTF, as it graphically demonstrates the improvement in soil structure and timeliness that can be achieved with a CTF system. We have had a number of gatherings in that paddock as a means of encouraging discussion and ideas about the future of CTF in the vegetable industry.

WHERE TO NOW?

While it is clear that a move to a fully integrated CTF system requires significant change, it is equally clear is that it won't happen overnight. For that reason, it is necessary to consider interim steps towards a full CTF system.

The cheapest way to make a start is to change very little, and most of the important initial steps are not even related to machinery. The following list outlines the priority issues to be addressed for someone considering a move to CTF:

- Get a clear understanding that soil compaction is an issue in vegetable production, and is likely to be affecting crop yield, uniformity of maturity and quality, infiltration, water holding capacity and tillage costs through– this is about the mindset, not the technology.
- Visit other areas and industries using CTF to talk to growers about their experiences.
- Keep all trucks off the paddock at all times – this should be done now anyway.
- Purchase a GPS guidance system for normal paddock operations to improve efficiency.
- Use the GPS guidance system to collect data to generate an accurate topographical map of the farm.
- Design a farm layout for efficient CTF operation, taking into account field logistics, access, drainage and erosion issues, and using a "clean slate" approach to any infrastructure that can be moved – eg fences.
- Make the easier changes to farm layout in accordance with the farm plan.
- Consider how irrigation system planning fits into the farm plan – the options of pivot, linear, solid set, drip and traveller and how they fit with controlled traffic and run-off and erosion management.
- Stop cultivating the tractor wheel tracks – remove the tines and other tillage elements that follow the tractor tyres from whatever equipment is being used. This will reduce power requirements, and with GPS guidance, it will be possible to return to the same wheel tracks after each harvest, regardless of how compacted the paddock has become from other wheel traffic. This step will be easier for some tillage equipment than others.
- Modify tillage equipment for efficiency of working width, taking into account lowered draft requirements due to not cultivating the tractor wheel tracks.
- Modify planting equipment to work only between the wheel tracks.
- Try to establish a rotation that minimises traffic in the cropping zone from one season to the next. Selection of compatible crops in the rotation might include consideration of harvest machinery, opportunity to direct drill, the retention of drip irrigation, use of green manure crops and other factors. This requires rotation planning up to 24 months in advance.

All of these interim steps could be done without changing the track width of the system, and it may be possible to access some equipment to minimise traffic on the cropping zone. This approach provides the opportunity to learn about using and developing the CTF system without embarking on the expense of significant machine modifications, particularly in an industry where total compatibility of equipment depends on the agreements and actions of many players. Beyond these steps, progression to another track width requires modification of a range of machines, particularly harvesters.

THE REST OF THE JOURNEY

Change to a fully integrated CTF system in the vegetable will require a considerable degree of co-operation. Since most crops are grown under contract, the role of fresh vegetable packers, vegetable processors, extractives companies and contract operators will be critical. Each company provides a range of services to its growers, and so is in a position of influence in relation to future directions. Once the first moves are made, it is likely that CTF will exist as a compromise system for some time, while people become more attuned to the idea and have the opportunity to experience their own successes and failures.

The first steps forwards are going to be taken by those who can see the benefits of CTF in the long term, even if they can't fully see how to get there yet. This is a time when those growers who are making the move will need as much support as possible from a range of advisers, machinery suppliers and others. Fortunately, although the vegetable industry has its own set of complexities to deal with, the experiences of the grain industry mean that at least there are people in some areas of the machinery industry who know what CTF is about.

Networked RTK using the Internet for Controlled Traffic Farming

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INTRODUCTION

The Department of Sustainability and Environment (DSE) in Victoria has developed a Global Navigation Satellite System (GNSS) Continually Operating Reference Station (CORS) infrastructure called GPSnet™ (Refer to www.land.vic.gov.au/GPSnet). GPSnet™ provides Networked Real-Time Kinematic (NRTK) correction services that are suitable for many high accuracy applications such as surveying and construction. Recent trials conducted with the Department of Primary Industries (DPI), the Balliang Controlled Traffic Farmers Group and several industry partners have demonstrated ±2 cm horizontal navigation capability for controlled traffic farming applications by using NRTK.

This paper describes how centimetre accurate GNSS navigation guidance from Victoria's GPSnet is generated by using the internet and a "virtual" base station at the farm site. Use of GPSnet means not purchasing a local base station on the farm. NRTK corrections from GPSnet provide a range of additional benefits including strict compliance with Australia's national datum GDA required for pass-to-pass precision and year-on-year accuracy.

CONTINUALLY OPERATING REFERENCE STATIONS (CORS)

CORS are stable, monitored GNSS reference points. Combined into a network, CORS provide continual, uninterrupted GNSS satellite information used to compute parameters which determine the national datum, measure continental drift and monitor changes in sea levels.

CORS networks in Australia

CORS networks in Australia are a fundamental component of the nation's spatial infrastructure; position, navigation and time. The Australian Regional GNSS Network (ARGN) is the primary network managed by Geoscience Australia. The Australian Fiducial Network, part of the ARGN, was used to determine the current national datum GDA94 and underpins legal traceability of position (http://www.ga.gov.au/geodesy/).

Geoscience Australia is developing the national CORS network project, AuScope (http://www.auscope.org.au/). Information at the State and Territory scale is summarised as:

GPSnetwork Perth (http://www.gpsnetworkperth.com.au) - private sector operated network with assistance from the WA Department of Land Information.
GPSnet (www.land.vic.gov.au/GPSnet) Victorian Department of Sustainability and Environment
SunPOZ (http://www.nrw.qld.gov.au) Qld Department of Resources and Water
NT CORS (www.ipe.nt.gov.au) NT Department of Planning and Infrastructure
SydNET NSW Department of Lands (http://sydnet.lands.nsw.gov.au/sydnet/login.jsp) (http://sydnet.lands.nsw.gov.au/images/MetroNETCoverage.jpg)

CORS in Victoria - GPSnet™

GPSnet is rapidly growing with the allocation of resources to build 7 new CORS during 2007/8. GPSnet started in 1996 and now has a real time network of 30 stations (Figure 1). The aim is to expand GPSnet to a state-wide ±2cm service available via the internet. GPSnet also aims to develop a CORS network management model that allows other states and territories, such as NSW, SA and even TAS, to share data between CORS networks.

GPSnet is a cooperative model where the department is a custodian that builds, operates and manages the network for all stakeholders. Hosts and contributors include a range of government, research, utility/industry organisations, Landcare groups and independent farmers. Along with the network development, the uptake of new GPSnet users has increased rapidly, particularly with respect to surveyors who require reliable centimetre positioning.

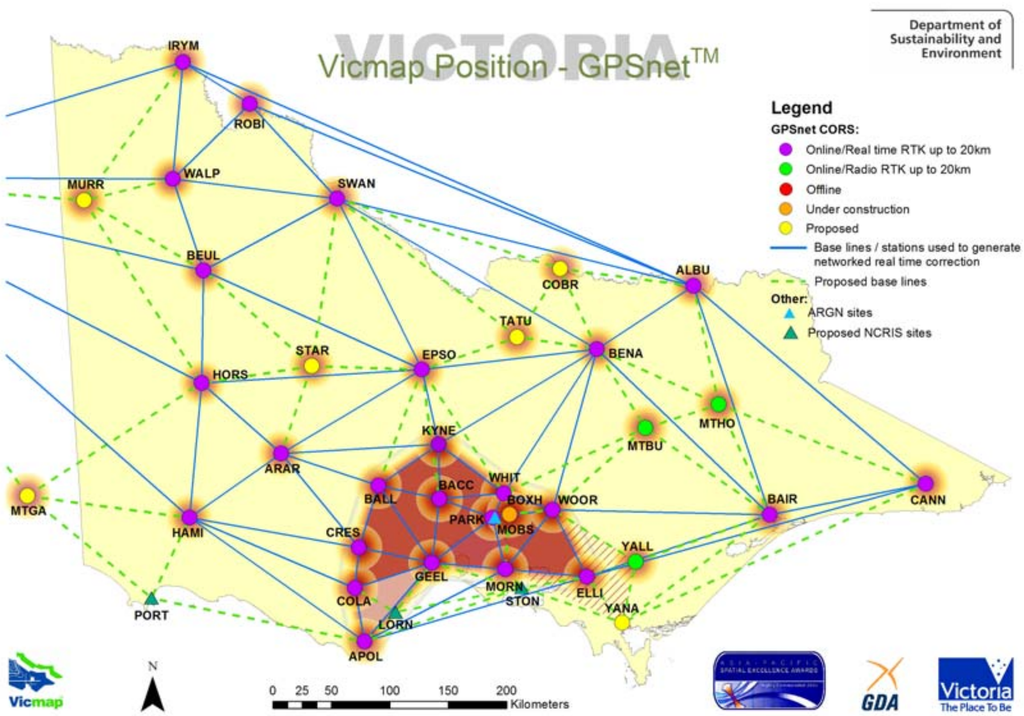

Figure 1. Victoria's CORS network, GPSnet

GPSnet uses a dedicated server processing centre to collect data from all the GPSnet CORS sites. The GPSnet web servers distribute corrections over the Internet using the NTRIP[1]. Users typically access the service using a GPRS enabled mobile phone, which transmits the corrections to a suitable GNSS receiver via Bluetooth. Alternatively, correction signals can be sent to a central location and transmitted to farm equipment using radios.

[1] NTRIP Networked Transport of RTCM Via Internet Protocol – International Standard Refer to http://igs.ifag.de/index_ntrip.htm

GPSnet quality

The GPSnet specifications achieve accuracy, reliability and quality by the use of specialised quality control programs that ensure a target service up-time of 99.98%. Research into the development of real-time quality indicators is on-going (Cooperative Research Centre for Spatial Information www.crcsi.com.au Project 1.2)

NETWORK REAL-TIME KINEMATIC FOR CENTIMETRE POSITIONING

Standard GNSS positions without corrections are typically accurate to 20m, with precision to 5m in ideal environments. However, signal multipath (the reflection of satellite signals bouncing off objects like trees, sheds and machinery) will cause large unwanted errors.

There are several techniques used to achieve greater GNSS accuracy, one of which is Networked Real-Time Kinematic (NRTK) corrections (Table 1). By streaming GNSS observation data from individual reference stations to the processing centre, a reference network is created that models atmospheric (ionospheric and tropospheric) errors and satellite orbit biases over the entire network area. The user receives a more reliable correction model based on their location within the network. The NRTK approach generates a *virtual* reference station (VRS) to imitate a base station close to the users' position. In this way the 15km RTK range limitation for single base is increased to over 70km for the NRTK method.

Table 1. Positioning methods

Positioning Method	Accuracy	Range Limit	Correction Method	Uses in Agriculture
Standard Positioning	20m – 5m	World wide	No corrections	"Where am I" navigation
Differential GNSS	5m – 2m	100 km from base station	Single base via Radio, Internet, or Communication Satellite	Yield mapping, transition between soil zones
Network Differential GNSS	2m – 0.5m	Anywhere in network (500km)	Network via Radio re-broadcast or Internet	Yield mapping, geographic information site surveys, soil zones
Real-time Kinematic	0.2m – 0.02m	15-20km from base station	Single base VHF/UHF Radio	Automated machine guidance, engineering construction surveys
Network Real-time Kinematic	0.05m – 0.02m	Anywhere in network with 70-100km triangles	Network via Radio re-broadcast, Internet and mobile phone	Automated machine guidance, engineering and construction surveys

Creating a Virtual Reference Station (VRS) for a farm location

Victorian farmers can create a VRS using a Personal Computer (PC) or Laptop with access to a Broadband internet connection, free downloadable software (called GNSS[2] Internet Radio) and a transmitting/receiving set of radios/modems.

[2] Note: GNSS Internet Radio software has been developed to support an international standard for streaming of GNSS correction data over the internet refer to http://igs.ifag.de/

The farmer specifies a location to create a VRS by inputting known coordinates (from a map or GPS) into the GNSS Internet Radio software. The farmer then receives real-time GNSS corrections based upon this position within the CORS network. The software then requests corrections by making an automatic connection to the GPSnet service. The corrections are streamed to the PC as real-time data with a choice of formats like CMR+ or RTCM. A radio/modem is connected to the PC comport (COM1) to rebroadcast correction data from the PC and to a receiving radio/modem and GNSS on a tractor or harvester in the field (Figure 2).

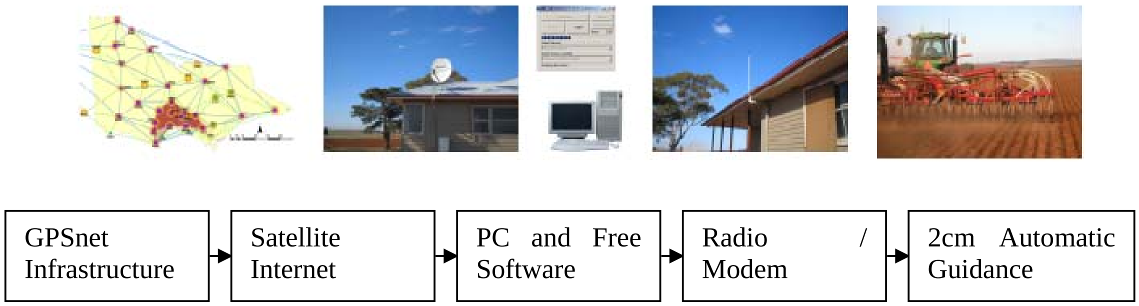

Figure 2. CORS NRTK system for 2cm automatic guidance

BENEFITS OF CORS NRTK

Datum coordination and monitoring

The advantages of using a CORS network include not having to purchase a base station receiver and antenna, and the costs of installing, operating and maintaining this equipment. Also, surveying the base station to the GDA94 datum and creating a reference point with exact coordinates in case the base equipment needs to be moved or changed is not required. Connection to a datum is absolutely necessary if year-to-year accuracy is required on the local farm, within the district, across the state and over the entire nation.

Without uniform coordination there will be distance errors between neighbouring reference stations. At worst, if the WGS84 datum is used to correct roving GNSS equipment, users may experience high precision from pass-to-pass in one season, yet year-to-year accuracy will drift north east along with the Australian continent at about 7 cm per year! CORS networks such as GPSnet are directly connected to GDA94 with Regulation 13 certification provided by Geoscience Australia, eliminating the effects of tectonic plate movement. In this way CORS are the primary means of connection to state and national spatial infrastructure.

Redundancy and efficiency

Unlike a single base local RTK solution, a network solution is founded on at least 6 contributing reference stations. If a CORS station has a problem there are multiple other stations available. The overall network is designed with redundancy for reference stations, with efficient data processing and internet signal distribution.

Connecting a series of GNSS reference stations in triangles generates an accumulative growth in the area covered by the physical reference station sites – a classic effect of networking. For example, 6 connected triangles in an ideal network will cover an area more than double of that of 7 non-connected single base stations. For a large continent like Australia, a well designed network of GNSS reference stations would promise significant cost savings and efficiency gains due to this network effect. For example, Figure 3 displays the current GPSnet coverage area surrounding Melbourne of 27,105km^2 compared to a reduced coverage area of 16,328km^2 for the same number and location of reference stations operating in isolation and not connected as a network.

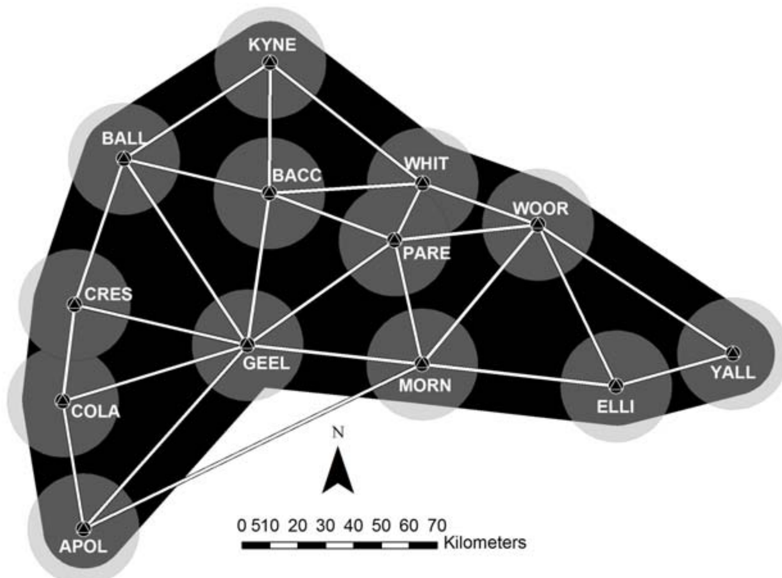

Figure 3. Network RTK compared to Single Base RTK

Reliability and quality

Secure remote access to each reference station and the streaming of data to a central processing centre accumulates additional benefits. Network processing produces a more reliable solution, with better atmospheric models and error corrections. Reference stations are continually monitored for quality, continuity of operation and data completeness, while upgrades and maintenance can be managed over a remote connection, adding to the reliability and quality of the service.

CASE EXAMPLE: NRTK FOR CONTROLLED TRAFFIC FARMING IN VICTORIA

The advantages of controlling farm machinery to 2cm accuracy are well known and discussed within the Precision Agriculture (PA) industry and farming groups such as Controlled Traffic Young Farmer Groups (CTYFG). One of the groups, based around Balliang, north of Geelong in Victoria, has hosted and tested the capability of GPSnet to provide reliable pass-to-pass accuracy. Balliang is within the high accuracy coverage of GPSnet and is an important grain production region. The success of the project was aided by the enthusiasm of the group and the precision agriculture industry at large, without this level of cooperation, testing of the networks capability would be problematic.

Local farmer Chris Sharkey has a satellite broadband connection at his property and saw this as an opportunity to introduce the capabilities of GPSnet to the broader farming community.
Chris said ‘a network of base stations is the only way forward for centimetre guidance, it’s just a waste of money having individually owned and run base stations 15 km apart when we can have GPSnet base stations at 70 km’.

Unfortunately, the Sharkey's satellite broadband connection did not deliver the data required for the project, and Paul Jensz volunteered to host the trials. A specially designed internet connection was installed and tested. The work done has led to the discussion presented in this paper. The Group see networked GNSS reference stations delivering NRTK corrections as the future and a way to remain internationally competitive. Moreover, a state-wide CORS network will be highly valued by sowing and harvesting contractors.

Ultimately, a state-wide GPSnet would mean all users can achieve consistent 2cm guidance in terms of GDA94 anywhere in Victoria. The enthusiasm of the Balliang CTYFG to host these trials is greatly appreciated and demonstrates their belief in the potential of a NRTK correction service. The group is very keen to continue its involvement with the technology and the members are ready to be the first to use GPSnet when it becomes commercially available to the farming community.

FUTURE CHALLENGES - GPS TO FULL GNSS IN TEN YEARS: 2017

There are numerous challenges that users of satellite navigation systems face in the future. Access to new generation satellite constellations and GPS modernisation is paramount to equipment specifications and purchasing decisions over the next 5 years. The unified CORS infrastructure across Australia, equipment costs and interoperability, productivity benefits and the role of commercial partnerships will all be important considerations.

Over eighty GNSS satellites will be commissioned by 2017 with twenty five satellites in view at any time. In addition to satellite availability, industry experts regard CORS and differential techniques as essential providers of the accuracy required for CTF and other applications.

GPS modernisation (www.navcen.uscg.gov/gps/)

Global Positioning System (GPS) from the USA is the best known and fully operational with 30 satellites. GPS modernisation includes a civil L2 and new L5 signal with an overall plan for 30 GPS-III satellites ready for deployment between 2013 and 2018.

Russian GLONASS (www.glonass-ianc.rsa.ru).

The Russian Federation operates GLONASS with a total of 10 operational satellites, two launched in April 07. The intention is to achieve a full 24 satellite constellation transmitting two civil signals by 2010 and GLONASS modernisation by 2017.

EU Galileo (http://ec.europa.eu/dgs/energy_transport/galileo/index_en.htm)

The European Union Galileo program has slipped behind its original deployment schedule with the full operational capacity estimated for 2010. Only one test satellite currently in orbit! A completion date for 30 satellite constellation around 2012 – 2014 is projected.

CONCLUSION

Continually Operating Reference Stations are being established in each State and Territory in Australia as the primary means of connection to the national datum GDA. The connection to GDA ensures year-to-year accuracy between neighbouring farms and across the whole continent. Victoria's GPSnet is well advanced with state wide coverage for high accuracy nearing completion. GPSnet offers a range of services including NRTK that provides centimetre accuracy in real-time. The uptake of GPSnet services for survey and construction has been increasing in metropolitan areas well serviced by wireless internet coverage.

The difficulty in obtaining reliable internet in rural areas was the motivation behind developing a system to re-broadcast a "virtual" reference station solution to a farm using a satellite internet connection. A new approach to 2cm guidance using a CORS NRTK system was demonstrated at Balliang. The Balliang Controlled Traffic Young Farmers Group tested a CORS network that doesn't require individual base station equipment. Additional benefits include a consistent national approach to providing CORS infrastructure. With over eighty GNSS satellites scheduled to orbit by 2017 there are many challenges ahead for GNSS users, CORS network operators and local base station owners to extract the maximum benefits from high accuracy satellite positioning systems.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the collaboration between the Department of Primary Industries and Department of Sustainability and Environment facilitated by Chris Bluett from DPI; the assistance and generosity of A1 Lasers and GPS for supplying and installing Trimble Ag GPS; NewSat for providing satellite internet connectivity; CNG systems for installation and PC; Paul Jensz for use of his farm and John Deere tractor and Luke Pendretti for his driving and patience. Finally, thanks to the Balliang Controlled Traffic Farmers Group for their enthusiasm for continuing the development of GPSnet services.

Using CTF as the Basis for Novel Farming Systems — Improved Nitrogen Utilization as a Case in Point

Clay Mitchell, The Mitchell Farm, Iowa USA

INTRODUCTION

Intercropping forces controlled-traffic farming, gains its benefits

Strip-intercropping maize and soybeans requires precise co-linear field operations year-after-year to maintain a proper rotation all the way to the crop edges. This forced controlled-traffic farming situation encourages the elimination of tillage and consolidation of wheel traffic that is normally associated with CTF.

In conventional cropping, field operations are often done on intentionally non-parallel swaths; even when some operations are repeatedly done in parallel, yearly passes are not co-linear. Thus, the effects of non-uniformity—whether in residue distribution, tillage depth, fertilizer distribution, planting depth, spray coverage, or other factors—become quickly buried in noise and blurred into a fuzzy picture where yield-limiting factors which follow directly from mismanagement, can never be seen.

In CTF, because all fertilizer, seed, chemical, and machine traffic was linear with the crop rows, misapplication shows up as yield variance between rows and the Recker number can be very closely estimated. Data collected by Bob Recker showed a yield difference of 30 bu/acre in one maize field of The Mitchell Farm last year which had an absolute yield of over 200 bu/acre.

In CTF, remote sensing offers a promising means of nearly direct measurement of the Recker Number.

The Recker Number

The ratio of actual yield to the yield that would have been achieved by all operations completed with uniform target application is known as the Recker Number.

$$\text{Recker} = Y_a/Y_t$$

The defining feature of the Recker Number is the lack of downside yield risk associated with efforts to improve upon it. Unlike precision farming practices that employ intentional variable rate application, solutions for uniformity do not depend upon large geospatial data sets, complex agronomic models, and estimated yield response curves—all of which carry error possibilities that add unique risks. On The Mitchell Farm, efforts to improve the Recker Number carry high expected returns, primarily through more uniform fertilizer application.

Basis for intercropping solution

We can think of strip-intercropping* systems that improve sunlight utilization as expanding our land base in proportion to the Land Equivalent Ratio (LER): The total area of sole crops required to produce the same yields as would be obtained when they are intercropped. The total land-equivalent ratio is the sum of the partial land-equivalent ratios of each component.

Today, in a special circumstance, the set of conditions which define the universe of incremental effects of strip-intercropping are a highly fortuitous convergence of "happy accidents," which has very suddenly made strip-intercropping economically optimal for the two crops that are in both area and value, the most important in the United States: corn and soybeans. Moreover, these special conditions allow gains in LER without an expected increase in yield volatility and without increased operational costs—a pure arbitrage opportunity.

Happy accidents leading to sunlight arbitrage

- Multiple crops as good rotational partners
- Taller crop more valuable than the shorter crop.
- Taller crop C4 photosynthetic process and shorter crop C3 photosynthetic process.
- Both crops optimally planted and harvested on one swath width.
- Intercrop rotation's soil erosion less than soil erosion of mono-crop rotation.
- Both crops available with same set of herbicide resistance.
- Automated guidance available with sufficient accuracy to separate planting and harvest operations for each crop without giving up area.

Table 1. Difference in sunlight utilization between C3 and C4 crops in selected characteristics

Species	**PS pathway**	**gDW/mw/week**
Maize	C4	47
Sorghum	C4	43
Sugarcane	C4	50
Spinach	C3	13
Tobacco	C3	25
Alfalfa	C3	20
		tons/acre
Maize	C4	3.02
Sugarcane	C4	3.67
Rice	C3	2.28
Tobacco	C3	.30
Soybean	C3	.28

Characteristic	**C3**	**C4**
Leaf anatomy	palisade + spongy	bundle sheath
CO_2:ATP:NADPH	1:3:2	1:5:2
gH_20/g dry wgt	450-950	250-350
CO_2 compensation pt.	40-90ppm	2-15ppm
Photorespiration	Yes	No
Temperature optimum	18-25C	30-45C
Dry matter production (tons/hectare/year)	20	40

Importance of herbicide resistant crops

Traditionally, in strip-intercropping each crop strip has to be treated individually. With at least a doubling of required field passes at a per pass cost of $4/acre, strip-intercropping incurs direct incremental production costs of at least $4/acre. Strip-intercropping also narrows available herbicides by non-viability of volatile herbicides, such as Clarity or Banvel, potentially raising herbicide costs and reducing efficacy. Having fewer herbicides to chose from compared to monocropped fields of the same crops means that herbicide options will potentially be more expensive, less effective, and have lower crop tolerance. The inverse and converse will never be true.

More importantly and with much associated risk, uncertainty, and unpredictability, weed competition from incomplete spray coverage or damage from herbicide drift at the strip boundaries reduces boundary yield, precisely where the interactions between the multiple crops are intended to bring yield gains from strip-intercropping. Border rows in a 10 ft swathing system with 30" row spacing can represent over half of total system yield - all of which is at risk when applying crop-specific herbicides.

With herbicide tolerant crops, application passes, timing, cost, and efficacy are the same as in monocropped fields of herbicide tolerant crops. Moreover, such herbicide tolerant crops are generally cheaper and safer to treat than conventional crops. The largest incremental risk associated with strip-intercropping is vanquished.

Table 2. Herbicide resistant crops by registration date

Crop	Bromoxynil	IMI group	Glufosinate	Glyphosate	Sethoxydim	SU group
Alfalfa				2003		
Canola		1999*	1999*	1999*		Canada
Maize		1992	1997	1998	1995/96	
Cotton	1998			1997		
Flax						Canada
Potato				2002		
Rice				2003		
Soybean			1998#	1996		1993
Sunflower		2001				
Sugar beet		2002	2000**	2000**		
Wheat		2001	2005	2003		

Some herbicides are labeled for use across a variety of crops which may be intercropped. For example, the following chemicals may be applied to conventional corn and soybeans: alachlor, sencor, dual, prowl. However, no combination of these chemicals provides affordable, full-spectrum weed control, and crop safety. Therefore, in traditional strip-intercropping, at least one separate pass must be made to treat the corn and soybeans separately. While strip widths may be between 10 and 30 feet, sprayer boom widths are commonly between 60 and 120 feet. Because each strip must be covered individually when spraying crop-specific herbicides, the number of additional passes required increases by 2 to 8 times.

The enabling guidance technology for strip-intercropping

Without automatic guidance, it is usually necessary to plant each crop at the same time with the same planter, generally in a split-planter configuration. Alternatively, visual cues can be used when no-till intercropping into discernable rows. Mean reverting influences upon proper row placement are weak, and crop swaths will eventually result in crossing of the crop borders unless a very narrow fallow strip is added to the border.

On The Mitchell Farm, automatic guidance with RTK precision is used to plant and harvest the maize and soybean strips non-sequentially, and to further gain the benefits of precise placement of fertilizer strips relative to corn, 15" soybeans between old corn stalks, and CTF where only 17% of the ground surface is tracked. All machines on The Farm operate with RTK-level autosteering.

Switching from conventional farming includes the cost necessary to meet the minimum requirements: a tractor with RTK autosteering and an integral planter or planter with centimeter-level implement guidance, whose planting width is an even multiple of the combine header widths. Synergy with no-till/ strip-till and CTF mean that operational costs and machinery capitalization for intercropping farms will be lower than for conventional farms. Notably, each machinery feature necessary and useful for intercropping is also useful in best management practices for monocropping.

*Definitions

Strip-intercropping is an easily confused term because of confusion with "strip-tillage" and with other methods of intercropping.

- *Intercropping* is growing two or more crops simultaneously on the the same field with the intention of benefitial interactions between the crops. The crops can be interspersed in either time or space.
- *Mixed* or multiple cropping is the growing of two or more crops simultaneously on the same field without a row arrangement
- *Relay* cropping is the growing of two or more crops on the same field with the planting of the second crop after the first one has completed its development
- *Row* intercropping is the growing of two or more crops simultaneously on the same field with a row arrangement
- *Strip* intercropping is the growing of different crops in alternate strips of usually uniform width and on the same field. It has two types; contour strip cropping and field strip cropping. Contour strip cropping follows a layout of a definite rotational sequence and the tillage is held closely to the exact contour of the field. Field strip cropping has strips with uniform width that follows across the general slope of the land.

Intercropping effects on nutrient needs

Preliminary data from strip-intercropping maize and soybeans shows >25% increase in yields of maize border rows with a concurrent decoupling from phosphorus limitations. Recent advances in crop genetics and production technology make row-intercropping (wherein border rows become interspecific on both sides and every row becomes a border row) viable while an increasing maize/soybean value ratio makes the tall-crop favoring system attractive.
Overwhelming evidence suggests that row-intercropping offers a means to increase the percentage N derived from N_2 fixation.

IMPROVING N UTILIZATION

Applied N

Over 12 million tons of nutrient N are applied to cropland in the United States annually, with half going toward maize production (USDA-ERS, 2006). It is now estimated that applied N to cropland is now great than that from combined natural sources (Vitousek, 1994). The energetic cost of synthesizing N fertilizer through the Haber–Bosch process is 27 GJ t^{-1} NH_3 (Smil, 2001).

N benefit in intercropping

If the intercropped non-legume is taller than the legume, shading will occur and photosynthesis and subsequent N_2-fixation will be reduced (Hardy & Havelka, 1976). Because per plant photosynthate but not canopy level photosynthesis is reduced under higher crop densities, N_2-fixation is similarly reduced under high densities on a per plant but not on a per area (Waters et al., 1998).
Whereas early season N application does not usually increase soybean yields, N fertilization during pod-filling can result in significant yield gains with nearly all applied N translocated to the seed (Afza

et al., 1987, Taylor et al., 2005), or no yield effect whatsoever (Barker & Sawyer, 2005, Schmitt et al., 2001).

While experiments have shown 15% of the N in N_2-fixing soybeans could be transferred to intercropped maize through deposition as ammonium, amino acids, and sloughed-off cells during the growing season, for other legume/non-legume intercrops no field-level transfer is found even though it may be found in the laboratory (Hauggaard-Nielsen & Jensen, 2005). While focus on improving N utilization in intercrops usually focuses on the legume, the choice of non-legume can have pivotal effects. Biomass, grain yield and N acquisition of faba bean were significantly increased when intercropped with maize, and decreased significantly with wheat, irrespective of N-fertilizer application, indicating that the legume could gain or lose productivity in an intercropping situation (Fan et al., 2006).

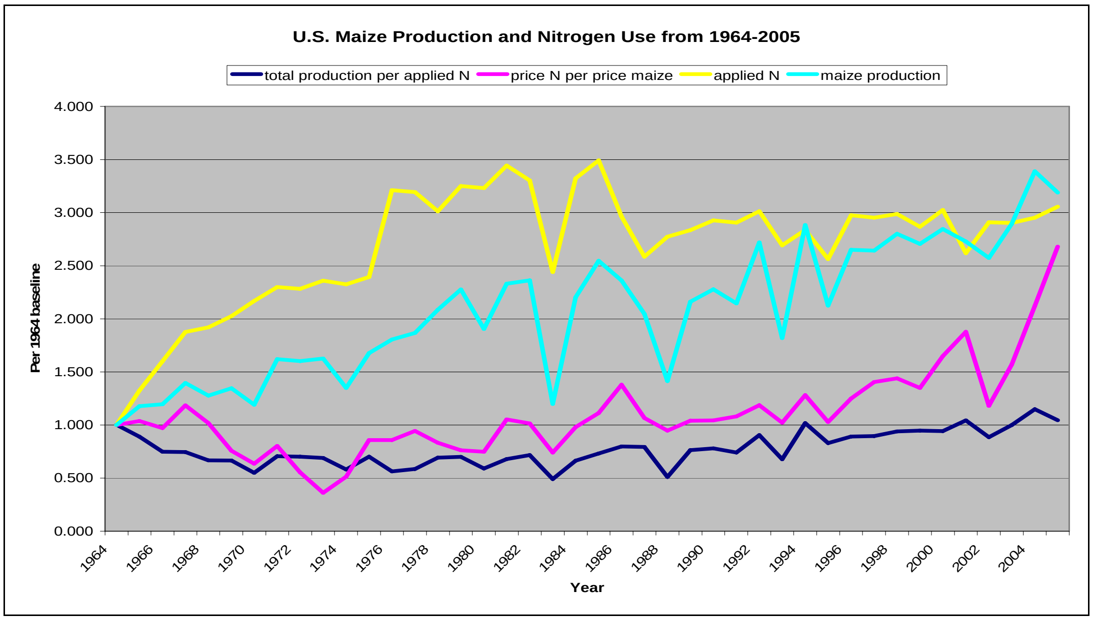

Figure 1 Maize production and price compared with N applied to maize and N price, all compared to 1964 levels. Maize production and total N applied have both tripled. The price of N compared to the price of maize has also nearly tripled. Efficiency of N use (ratio of total maize production to total applied N) has remained relatively unchanged since 1964 (USDA-ERS, 2006).

Fungal explanation

While direct transfer of N from soybeans to maize through common mycorrhizal networks (CMN) has been shown (van Kessel & Hartley, 2000), most evidence shows that meaningful quantities of N are only transferred indirectly through the AM hyphae (Hauggaard-Nielsen & Jensen, 2005).
Experimental observations have indicated that arginine in AM fungi is usually the principal nitrogenous product accumulated during periods of ammonium feeding at the uptake site, providing support for the importance of these amino acids in N transfer between fungal and plant cells (Chalot et al., 2006).

For endomycorrhizal networks between maize and soybeans, uptake by the receiver plant of the N excreted by the donor plant root system appears to be the mechanism of N-transfer between plants rather than transfer through the fungi, and the transfer is highly dependent on the degree of contact between the root systems (Hamel et al., 1991). However, the fungi do play important rolls in reducing N loss from soybeans while improved the ability of the maize to recover N lost from soybeans with overall improvement in N use—an effect that would not necessarily be experienced differently under intercropping compared to sole-cropping.

Increased fixation due to soil N depletion

Rather, than transfer through CMN, the explanation for N benefits in intercropping appears to be that the % N due to fixation by the legume is greater in the mixed crop because the non-legume effectively drains the soil of N (Hardarson & Atkins, 2003, Li & Zhang, 2006). Levels of available soil-N influence infection, nodule development, the rate of N_2 fixation, and the senescence of nodules (Hauggaard-Nielsen & Jensen, 2005). With significant uptake by maize of soybean N rhizode-posits, less soil N is available for the soybean to reabsorb and therefore there is reduced N-fixation inhibition within the soybean. When roots have facilitative interactions, soil N depletion forces the legume to fix more N. The increase in N fixation correlates very strongly with total dry matter yield in the intercropping system (Fan et al., 2006).

Glyphosate tolerance

While glyphosate tolerance among both maize and soybeans is the enabling biotechnology for intercropping, it also presents a unique hurdle to optimizing N. Because glyphosate is toxic to the soybean N-fixing symbiont, *Bradyrhizobium japonicum,* N fixation and/or assimilation is slightly affected at label use rate, but consistently reduced at above label use rates of glyphosate and the greatest reductions occurred with soil moisture stress following glyphosate application (Zablotowicz and Reddy, 2007).

Regulation of biological fixation rates

Achieving agronomic benefits from management of the finely regulated and energy intensive processes of biological N fixation through farming practices or breeding, e.g. genetic engineering, can be more reliable in the first effort and achievable in the second through an understanding of the regulation process. The bases for three competing theories are (1) carbon supply at the nodule, (2) oxygen diffusion into the nodules, and (3) feedback inhibition by the product of N fixation (Allaway et al., 2000). Some unification of theories may be found in the critical role that alanine synthesis performs between carbon and N metabolism in bacteroids. While low- and high-density bacteroids secrete similar levels of ammonium, high-density bacteroids secrete alanine and thus have higher total N secretion and carbon metabolism due to synthesis by AldA, indicating an important cross-regulation between carbon and N metabolism (Parsons and Sunley, 2001).

Root distribution interactions

Spatial distribution effects are fundamental root interactions of intercropped species that are easily measured by auger and monolith sampling (Willey, 1979). While the root distribution of maize intercropped with faba bean (*Vicia faba* L.) showed lower increase in root length density than with wheat, the response was consistent with the shallower root distribution of faba bean. The roots of intercropped maize spread under faba bean, and consequently occupied a greater soil volume than sole-cropped maize, providing evidence that agronomic benefits from intercropping can occur from increased lateral root growth and greater root length density due to compatibility of spatial root distribution of intercropped species (Li et al., 2006).

Intercropping N uptake

Because genetic and environmental complexities in a crop setting exceed the categorical decision options perceived by farmers, N transfer is not universally achieved with intercropped legumes and conflicting reports of transfer have been borne out in research. Whereas the N contribution of the intercropped legume to maize has been estimated at 40 kg ha^{-1} (Searle et al., 1981, Wahua & Miller, 1978), others did not find any evidence for such N benefit (Chalka and Nepalia, 2006).

Total N uptake for maize soybean, maize cowpea, maize greengram, and maize blackgram averaged 37.5, 22.1, 18.5, and 17.1% over sole maize in a multiyear study while maize cowpea and maize soybean were superior in reducing N uptake by weeds (Elmore and Jackobs, 1986). An increase in total N of sorghum intercropped with nodulating soybeans was reported, but not when intercropped with non-nodulating soybeans (Fried and Broeshart, 1975). This beneficial effect of the nodulating soybean on sorghum was attributed to transfer of N from the legume to the non-legume

^{15}N techniques

Using ^{15}N-enriched ammonium sulfate, (Kessel and Roskoski, 1988) maize intercropped with cowpea showed lower atom % ^{15}N excess values than the monocropped maize. This was caused by excretion of fixed N by the legume and subsequent uptake of N by the maize. ^{15}N techniques were used to test row spacing effects on N_2-fixation, yield, and N uptake in maize and cowpea at row spacings of 40, 50, 60, 80, and 120 cm and intercropped at row spacing of 40, 50, and 60 cm (Claasen and Wilcox, 1974, Feng and Barker, 1992, Magalhäes and Huber, 1989). Using the ^{15}N-dilution method, the percentage of N derived from N_2-fixation by cowpea and the recovery of N fertilizer and soil N uptake was measured for both crops at 50 and 80 days after planting. Maize grown at the closer row spacing accumulated most of its N during the first 50 days after planting, whereas maize grown at the widest row spacing accumulated a significant portion of its N during the last 30 days before the final harvest, 80 days after planting.

Areas for research

While intercropping is typically viewed as a system for low synthetic N inputs, field-level studies range from no fertilizer N to high fertilizer N, but consistently use uniform application methods that do not attempt to localize the fertilizer relative to the non-legume/legume arrangement (Altier, 1992, 1990, Chalka and Nepalia, 2006, Chu et al., 2004, Dahlan, 1981, Dalal, 1974, Eaglesham et al., 1981, Elmore and Jackobs, 1986, Fan et al., 2006, Gondwe, 1992, Hamel et al., 1991, Hauggaard-Nielsen and Jensen, 2005, Kessel & Roskoski, 1988, Li et al., 2006, Li and Zhang, 2006, Mangoendidjojo, 1983, Martins and Cruz, 1998, Mason et al., 1986, Peters, 1986, Searle et al., 1981, Shen and Chu, 2004, Waterer et al., 1994, YanBo et al., 2005). Agronomic practices such as root-zone banding, and use of nitrification inhibitors and encapsulated fertilizers would present a novel means of matching fertilizer location, source, and timing to the maize/soybean system that is consistent with modern production practices. Managing fertilizer release by encapsulation with polymer-coated urea is just beginning to make inroads in grain production and has been used successfully to delay fertilizer availability for soybeans until pod-fill (Schmitt et al., 2001).

Phosphorus is analogous to N in that both nutrients are known to move through CMN, which is of particular interest in intercropping. Also, both nutrients exist in the soil largely in organic, solution, fixed, and exchangeable form unlike potassium which is largely in mineral form. While nitrate moves primarily through mass flow and phosphorus through diffusion, ammonium moves primarily through diffusion and preferential uptake may be advantageous. The most significant difference is that nitrate leaches readily whereas phosphorus is not very mobile, with most loss occurring in runoff. N is therefore managed with applications intended exclusively for the current crop, whereas phosphorus is applied with regard to its residual effects.

Previous analyses comparing tradeoffs of synthetic N fertilizer to N from legumes attempt to construct absolute value models that include nuances of leaching, a range of rotational options that may include pastures or non-harvested crops, and environmental hazards as far reaching as, eutrophication, global warming, groundwater contamination, and stratospheric ozone destruction (T.E. Crews). However, farm-level decision-making depends not on absolute yield models, but incremental effects on input cost and yield which fully encompass both the economics and scope of management options particular to the farm.

PRELIMINARY DATA

Methods

In order to test the effects of interspecific root interactions between maize and soybeans on phosphorus response, a replicated trial was conducted in 2006 in a field intercropped in 9 m swaths. No-till seeding was done on May 9 with maize planted in 12 rows on 30” centers and soybeans seeded in 24 rows on 15” centers in a North-South orientation. Maize and soybean rows were separated by 22.5”. Four swaths of maize were divided into 800 ft subplots and planted at 3 different populations. N was applied at 4 different rates on sets of 4 rows with all blocks and treatments described in the following figure. Phosphorus was uniformly applied at 150 lbs of nutrient P per acre.

Yield results were harvested by a single row-harvester which collected GPS-based grain flow at 1 second intervals to create a yield map. The harvester recorded cumulative results for each of the 144 rows. For each row, total yield was also recorded by a grain cart with weigh scales. After harvest, soil cores were taken from within each row and combined into 144 representative samples from which phosphorus levels were tested with a Melich-3 extraction method.

RESULTS

The mean yield for outside rows was 242 bu/acre and the mean yield for inside rows was 192 bu/acre. Soil phosphorus varied by row from 9 to 47 ppm. Yield response by row position is shown in Figure 3.

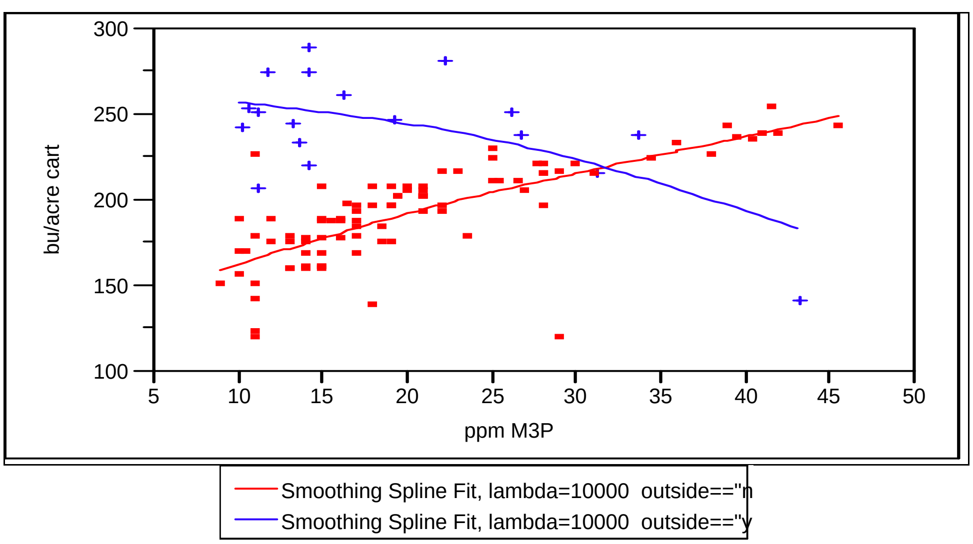

Figure 2. Bu/acre cart by ppm M3P

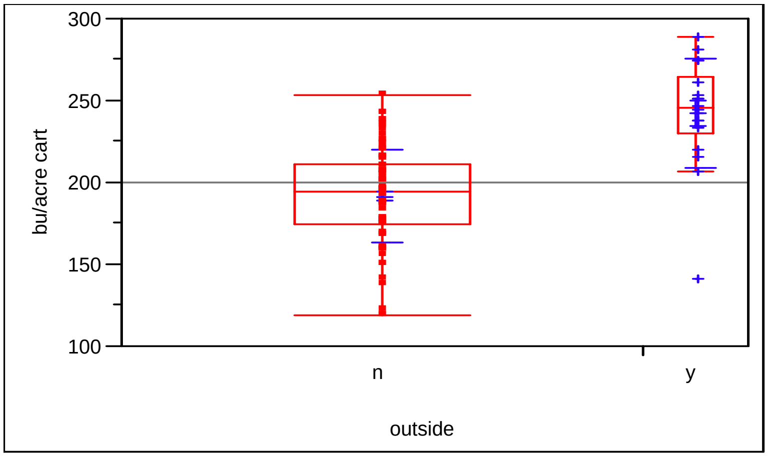

Figure 3. Bu/acre cart by outside

Table 3.Means and Standard Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
n	120	191.7	28.5	3.0	185.7	197.6
y	24	242.3	33.8	8.0	225.5	259.1

DISCUSSION

Phosphorus concentration varied by more than a factor of 5 even though application was intended to be equal. Reasons for variation include field-level geospatial variations as well as multi-year cumulative systematic variations due to imperfect fertilizer application equipment. Phosphorus was strictly yield-limiting for interior rows and showed strong correlation across all yield levels. Yield on outside rows was not only higher than the yield of interior rows, but was independent of phosphorus concentration.

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A High Quality CORS Network for WA

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Landgate is Western Australia's Land Information Authority and custodian of the State's Geodetic Network. The Geodetic Network underpins all spatial data in Western Australia and supports land development through property boundaries; infrastructure utilities - roads, water, power, local government; mining; environmental studies - wetlands, saltlands; hazard management – flood, seismic, sea level monitoring; and general mapping purposes. Landgate has participated in a successful consortia bid for funding through the Federal Governments National Collaborative Research Infrastructure Strategy (NCRIS) for a significant upgrade to Australia's Geodetic Infrastructure. The funding will provide for a National network of 90 Continuously Operating Reference Station (CORS) Global Navigation Satellite System (GNSS) installations. It is contingent on co-contribution funding from participating organisations including Landgate. Landgate will receive funding through NCRIS for 13 sites and will fund a further 13 sites and also provide funding and logistical support for the installation and ongoing maintenance and operational costs of the network. This new network will provide infrastructure that supports research into sea level monitoring related to climate change, atmospheric modelling for improved weather forecasting and crustal deformation/seismic monitoring, possible subsidence due to ground water extraction, and precise satellite orbits for improved GPS services and accuracy. It will also provide the base framework upon which real time services can be developed with applications in surveying and mapping as well as machine guidance/auto steering for engineering, mining and precision agriculture, vehicle navigation and tracking, location based services and speed limiting systems.

Western Australia currently has 6 high quality CORS sites these being Gnangara, New Norcia, Mingenew, Roebourne, Christmas and Cocos Keeling Islands. These sites merely transmit data to Canberra, which is then made available for post processed surveying and research applications. There is also a real time service provided by private industry, operating over the greater Perth Metropolitan area from Binningup to Two Rocks and east to the Darling Scarp.

The new National CORS network initially needs to meet science objectives, hence must be placed near key precision tide gauges – in WA these are located at Hillarys, Broome and Esperance. Note that Hillarys already has an associated CORS but its stability cannot be guaranteed to the same degree as that required for the National Network. Other scientific and design requirements for WA are an East - West Transect at about the Latitude of Perth, coverage of the South West Seismic Zone and the main transportation routes – at a spacing of around 200km. The current network design achieves the 200km spacing in the southwest region, however the sites will initially be more sparsely placed in the northern region of the State. The original proposal to NCRIS had planned 35 CORS sites in WA, however due to funding cuts, this was reduced to 26. Landgate will be looking for opportunities to partner with private industry to achieve the optimal 35 sites. The sites will use the latest technology, high quality GNSS equipment and include a digital metrological station. The antennas will be placed on a substantial concrete pillar linked to bedrock where possible. Gravity measuring facilities will also be established at selected sites.

The rollout schedule is for 5 sites to be established in 07/08 – these will be Broome, Esperance, Kalgoorlie, Albany and possibly Burakin. Then for the following 3 years, 7 sites will be built each year – specific sites for these out years have not as yet been determined.

Figure 1. Map showing WA's proposed CORS Network

Figure 2. Housed receiver and computer equipment

Figure 3. Antenna Pillar

The Landgate WA CORS network will not provide the full suite of end user solutions. Instead the network is designed to provide a high quality multi purpose base framework and Landgate will be looking to private industry to densify the network and develop value add real time services in strategic areas – such as the south west region of the State. Currently these services require a much closer density of around 70km – however as the technology (hardware and software) continues to develop it is expected that the distance from base stations will also be able to be extended beyond 70km. In addition, there are developments in the satellite system arena - GPS Modernisation, Russia's GLONASS revitalisation and proposed new Satellite Systems - Europe's Galileo and China's Compass system are all proposed over the next 5-7 years. These developments also have the potential to improve reliability and extend the distance from base stations for accurate positioning services.

For Landgate the network will provide a modern base framework for the geodetic network in support of surveying and mapping in Western Australia. The proposed involvement of value added resellers to offer services from the network and provide infill sites hopefully will provide Landgate with a revenue stream to fund future equipment upgrades as the technology develops and new satellite systems come on stream.

Figure 4. Map Showing South West Region – Red are existing High Quality Sites; Yellow are the commercial real time network; Blue are proposed new sites

Precision Agriculture for CTF farms

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INTRODUCTION

With CTF and tractor guidance providing enormous improvement in farming systems, many of our clients were asking "what is the next step/leap"? As part of our GRDC funded project, ***CTF Solutions*** evaluated other new technology to increase dryland grain production profitability and sustainability.

After 4 years of research, with 100 co-operators across Australia, successful new technologies include **topography mapping (from 2cm RTK GPS), yield map interpretation, and high resolution satellite imagery**. Other technologies (EM mapping, VRT, PA management zones) provided minimal gains at best.

As well RTK guidance systems are now evolving, where in the near future, fully automated farm recording will be a reality.

TOPOGRAPHY MAPPING

Topography mapping is basically the collection of height/elevation data using RTK GPS (i.e. the same system that is used for guiding tractors). The intense field data collection is made easier by using a 4WD vehicle. Once collected, ***CTF Solutions*** analyses the data using a Geographic Information System (GIS), producing contour maps, elevation maps and slope maps.

The maps are then used to identify problem areas and design layouts for drainage, waterlogging and erosion control. They can be overlayed with other data such as imagery, soils, yield maps or farming operations.

The picture below (Figure 1) shows 10cm contour lines overlaying high resolution (1m pixel) satellite imagery. Areas of poor drainage are shown in dark colours, which are reflected by the topography lines. Drainage works costing $5,000 are generating an extra $50,000 production per annum.

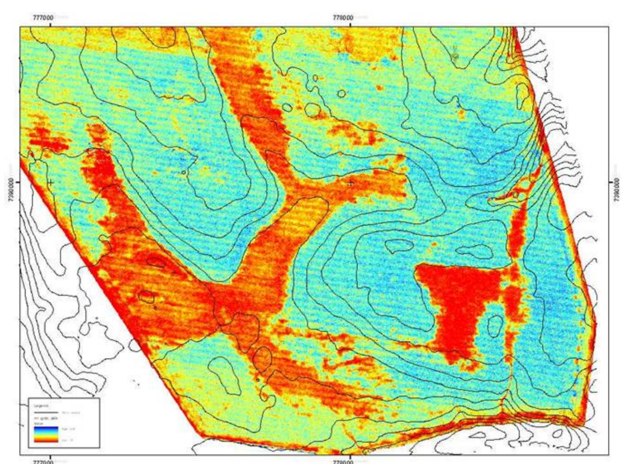


Figure 1

CTF Solutions offers a topography mapping service using our in-house RTK GPS for a cost of between $6-10/ha (depending on conditions). If you have your own RTK GPS (such as Trimble, GPS-

Ag, Ag-Guide, or Beeline) then we can produce topography maps for $2.50/ha using your own data collected when completing a field operation. CTF Solutions can provide advice on farm planning to add value to the service.

YIELD MAPPING

Yield maps have been around for some time, but only a few grain growers are collecting yield data and even fewer are making any sense of it. With CTF and 2cm guidance, the quality of yield maps is maximised.

The yield data below (Figure 2) is from round and round harvesting – not CTF. The darker areas are an artefact of the harvesting, not the actual yield. This is difficult to remove from the data, and any further analysis is flawed if they are not removed.

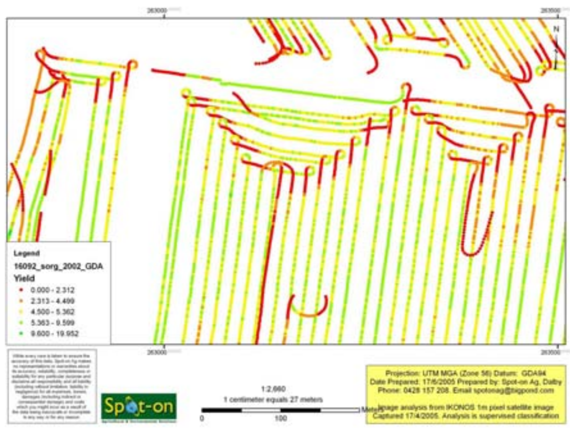


Figure 2

Figure 3 (below) is yield data from a CTF system with guidance. The even spacing of the data ensures its integrity, and further analysis is valid and useful.

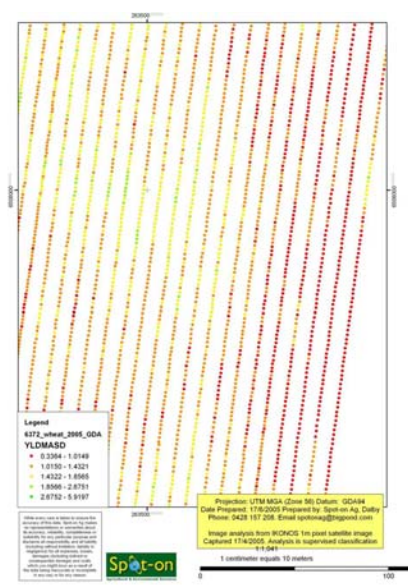


Figure 3

CTF Solutions has developed techniques to overlay yield maps from a number of years to produce **'yield stability' and 'averaged yield' maps**. This helps identify where the most yield variation is, and to understand what is causing the variation. We also know now that there is significant value in properly evaluating your yield maps every season, rather than just filing them for a rainy day!

The average yield analysis (figure 4) highlights a significant problem in the bottom part of this paddock. The darker areas are yielding approximately half as much as the lighter areas in the top half of the paddock (3 years of data).

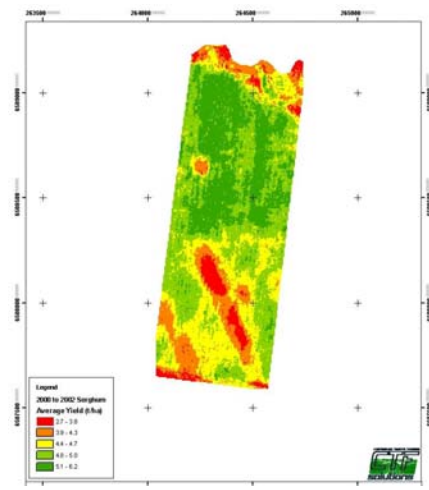
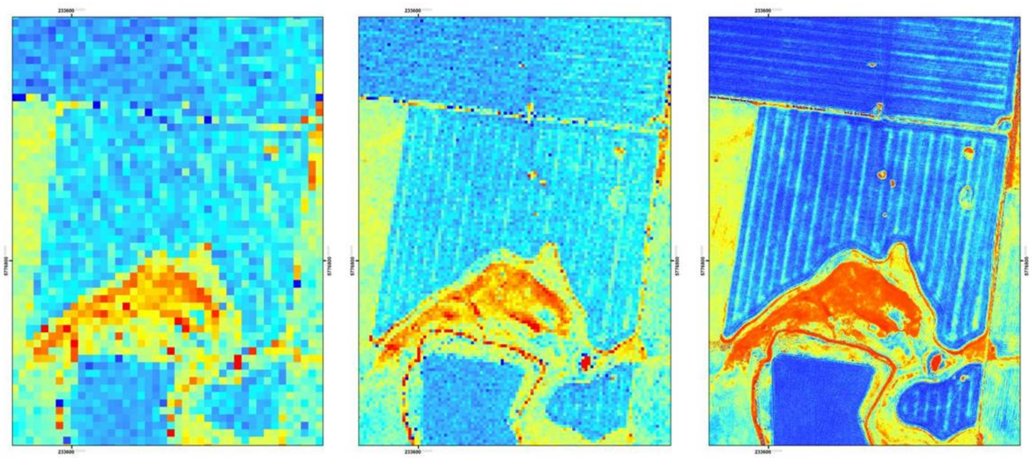


Figure 4

HIGH RESOLUTION SATELLITE IMAGERY

The **most exciting new tool** that we have identified is **high-resolution satellite** (or aerial) **imagery**. A pixel size (the smallest 'piece' of the imagery on the ground) of 1m to 2m is needed to see detail. ***CTF Solutions*** has captured over 750,000ha of high-resolution satellite imagery over grain, cotton, sugar and horticultural farms across Australia. The imagery shows every bit of detail of the crop, and farmer responses have proved its value. The imagery is also spatially accurate, meaning you can go to any point in the image using a GPS unit. This makes ground-truthing of the data simple.

The images below (Figure 5) represent different pixel sizes. You can clearly see responses when high-resolution (1m pixel) is used, and the detail identifies causes. The striping is a result of missed fertiliser.



25m pixel 10m pixel 1m pixel

Figure 5

The image below (Figure 6) shows an area of pest outbreak in a crop of canola. After ground-truthing, an analysis has been conducted to separate the paddock into affected (lighter colour) and non affected areas (darker colour). It was calculated the 20% of the paddock was affected by this particular pest, justifying control costs. With some pests, control can be very expensive, so the only affected areas can be targeted. More precise checking of the outcome is possible as well as monitoring in subsequent years.

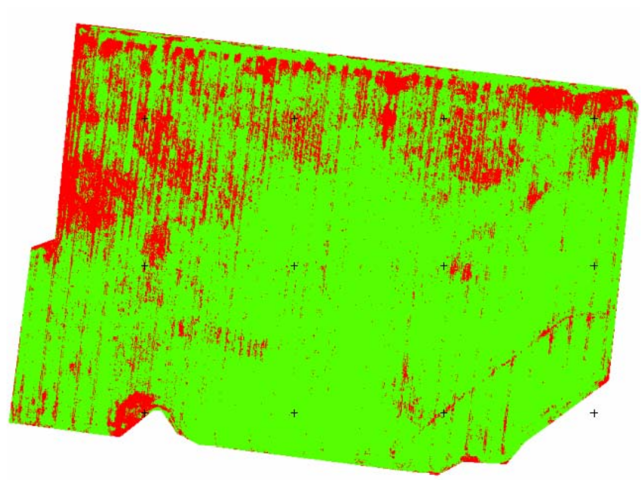


Figure 6

The image below (Figure 7) shows an analysed image and ground truthing information. The areas of good growth (higher NDVI) have higher tiller density and hand harvested yield, than the areas of poor growth (lower NDVI) .

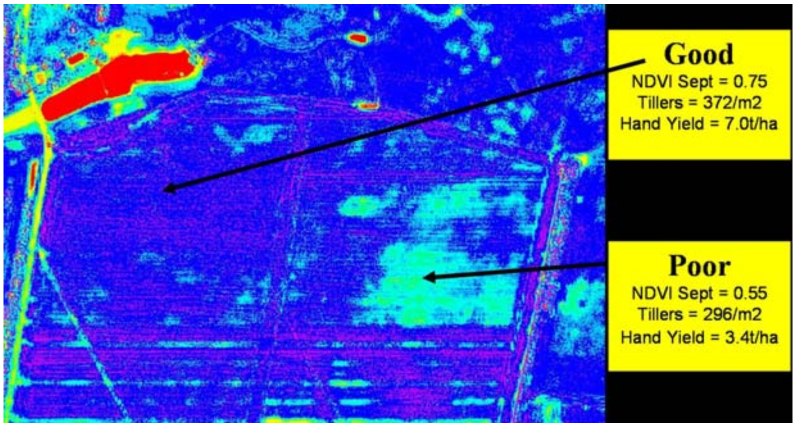


Figure 7

AUTOMATED PADDOCK RECORDING

Using a GPS can give us 'real-world' coordinates for everything we do on farm. Yield monitors were probably the first example of this principle. With yield data we know everything about the harvesting operation, exactly where it was performed. The same can now happen for all operations. Many guidance companies are now combining controllers with their systems to allow full recording of what was done, and exactly where it was done. Even details about machine performance (such as engine temperature, oil pressure, etc) can also be monitored and recorded for fault diagnosis.

Software programs will soon catch up to enable paper-free paddock recording automatically. This is removes the need to spend hours each evening typing in the day's operations into a typical farm mapping and recording program.

Companies such as Rinex, AgLeader, John Deere, Farmworks, Dygron and AGCO have already developed the framework of this principle. Fine tuning in the future will enable this to become a reality. Many of these companies are also developing farm networks, so that the data can be streamed automatically back to the farm office computer for storage and processing without the need for data-sticks or flash cards.

CONCLUSION

New technology such as RTK GPS has taken agriculture a long way in a short time. RTK can obtain detailed topography maps at a small cost. This can dramatically improve your CTF layouts and help manage water logging, drainage and erosion. There are additional pieces of new technology to further refine and fine tune production in CTF systems. The variability at a micro scale (i.e. less than a planter width) has been largely managed by CTF due to the removal of compaction. The next priority is to manage variability across paddocks and farms with the help of imagery and yield mapping. These tools have been shown effective to do this.

Getting the Most Out of your Spatial Data

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INTRODUCTION

Low uptake of Precision Agriculture (PA), despite evidence of economic benefits, is partly due to the uncertainty of how to use spatial data to make management decisions. There is a range of inputs or management which can be varied spatially, such as started fertiliser, top-up fertiliser, herbicides, pesticides, lime, clay or dolomite. The difficulty most farmer face is determining what to vary and where to vary it.

There is a large range of spatial information available which can assist with making these decisions but the key is to understand what the data measures, its pros, cons and costs. The greatest value from the spatial data is gained when it is added to farmers' spatial knowledge and management information and targeted soil sampling. To provide some of this understanding to farmers we have produced a table explaining the value of the more commonly used spatial data for application to PA (Table 1). We have been trialling this process with farmer in workshops, field days and farmer visits and will discuss the process and comments from the workshops.

METHODOLOGY

In 2006, workshops were held with 8 farmers in the Liebe and Mingenew-Irwin Groups in the northern agricultural region of the Western Australian (WA), and at a field day with the Kellerberrin Demonstration Group, located in the central wheatbelt of WA. Farmers were assisted in creating management zones in their paddock by drawing a "mud map" which integrated their own knowledge about the variability of soils and yield across a paddock with other precision agriculture spatial data such as yield maps, electromagnetic survey (EM), gamma radiometrics, biomass imagery, stability analysis, soil testing and interpretation. During the process the farmers were asked to consider the following questions in relation to their own knowledge or "mud map":

- Do they have spatial variation with in their paddocks and by how much does it vary?
- Is the crop performance stable over time i.e. good yielding areas always perform well?
- What do they think is causing the spatial variation and stability?
- What other information do they need to make a management decision?

RESULTS AND DISCUSSION

Do you enough have variability and where is the variability in yield? (See Table 1)

There needs to be >1.5t/ha difference in yield, between the highest 1/3 and lowest 1/3 of the paddock, to manage areas differently (Robertson *et al.* 2006). This information can be obtained from yield maps, monitoring as you drive over the paddock or gut feel. In the workshops the majority of farmers thought they had yield variation greater than 1.5t/ha every year.

Management zones can be created using yield maps and NDVI maps over a number of years of cereal rotations, not using drought years in the analysis. Commonly paddocks are divided into three zones of high, average and low yielding areas, but more or less can be used. In the workshops, the most common form of spatial information associated with PA was yield mapping. Even though 75%

farmers at the workshop had yield maps (some over 5 years worth) and all thought this was the most reliable data source, very few could overlay or manipulate the maps. At the start of the workshop 50% had biomass imagery or considered paying for it, but by the end 90% would buy it.

Where is the variability in soil/landscape – does this relate to yield performance? (Table 2)

Yield potential is related to soil plant available water capacity (PAWC) (Oliver *et al*.2006) which is affect by soil type and rooting depth. Soil type and soil type boundaries are often determined from EM, gamma radiometrics and elevation, but it was found in the workshops that these were the least understood spatial data layers. The rooting depth can be determined from soil depth estimated from a calibration of the gamma signal in lateric landscapes or rooting depth is influenced by subsoil salinity which can be detected by EM. However care must be taken with both methods, as they often require calibration and expert knowledge to validate the data. Soil information is less accurate at determining performance zones but can assist in determining why areas perform they way they do (Table 2).

How stable is the performance in your paddock?

The stability of the paddock can be determined by using a few years of yield maps of biomass images (Adam and Maling, 2005) and areas which have a high coefficient of variation are considered unstable. Areas that are unstable perform well in one year (relative to rest of paddock) and poorly in other years (relative to rest of paddock). If areas are not stable it is difficult to determine how to manage nutrients, however you may still mange other factors spatially such as soil ameliorants.

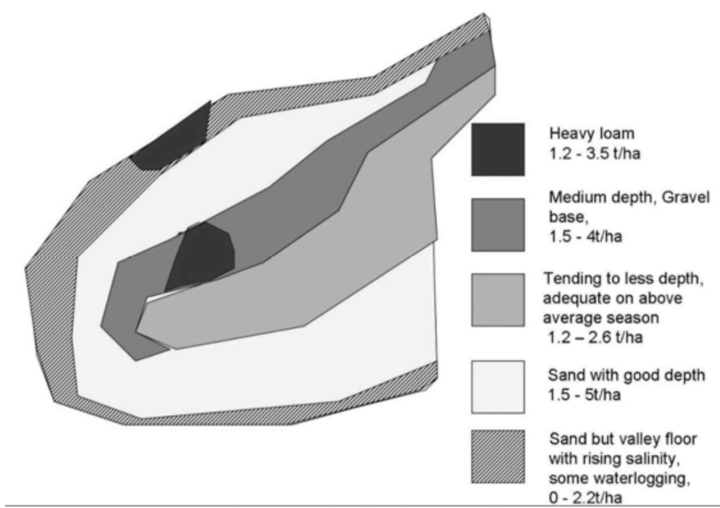

Figure 1. Example of a farmer mud map

What is causing the spatial variation and stability (Table 3)?

The zones were then compared to farmers "mud maps" which included their knowledge on zone locations, range of yield, soil types, soil constraints and management issues in that paddock (example in Fig 1). In the workshop, most thought the variation in yield was related to soil type and some mentioned plant available water capacity. Other reasons included weeds, frost and subsoil constraints. Despite no farmers having a soil survey of their paddock or farms, all could draw a soil map if asked but 62% thought they would acquire a soil map after the workshops.

Some validation of NDVI or yield maps with your mud map is required before they are used to create management zones. These spatial data can have errors due management issues such as double sowing or changing variety mid paddock or seasonal factors such as poor establishment, frost, areas which finished poorly, weeds, disease. Understanding of the season, soils and constraints coupled with a “mud map” can assist in spatial management. For example water logging will affect the yield in wet years which can cause unstable areas, non-wetting will cause establishment problems and low yield, granitic outcrops cause shallow rooting depth and obvious salinity reduced yield.

Do you need to understand the causes of variability?

No – means you will manage the zones according to the current yield potential. It may mean there are no constraints to production, and the areas (zones) are performing to their yield potential based on the soil type. The next step is to soil test in each zone, as this can assist with better macro and micronutrient management compared to bulk soil test for the whole paddock, and then determine the nutrient requirements for your yield potential target.

Yes – means you want to understand why the yield varies as to change management practice or improve yield. Using your knowledge and PA tools to determine poor performing areas, you then target soil and plant sampling in these areas (Table 3).This will help you to understand the yield potential for different soils (or PAWC’s) with and without the constraints and then decide whether it is worth ameliorating or not. If the low yield is due to a site which cannot be ameliorated, is soil types such as shallow soils or acid to depth, then the best option is to match input to yield expectation.

Creating management zones

The creation of management zones can start with your knowledge of the paddock, add a yield maps or two, then bring in other spatial data and targeted soil sampling. The management zones can then be refined as more data (or yield maps) are available and with improved the understanding about constraints to production. This process means that farmers do not need to wait 5 years before managing their paddocks variably, so with farmer knowledge and 1 yield map (or biomass images) variable rate or spatial management can start in year 2.

CONCLUSIONS

The workshop activity to hand-draw a management zone map was to highlight to the participants that managing the paddock spatially does not need a highly technical approach. Often the best tool to start with is an aerial photo and the farmer knowledge of soils and productivity. This can help the farmer make a decision on whether it is worth investing in more technology based information or equipment, for example yield maps. By adding yield maps and biomass map we can add more confidence in these zones or be able to improve historic knowledge by overlay a number of years of information. After the workshop, the main actions by the farmers to improve confidence in zone management were: to find out about soil types (and boundaries) and yield potential, use a number of years of yield maps and overlay other data to create zones, conduct strip trials, and to investigate the cost and ease of yield mapping.

These workshops/field days highlighted some farmers are managing their paddocks spatially without PA technology. The farmers have a wealth of knowledge about their paddock variability from their own experience and often have a collection of PA information under utilised. Following a process like this workshop can assist farmers to integrate their own knowledge with understanding of the PA tools, and increase their confidence to manage their paddocks spatially by thinking about applying the “right inputs” on the “right place” at the “right time” to increase profits.

ACKNOWLEDGMENTS

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Table 1. Defining zones from plant performance – primary data layer in any development of performance zones in a paddock

Observation technique	**How measured**	**Cost**	**Attribute estimated**	**Pros**	**Cons**	**General Pros /cons**
Aerial photo	Aircraft	Orthorectified aerial photo costs approx $500 for a farm of about 1000 ha – or Google Earth	Some difference in crop performance or stubble can be seen Plant establishment/performance from stubble	Useful starting layer, readily accessible Easy to acquire, useful for farm overview	May not give a good indication of yield variation Plant establishment estimation requires the high resolution image which can be costly	
Yield map	Harvester	One off cost for yield monitor (range $5,000 -10,000) GPS cost range $500-$10,000	Yield variation across the paddock	Records actual crop yield Valuable for variable rate This is the plant interpreting the environment	Will not explain why yield is varying Requires some data processing by computer to obtain the maps Will not explain low yield due to weeds or frost	Ideally have few years of yield maps or biomass maps to understand the variability both across the paddock and over time and between crops
Visible/Near Infra Red (NIR) reflectance i.e. NDVI and biomass imagery	Aircraft/ or landsat satellite	~$500-600 imagery but analysis and interpretation cost ($5/ha) for standard resolution It can cost more for higher resolution images	Biomass variation across the paddock Other minor attributes are : Leaf area index, N status, physical damage	Valuable for variable rate as it is the plant interpreting the environment Can obtain a number of years of images without having to wait 5-10 years to get the yield maps Commercially available High resolution images can be useful for diagnosis small scale changes.	Biomass may not relate to yield particularly in poor finishing seasons Weeds may give a high biomass Need to be careful about the date the image was taken High resolution image is expensive. May not always be needed – depends on the scale of the management issue	May not provide understanding as to causes of variation
Zoning and performance analysis	Silverfox or Skyplan	Silverfox analysis $5-7/ha	Zone paddocks based on the variability and performance of the crops (from yield or biomass data) ***AND*** determine the consistency these zones	Can provide management zones to put into the controller. Can determine if a paddock is worth variable rating based on the amount of variation and consistency i.e. if inconsistent patterns occur over time then it may be difficult to variable rate	Correlation between soil parameters and plant performance can be weak	

Table 2. Defining zones from soil information –useful in explaining plant performance but not the primary layer in developing zones

Observation technique	**How measured**	**Cost**	**Attribute estimated**	**Pros**	**Cons**	**General Pros /cons**
Aerial photo	Aircraft or Satellite imagery	Orthorectified aerial photo costs ~$200 for a farm of about 1000 ha for an or Google earth	Soil colour/ boundaries	Readily accessible Simple way of defining soil boundaries that are visible in summer Can show trees, creek lines which may explain yield variability	Poor indication of crop performance as boundaries may not match biological performance May not show all soil types	
DEM (digital elevation model)	Ground survey	Collected when EM or farm surface water control layout is done	Topography	Related to (but does not measure) soil types, water flow, frost, soil depth, water logging potential.	Topography may not always relate to yield	Might define soil zones but does not indicate performance in the zones
- Elevation	Aircraft	Low precision but easy to access		When combined with other information such as soil type or EM, it can be used to explain some of the variation in yield		
	RTK GPS on farm e.g. autosteer	High accuracy and low cost if your controller is capturing data				
EM (Electromagnetic Induction)	Aircraft or ground survey	$5-7/ha to + $7/ha	Soil salinity or Boron content after calibration with soil samples	Can determine the extent of salinity or boron toxicity which are subsoil constraints	Needs to be calibrated with soil sampling	
- Measured bulk soil electrical conductivity (ECa) down to 1.5m			Soil type (clay content), Soil depth and plant available water capacity (PAWC)	May indicate soil type boundaries and this can help determine where to sample Yield potential can be estimated when soil depth, soil type is linked to estimate of PAWC	Requires calibration by soil sampling as high EM could be clay soil or saline soil. Needs marked range of soils or soil depths (i.e. clays and sand).	May assist in determining why areas perform they way they do, but there is often little you can do to ameliorate (e.g. salinity, boron toxicity, soil depth) but you can manage differently
Gamma ray Emission Measures the emission of radioactivity from the top 30 cm of soil	Aircraft or ground survey	$8,000-$12,000/farm depending of mobilisation cost of aircraft without interpretation	Soil type, soil depth and PAWC	Gamma signal is related to mineralogy and clay content User can combine the inferred soil type and soil depth information to estimate PAWC Can obtain data for a larger area easily	Requires specific calibration for different geographical regions Needs a lot of interpretation and calibration	
Other geophysics surveys – ground penetration radar, gravity	aircraft		Geological information such as dykes and faults	Can indicate geological structures which effect water flow across farms. Can relate to areas of saline seeps.Often used in salinity management plans	Needs some interpretation by a hydrologist about what to do	

Table 3. Integration - management zones from plant or soils + farmer knowledge+ targeted soil sampling + analysis

Observation technique	How measured	Cost	Attribute estimated	Pros	Cons	General Pros /cons
Create zones +	**From yield, NDVI, soil or farmer knowledge+**					
Farmer knowledge/ mud map +	Farmer	Your time making observation and driving over paddock in car or tractor	Approximate soil type, boundaries and performance in areas across the paddock Information on weeds, water logging, poor establishment, management etc	Information that all farmers relate to. Can explain variation in yield maps and biomass maps due to management and season such as weeds, frost etc.	If new farm or are not driving over paddock may not have this knowledge May not differentiate plant performance	Provide zones based on understanding the reasons for the variation in yield in a season and how stable these zones are over a number of seasons
Soil and plant survey - Assessment of the performance of crop and soil constraints by point sampling + =	Ground/ person with GPS	Agronomist time (~$160/200/hour) Soil analysis from $40-$80 per site Plant analysis – tissue test ~$x	Soil type, PAWC and rooting depth → Soil chemistry → Soil nutrition → Crop performance survey →	PAWC related to yield potential and therefore appropriate fertiliser rate. A simple observation of rooting depth may indicate suitability of soil for plant growth. Soil chemistry can assist with understanding subsoil constraints if sampled to at least 60cm depth. Nutritional data to determine appropriate rates for N,P and K Can explain variation due to management and season such as weeds, frost and nutrition Ground based observation is at a scale which is appropriate to manage.	May be time consuming and costly Looks only at a point and is difficult to relate to a paddock i.e. does not look at the spatial variation of the yield	Requires some expert knowledge of data processing and agronomy and is complex to interpret the large amount of information
Combination of all the tools and methods	Knowledge of zones and stability c***ombined*** with other data layers to ***target*** soil and plant sampling to diagnose the causes of the variability to make informed management decisions			Provides understanding of the reasons for variation to determine if amelioration is possible to increase yield or what the target yield should be.	Can be expensive and time consuming	

Note : Farmers do not need to wait 5 years before managing their paddocks variably.
The addition of farmer knowledge 1 yield map (or biomass images) can allow farmers to start variable rate in year 2 – As more data (or yield maps) are available then the zones can be refined

OmniSTAR leads CORS Network High Performance Positioning Study for Greater Accuracy

Rosanne Pacecca

INTRODUCTION

OmniSTAR, the market leaders in providing Differenctial GPS solutions via satellites continue to strive to bring greater accuracy and quality of services to their customers. To achieve this goal. OmniSTAR are currently undertaking a Cooperative Research Centre for Spatial information CRCSI) managed and funded study to determine whether having greater 'reference station density' will improve the accuracy and reliability of OmniSTAR's HP position solution.

What do we mean by reference station density? To facilitate OmniSTAR's DGPS services there are twelve GPS reference stations located around Australia. The stations are located to provide optimum coverage for the agricultural user. However, as Australia is such a large continent it is not unusual for a user to be located between 400 - 800 kilometres in distance from a reference station. In this scenario, the reference station density can be said to be sparse.

In recent years, State agencies have introduced their own networks of GPS reference stations in order to better map and manage land and state infrastructure. Collectively these types of networks are often referred to as CORS (Continuous Operation Reference Stations). Victoria has installed the VicPOS / MelbPOS networks, New South Wales have installed the SydNET network, and Queensland the SunPOZ network. These networks are designed so the maximum distance the user will be from a number of reference stations is 200 kilometres. Other participants in this project include the Victoria Dept Sustainability and Environment, New South Wales Dept of Lands, Queensland Dept Natural Resources and Water and Geoscience Australia.

With this study, it is hoped that the OmniSTAR solution can demonstrate 2 - 5 centimetre accuracy, as a result of the higher density networks of reference stations. Curently, the greatest accuracy that is available via satellite transmission is 10cm (OmniSTAR-HP).

So… What does this mean for the user? If successful, the next stage is to investigate how private and public organisation can work together to deliver high accuracy services.

Further information on OmniSTAR is a www.omnistar.com.au. OmniSTAR is a member of 43 Pty Ltd, the SME consortium of the CRCSI.

Controlled Traffic Delivers Soil Structure Benefits at Depth in Cracking Clay Soils

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KEY MESSAGES

- In cracking clay soils, controlled traffic alone could lead to soil structure changes at depth in the profile
- Not all cracking clays behave in the same manner in response to controlled traffic and/or raised beds
- A 10-20mm increase in plant available water in the top 40cm of soil of raised beds was a significant outcome for raised bed crops that frequently encounter water deficits during grain fill. The additional water could deliver yield stability across sub-optimal rainfall years,

INTRODUCTION

Significant land use change from perennial pasture to grain crop production, accompanied by rising productivity, has occurred on a diverse range of soils in high rainfall South-West Victoria (SFS, 2000). This change has occurred partly because farmers have adopted raised beds to overcome waterlogging. Despite well-distributed growing season rainfall, the low permeability of most SW Victorian soils can frequently restrict root growth and water movement, and can cause a severe perched water table (Belford *et al*., 1992).

The work reported here was conducted on two cracking clay soils, classified as Vertisols (Isbell, 1996), that were known to behave differently from each other (Adcock, 1998) both in response to waterlogging and in their crop and pasture productivity. One of them was a black, friable cracking clay (Gnarwarre A) and the other was a mottled olive clay with increasing sodicity at depth (Gnarwarre B). Gnarwarre B was considered to be more hostile to crop growth than Gnarwarre A due to its higher bulk density at depth and low porosity. These characteristics contribute to this soil being more prone to a perched water table under average rainfall conditions. Raised beds were installed on these soils and three crop and pasture systems were managed to best practice over a six year period. Physical characterisation of the soil in the beds was undertaken in the third and fifth years of the experiment.

By design, controlled traffic and minimum tillage are essential components of a raised bed farming system. All the crops and pastures were sown with a single bed seeder fitted with knife points and press wheels, with tractor and machinery wheels travelling only in the furrows. Other than these seeding passes the beds were not renovated or disturbed throughout the experimentation period, despite some compaction by sheep during the pasture phases of the rotations.

Three different rotations were used. They were continuous cropping, two years of crops followed by two years of pasture, and four years of crops followed by four years of pasture.

RESULTS AND DISCUSSION

In 2002 (three years after the commencement of the trial) and in 2004, (five years after commencement) the bulk density, soil porosity and the drained upper limit (field capacity) of soils under the raised beds were assessed and compared with flat, unimproved perennial pasture areas adjoining the beds. This was done in order to understand and describe the root zone that the crops and pastures on raised beds were experiencing.

Results show some of the changes and improvements in the soil measured in, and under, the raised beds. A lower number for bulk density (in grams per cubic centimetre of soil) is better than a higher (heavier) number. If a certain volume (in this case a cubic centimetre or cc) of a soil is heavier than the same volume of another soil, the soil with the higher bulk density is probably more compacted, containing less air spaces (lower porosity) and less able to hold water for plants to use.

The results presented here show that one of the main reasons why farmers should try to improve the soil is that the improvement may increase soil macro-porosity, thus enabling the soil to hold more plant available water. This should improve crop growth and grain fill.

Results suggest that the soil bulk density experienced by crops and pastures was lower on raised beds compared to the flat pasture. The bulk density of the Gnarwarre A soil appeared to improve more than the Gnarwarre B (Figure 1).

(In Figure 1, the soil bulk density on the flat soil is represented by the value zero and the improvements (reductions in bulk density) are shown by the horizontal bars for each soil type under raised beds. For example, the top grey bar shows that at the 0 – 10 cm soil depth, the Gnarwarre A soil under beds had, after 5 years, a bulk density a little over 0.2 grams lower [better] than it did under nearby flat pasture).

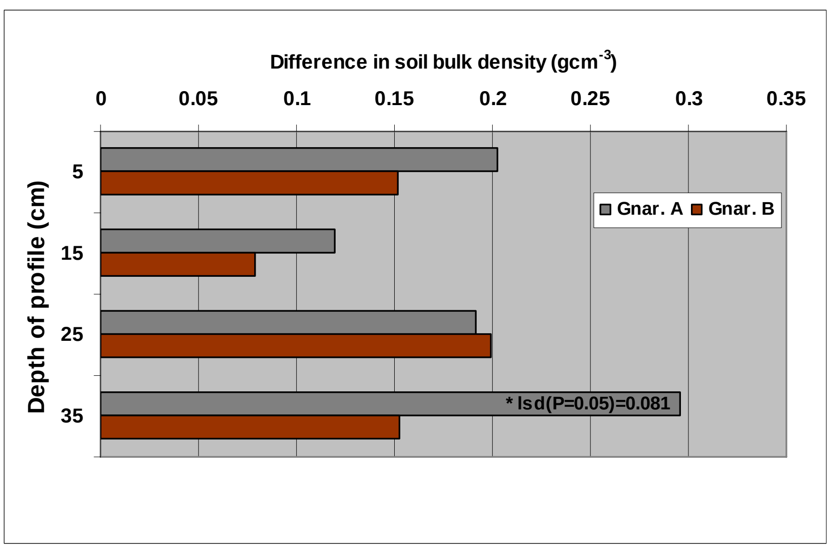

Figure 1. Bulk density of Gnarwarre A and Gnarwarre B soils after five years of raised beds, at four depths, relative to the bulk density of unimproved pastured on flat soil.

It is noteworthy that at the 30-40cm depth in the profile, the bulk density difference was significantly greater in Gnarwarre A compared to Gnarwarre B. The depth at which this difference was noted is below the depth of tillage. This suggests that, when controlled traffic is adopted, some soils may actually be able to reverse or repair compaction, or naturally dense constitution, through both physical and biological processes (McCallum *et al*., 2004).

It is difficult to separate the effects of the absence of compaction from those of biological drilling by plants roots and organisms in the subsoil. But there is wide consensus (Cresswell and Kirkegaard, 1995), that the absence of compaction may be essential for soil biological processes to continue uninterrupted. If this is so, then the fact that the raised beds abolished soil compaction and its harmful effects may be the primary reason for the differences in soil structure measured in this trial.

Greater shrinkage (Adcock, 1998, Loveday, 1972) of the black cracking clay (Gnarwarre A) is likely to have contributed to its significantly lower soil bulk density at depth compared to Gnarwarre B. The wetting and drying cycles in that soil cause a greater depth of aggregate formation (Sarmah et al., 1996) and this can result in a lower bulk density. This effect would have been enhanced by the absence of compaction.

Figures 2 and 3 show changes to soil water storage at depth in the two soils, measured in 2002 and 2004 respectively. The results are from a combined analysis of the different rotations managed on the raised beds since 1999.

(In Figures 2 & 3 the horizontal bars of the graphs indicate the measured difference of the water held by the soils in the raised beds, compared to the flat pasture, at "field capacity" [called the drained upper limit {DUL} in the graphs]. The water held is given in millimetres per each 20cm depth band of the soil. The "field capacity" of a soil is the maximum amount of water it can effectively hold, and is defined as "the amount of water held in the soil just after excess has drained away").

Figure 2 shows that in 2002, after three years of the rotations, the water holding capacity of Gnarwarre A (the black cracking soil) appeared to have decreased while that of Gnarwarre B increased. This was the result of extreme drying following wetting of soil, particularly at the surface layer, leading to the formation of a greater depth of aggregates.

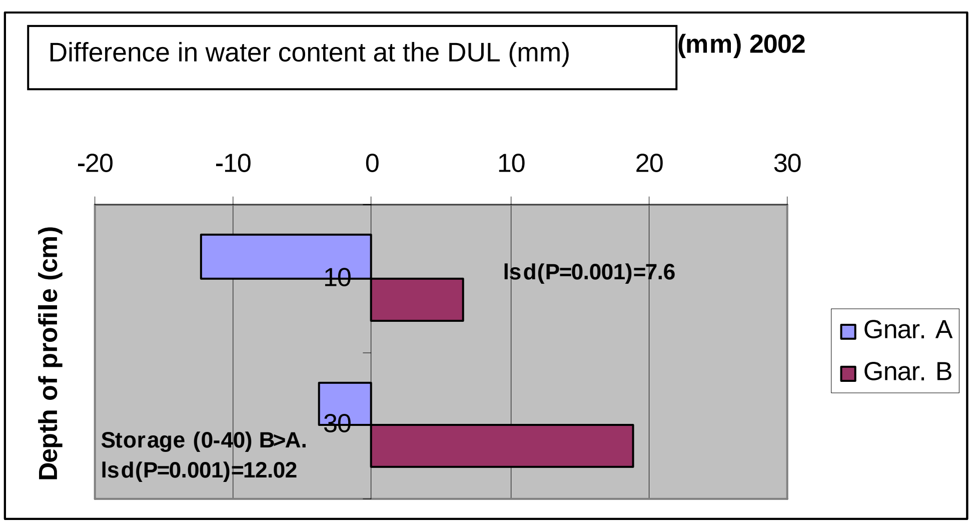

Figure 2. Comparison of the measured differences in soil water storage in the two soils in 2002

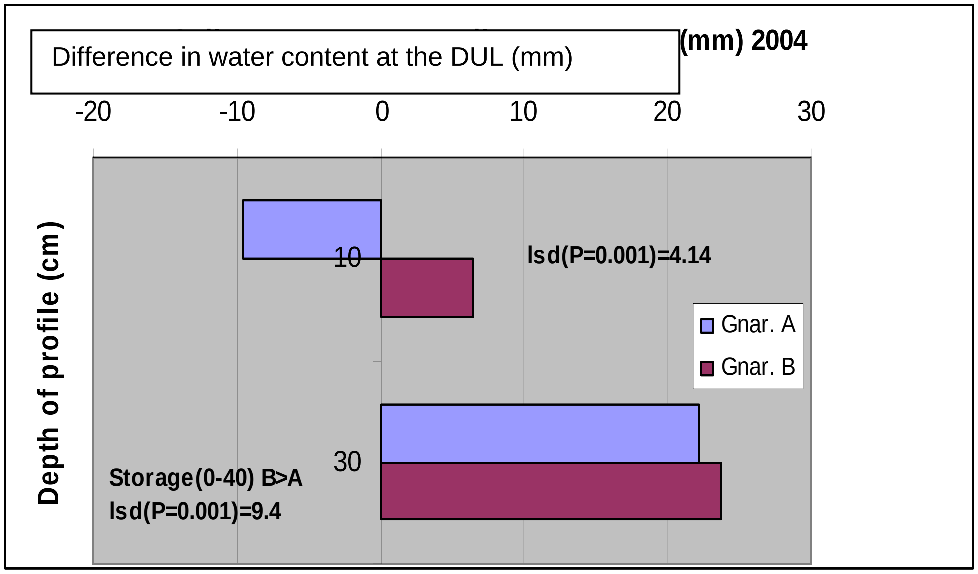

Figure 3. Comparison of the measured differences in soil water storage in the two soils in 2004

It seems that, despite the improvement in soil porosity, the loss of some pore connectivity may have resulted in the decrease of the Gnarwarre A soil's capability to hold water. In other words, the more open, friable nature of that improved Gnarwarre A soil may have made it easier for water to evaporate from it. The difference between the two soils suggests that not every heavy, cracking clay soil would respond similarly to raised beds. In this instance, perhaps controlled traffic alone, (abolishing the compaction without forming raised beds), might have led to a better outcome in the Gnarwarre A soil type.

The situation at the surface of the beds (0-20cm) had not changed much in 2004, three years later. However, below 20cm depth the situation reversed (Figure 3) and both soils appeared to improve their capacity to hold water, resulting in a smaller difference between them.

This is a good result, as crops frequently experience shortages of available water during grain fill. In this trial the crops on raised beds and controlled traffic had an increase in plant available water of 10-20mm, at depths down to 40cm, which is an important outcome.

CONCLUSIONS

Our results show a clear improvement in soil bulk density and plant available water capacity, at depths down to 40cm, in cracking clay Vertisols cropped using raised beds and controlled traffic. The two different soils responded differently to the raised beds and, in the case of the black cracking soil, some of the beneficial outcomes might have been obtained simply by controlled traffic alone. The mottled, olive clay Vertisol, which was considered comparatively more hostile prior to the adoption of raised beds and controlled traffic, appeared to improve more rapidly under the experimental conditions.

ACKNOWLEDGMENTS

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Chemical and Non-chemical Weed Control Opportunities in CTF – A European Experience

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ABSTRACT

This paper describes some of the weed control methods discussed at the 7th European Weed Research Society (EWRS) Physical and Cultural Weed Control Workshop, Salem, Germany 12-14 March 2007 and following study tour including Denmark. Harrowing after sowing wheat and placing nitrogen below the wheat seed were some of the non-chemical methods used. Lower than label chemical rates are also being used in Denmark as advised by an on-line weed control model that is used by 1000 growers and 200 consultants. Controlled Traffic Farming (CTF) allows all these methods due to access to the paddock but the same lines are not used each year due to ploughing. CTF offers the added advantage for Australia since ploughing is not common.

STUDY TOUR OUTLINE

Organic food is in great demand in Germany and Denmark but supply is a problem. Growers are facing increasing weed numbers and the cost of hand weeding is huge. The main focus of the EWRS working group is therefore targeted at organic growers. Papers included thermal (steam or flame) or cultural control with tillage – harrowing, inter-row and intra-row. The latest work involves detecting plants for controlling a physical or cultural method of control, such as gas flames, hydraulic controlled tools or a new rotary disc target the intra-row weeds, particularly for vegetables. Robotic weeders are currently very slow and expensive but this is an exciting area for future development.

The papers from the workshop are available on the EWRS website (www.ewrs.org/pwc).

Interesting points from the three day workshop were:

1. Thomas Bak (www.aau.dk) works in Intelligent Autonomous Farming Systems and he spoke of the problems of current robots being too slow. He has worked on identifying in-row weeds then spraying with fine nozzles (used a commercial cardboard box printer) and used hair removal lasers to target small weeds but with both systems height control is critical and a 3D camera is needed.

2. Alisha Cirujeda gave an interesting paper on using heavy brown Kraft paper (200g/m^2) as mulch instead of plastic for vegetables since the plastic caused a disposal problem for the growers.

3. Bill Curran found a crimper roller most effective for green mulching flowering cereals (best time Zadok 55-60) but was not effective on canola.

4. Johan Ascard described why some non-chemical weed control methods are adopted in practice while others are not. He said men go for “Steel in the field” whereas women like living mulch to reduce weeds. Organic mulches have problems; perennial weeds, field mice and slugs. Band steaming is slow, expensive and high energy use; freezing is slow and expensive; electrical has a safety problem; flaming is expensive, short term effect but fast and reliable; weed harrowing has low selectivity but fast; brush weeders are expensive to purchase; ground driven rotary finger weeders seem to work as

there are lots of brands on the market and torsion weeders have to be setup correctly or crops can be damaged.

5. Pieter Bleeker released a new book "Practical weed control in arable farming and outdoor vegetable cultivation without chemicals", which I purchased. This book has a wealth of practical tips on crops and machinery but mainly covers wide row crops.

Following this I visited Dirk Rautmann (d.rautmann@bba.de) at the Application Techniques Division of the BBA Federal Biological Research Centre for Agriculture and Forestry, Braunschweig. All application technology equipment (granular and liquid applicators) to be used in Germany has to be approved by the BBA. The purpose of the Application Techniques Division is to check plant protection equipment adheres to the Plant Protection Act. The Division also publishes a list of certified equipment for growers to buy.

Rigorous testing which costs manufacturers around €3,000 includes a static spray pattern distribution, which has to have a coefficient of variation of less than 7%, a dynamic test on a vibrating floor and the coefficient of variation has to be less than 9% and a residual test. Voluntary testing is also done for manufacturers and growers. The potential exists that if a grower's sprayer fails the test, the grower's subsidies could be reduced if not brought up to the standard.

Orchard spray drift is a problem and remote controlled shields for one side of an orchard sprayer when on an edge run can reduce drift dramatically (Photo 1). All sprayers are tested on a tilting floor (fore and aft and sideways) to measure residual spray volume in the sprayer (Photo 2).

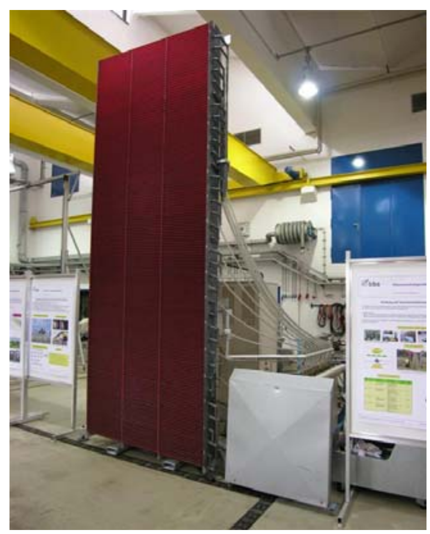

Photo 1. Dirk Rautmann with shielded orchard sprayer and vertical collection system (patternator).

Large boom sprayers are tested for spray pattern variability by bolting to a vibrating floor to simulate field dynamics. Dirk said the room size needs to be upgraded as the 36 m booms currently just fit but wider booms are coming on the market.

Andreas Herbst (a.herbst@bba.de) showed their Oxford Laser VisiSizer droplet size analyser. There still seems to be a problem getting the correct information on nozzle spray quality as he showed, as an example, the company catalogue for the Agrotop Airmix 11003KS nozzle shows medium spray quality but his tests show it as Coarse spray quality, and even Very Coarse at 1 bar pressure.

The wind tunnel is used to measure nozzle spray drift and it has a recirculating air system which has the ability to adjust temperature and humidity. Andreas had developed a technique to wash the spray off the fine food grade tube collectors that stretch across the wind tunnel at various heights (Photo 3).

Photo 2. Tilting floor for spray residual measurement.

Photo 3. Andreas Herbst measuring drift using an ultra-sonic bath (left) and wind tunnel (right)

Arnd Verschwele (a.verschwele@bba.de) works in the weeds section and he showed some outside plots where he is investigating row spacing of wheat for organic farms. He said organic growers are tending to use wider rows to be able to inter-row cultivate. He also showed their glasshouse herbicide resistance testing centre and spray cabinet. Weed seed is germinated on a petri dish then transplanted into small pots, sprayed and placed in a growth cabinet with daily temperature varying from 10 to 20°C. They also have outside pot work where crop competition is tested.

I visited the Research Station farm with Dirk and the Manager, Hermann Scheb-Wetzel, showed us the equipment they use. He has a new Hatzenbichler inter-row cultivator that has components that may be suitable for use in Australia. The five row unit at 75 cm spacing will be used for maize and it had tines close to the row that are followed by two light duty rotary harrows (Photo 4).

They have 15 ha of organic area where no herbicides are used and Arnd Verschwele is testing weed competition with different row spacings.

Photo 4. Hermann Scheb-Wetzel and Hatzenbichler front mounted inter-row cultivator

All the field is ploughed with a mouldboard before experiments are sown. The organic experiment has a rotation of eight different crops; rape, potatoes, field peas (semi-leafless), set-aside (sown with grass, mown several times and ploughed), rye, winter wheat for two years and spring barley. Potassium fertiliser is allowed on organic potatoes and 90 kg/ha of rock phosphate is applied over 3 years. Organic yields tend to be only 60% of conventional potato yields. Farms use non-permanent tramlines for spraying and spreading fertiliser on 20 to 36m tramlines. There was a housing development nearby and Hermann, being a bit of a character, said the most economical rotation in his experience is wheat followed by barley followed by houses.

Denmark

Visited the University of Aarhus, Faculty of Agricultural Sciences, Flakkebjerg. This centre was called the Danish Institute of Agricultural Sciences up until Jan 2007 but has changed due to a number of factors including government funding cuts. The main purpose of the visit was to see the work of Bo Melander who organised the EWRS workshop in Germany but also to see the work of others at the centre.

The reason Denmark wants to reduce pesticide consumption can be seen from the following timelines:

- 1981-85: Increase in use of pesticides, start of public debate
- 1986: First Danish Pesticide action plan – 1986-1997, reduce pesticide use by half, reduce treatment frequency by half, re-evaluation of all old pesticides, reduction should be stimulated by recommendations from advisers and scientists
- Since 1993: Findings of pesticides in drinking water
- 1994: Introduction of prohibition list
- 1996: Pesticide tax increased from 3% to 13% for herbicides and fungicides, 27% on insecticides
- 1997: Status on 1. Pesticide action plan
- 1997-1999: Bichel committee, to investigate the consequences of a partly and total phasing out of pesticides
- 1998: Tax is doubled, 33% on fungicides, herbicides, growth regulators; 54% on insecticides
- 2000: 2.Pesticide action plan

A Treatment Frequency Index (TFI) was developed to have a measure of reducing pesticide use. A FTI of one means one pass of a full dose or two passes of a half dose etc. The 2000: "2. Pesticide action plan" aimed to have the TFI of 2.0 but achieving this may be difficult.

The driving force to reduce pesticides comes from:
- Pesticides in ground water. The policy is to close wells not to purify water.
- 5% of public wells have higher concentrations than 0.1 ug/L.
- 13% of filters from ground water (517) have shown higher values than 0.1 ug/L
- Out of 40 analysed a.i and metabolites 29 have been found in concentrations above 0.1 ug/L

Products prohibited by law include:
- Atrazin, cyanazin, trifluralin, hexazinon, dichlorbenil, MCPA, mechlorprop, diclhorprop, 2-4D, propachlor, isoprotoron
- vinclozolin, iprodion, captan, fenarimol, thiabendazole, thiaphanat-methyl, thiram, guazatine, ziram, dazomet, propineb
- diquat, paraquat,
- dichlorvos, deltamethrin, diazinon, lindane, chlorfenvinphos, esfenvalerat

Met Eric Gallandt (Eric.Gallandt@agrsci.dk) from Main, USA and was on sabbatical working on weeds. He has a student going to do some work on row spacing with weeds and may include row orientation after Shahab Pathan's work in Western Australia.

Peter Jensen (PeterK.Jensen@agrsci.dk) presented his work on spray technology. He is focusing on biological efficacy testing, tests in field and semi-field conditions, spray drift, field testing and operator exposure – cleaning of equipment. They use 100 to 200 L/ha of water and there are a lot of banned chemicals. Some of his work on controlling ryegrass with a foliar acting herbicide at the 2-3 leaf stage found a significant increased efficacy angling the nozzles compared to the standard vertical mounting and the best result was obtained using the largest angling and especially forward angling. Questions remain on: should angling be adjusted to wind direction, can efficacy be improved by increasing the angling more, should boom height be reduced correspondingly, what if a crop was present and what about dicotyledon weed control.

He also mentioned the new Syngenta Hawk nozzle developed for control of small black grass, which is a 03 flat fan nozzle with a built in 40° forward angling (the nozzle cap is still vertical). A problem for Australia could be stubble and Syngenta suggest reducing the straw burden.

Ilse Rasmussen (IlseA.Rasmussen@agrsci.dk) who attended the workshop in Germany showed me the glasshouses, machinery they use and some organic field experiments she was working on with Bo Melander. Weed control in organic agriculture is her main focus and one experiment she showed me involved rotations with different levels of tillage before and after sowing. Permanent buried tubes were used to sample ground water for leachate nutrients. Some work appeared to show where animal manure (slurry) was used the crop tended to compete better against weeds. Denmark has a large dairy and pig industry and all waste has to be stored in tanks over winter for spreading in spring.

Per Rydahl (Per.Rydahl@agrsci.dk), a weed scientist, showed me his on-line spray decision system that includes three steps – assesses the level of control needed, selects single herbicides and calculates dose needed and then calculates tank mixtures and optimises cost. There is a demonstration site at www.pvo.planteinfo.dk in Danish, English and German and he has 1000 growers and 200 consultants subscribing to the site. He said sometimes 10% of the label rate is all that is needed and had not had a failure yet and is very confident with his model. He did not mention the possible increase in herbicide resistance with lower rates. He did say the biggest problem has been weed identification since most chemicals should be applied to small weeds and small weeds can be hard to identify. To help overcome this problem his on-line service includes pictures of at least 75 weed species at various stages of growth and a sorting function based on characteristics such as shape and size of the first leaf.

Bo Melander (Bo.Melander@agrsci.dk) spoke to me about ways to improve weed control by cultural methods such as harrowing before and after wheat emergence (Photo 5).

Photo 5. Harrowing wheat to control weeds (courtesy Bo Melander)

He found injecting animal waste slurry below the wheat seed gave better competitive wheat crops against weeds than slurry applied on top. The hypothesis for the result is the weed seeds that germinate tend to be shallow rooted and by placing the N fertiliser deeper than the wheat, the wheat roots may access the N before the weeds and so grow faster than the weeds. In spring barley he found 20% of the weed control was due to selecting a competitive variety, 30% due to placement of slurry and 80% due to harrowing. He also used inter-row hoeing in spring barley with an ECO-DAN automatic steering system (www.eco-dan.dk) and did inter-row hoeing in winter wheat using a ROBOCROP (www.garford.com) automatic steering system. He found weed biomass was reduced by half in spring barley with 24 cm rows compared to 12 cm rows.

He said vegetable crops have particular problems as weeds can be critical in the early growth of the crop. Intra-row systems include flaming, hydraulic tines, brushing and expensive hand weeding.

CONCLUSIONS

Tramlining or controlled traffic opens up many non-chemical options for weed control that is not possible with conventional farming systems. Operations such as harrowing in wheat and better spray timing are possible with controlled traffic since crop is not damaged by wheels. More work needs to be done in Western Australia on harrowing wheat in stubble to complete some of the work Mike Collins (okuraplantation@gmail.com) started in 2000 (GRDC project DAW617). He found stubble to be a problem and any positive effect was negated by high weed numbers so lower weed densities need to be investigated. Relative weed size to crop was also very important as was the need for dry top soil.

Herbicide resistance is an increasing problem worldwide so some of these current “organic” farming systems may play an important part of an integrated weed control program in the future.

ACKNOWLEDGEMENTS

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The Economic Benefits of Precision Agriculture: Case Studies from Australian Grain Farms

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INTRODUCTION

In commercial practice in Australia the implementation of precision agriculture (PA) has in common the use of spatially-aware technologies made possible through the use of global positioning systems (GPS). Most commonly this includes: the use of vehicle guidance to reduce overlap in application of agricultural chemicals, reduced traffic associated with tramlining to reduce compaction and operator fatigue, shielded spraying of pesticides in row crops, yield monitoring, variable rate technology (VRT) for application of agricultural chemicals, especially fertiliser, and within-paddock zone management for agricultural operations.

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. One of the chief reasons for low adoption of PA is the reluctance of farmers to invest many thousands of dollars in PA without knowing if the technology will return a profit. A number of studies have reported the economic benefits of tramline farming and guidance for chemical application. Few studies have examined the value of variable rate technology and zone management.

In this study we attempt to quantify the economic benefits of PA on six case study farms from the Australian wheatbelt. We did not confine our analysis to VRT alone but also considered benefits to guidance and reduced traffic. A more detailed report on this work can be found on the GRDC website.

THE ECONOMICS OF A PA INVESTMENT

One of the chief reasons for low adoption of PA is the reluctance of farmers to invest many thousands of dollars in PA without knowing if the technology will return a profit. Early PA adopters are often moving into systems based on high cost 2cm accurate GPS auto-steer systems with capital costs ca. $60,000 (Table 1). To potential adopters this seems too expensive and they question the application of PA to their farming system. In Australia the early adopters often crop large areas (above 3000 ha) which means highly accurate auto-steer 2cm systems are a good investment based on 10% savings in inputs from less overlap. GPS costs can range from $800 to $22,000 depending on what accuracy is most appropriate for the operation (Table 1). Highly accurate GPS systems are not an essential piece of the equipment for VRT.

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 (Jennings, 2005). An investment analysis using a ‘discounting’ process has been used to calculate a required ‘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 2 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: Typical configurations and costs for investment in equipment and services for precision agriculture technology

Level of investment	Total cost	Equipment and services
Low	$17,300	Variable rate controller - $3,500 GPS - $800 Zone analysis (using NDVI) - $3,000 Existing seeder variable rate ready 10 cm accuracy auto-steer - $10,000
Medium	$45,000	Yield monitoring and mapping - $7,500 Conversion of machinery to be variable rate capable - $10,000 to $30,000 10 cm accuracy auto-steer - $10,000 Annual subscription - $2,000
High	$75,000	Auto-steer - $32,000 per vehicle 2 cm accuracy GPS - $18,000 to $22,000 Controllers for seeding, fertiliser spreading, pesticide spraying - $16,000 Zone analysis (using NDVI, yield maps, soil testing) - $20,000

Typical gross margin increases required to offset the PA technology costs can be calculated for different regions in the wheatbelt according to statistics of cropped area on farms. For example, grain growing properties in the northern agricultural areas of WA average 3600 ha, of which about 1700 ha is cropped 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 southern cropping areas 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 increase in gross margin will be $3-6/ha depending upon the size of the investment

Table 2: Increase in gross margin ($/ha) required over 10 years 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)
$5 000	500	5
	1000	3
	2000	1
	4000	1
$20 000	500	11
	1000	6
	2000	3
	4000	1

METHODOLOGY

Farm case studies

The farm case studies covered a range of agro-climatic regions (Mediterranean, uniform and summer dominant rainfall patterns), cropping systems (wheat-lupin, wheat-canola, and winter and summer crops), farm sizes (1,250 to 5,800 ha cropping program), soil types (shallow gravels to deep cracking clays), and production levels (average wheat yields from 1.8 to 3.5 t/ha) (Table 3). The farmers had been involved in PA from 2 to 10 years and covered the range of PA technologies that are commonly used by Australian grain farmers. Among the six farmers, all had invested in guidance and were practising some form of variable rate management of fertiliser. However, only some were using auto-steer and tramlining. One was using NDVI and another, the GreenSeeker technology for in-season nitrogen management. As such, the data set covered the range of likely situations confronting practitioners of PA in the Australian wheatbelt.

Table 3: Summary details of the six case studies used for this analysis.

Farming family	*Location*	*Cropping program*	*Years experience in PA*	*PA technologies used*
David and Christine Forester	Casuarinas, WA	2,600 ha of wheat, barley, lupins	9	Guidance Variable rate fertiliser
David and Jo Fulwood	Cunderdin, WA	5,800 ha of wheat, barley, lupins	2	Auto-steer Tramlining Shield spraying Guidance Variable rate fertiliser
Stuart and Leanne McAlpine	Buntine, WA	3,400 ha of wheat, barley, canola, lupins	6	Auto-steer Tramlining Guidance Variable rate fertiliser
Michael and Bev Smith	Moree, NSW	1250 ha of wheat, barley, sorghum, chickpeas, canola, sunflower	7	Auto-steer Tramlining Guidance Variable rate fertiliser and pesticides
Richard and Tammy Heath	Gunnedah, NSW	3430 ha of wheat, barley, fababean, canola, sorghum, maize, sunflower	8	Auto-steer Tramlining Guidance Variable rate fertiliser In-season NDVI
Rupert and Claire McLaren	Barmedman, NSW	4000 ha of wheat and canola	10	Guidance Variable rate fertiliser In-season NDVI

Data collected and analysis

Each grower was interviewed and information was collected on: area of cropping program, crops grown, area of the cropping program to which PA technologies are applicable, average cropping gross margin, PA equipment purchased, included date and cost, management actions associated with PA technology implementation, the estimated reduction in overlap for tramlining / guidance, the rates of fertiliser applied in each zone for zone management, areas of management zones in each paddock, rates of fertiliser applied for uniform zone management, yield in each management zone, and growers' opinion of non-monetary benefits of PA.

Standard economic analyses were applied including gross margin calculations and discounted cash flow analysis. We used an investment analysis to estimate when the initial investment in PA would have been paid off. Annual benefits and costs attributable to PA were listed in time order when they occurred, adjusted for inflation using the Consumer price Index and accumulated from the time of entry into PA. The experience of Western Australia Department of Agriculture and Food staff, encapsulated in a spreadsheet calculator (Blackwell and Webb 2003), was used in this study to quantify benefits of tramlining and guidance gained through reduction in fuel, fertiliser and chemical use and more efficient use of labour. In each case study, the benefits were checked against what the grower thought the benefits had been.

Estimating the benefits of variable rate fertiliser

In order to calculate the benefit of variable rate fertiliser application, some estimate had to be made of yield on each zone if uniform management had been applied rather than variable rate. Two approaches, arrived at after discussion with the farmer, were taken depending upon the circumstances of each case study. In one type of case, total fertiliser use was unchanged between uniform and variable rate situations (Table 4a). In the other type of situation, all zones were assumed to be nutrient non-limited under uniform management due to high soil fertility status (Table 4b).

Table 4a: Example of assumed yield and fertiliser rates under uniform management when yields and fertiliser rates in management zones under variable rate management are known. In this case the high zone yield potential is assumed to be nutrient-limited and hence increases in yield under variable rate, while the low potential zone is nutrient non-limited and yield increases by 5% due to less "haying off". The medium zone remains unchanged.

Zone yield potential	*Under variable rate management*		*Under uniform management*	
	Grain yield (t/ha)	Fertiliser rate (kg/ha)	Grain yield (t/ha)	Fertiliser rate (kg/ha)
High	3.0	75	2.75	50
Medium	2.5	50	2.5	50
Low	2.0	35	1.9	50

Table 4b: Example of assumed yield and fertiliser rates under uniform management when yields and fertiliser rates in management zones under variable rate management are known. In this case all zones are assumed to be nutrient non-limited under uniform management and hence do not increase in yield under variable rate, with the exception of the low potential zone where yield increases by 5% due to less "haying off"

Zone yield potential	*Under variable rate management*		*Under uniform management*	
	Grain yield (t/ha)	Fertiliser rate (kg/ha)	Grain yield (t/ha)	Fertiliser rate (kg/ha)
High	3.0	75	3.0	75
Medium	2.5	50	2.5	75
Low	2.0	35	1.9	75

RESULTS AND DISCUSSION

Investment in PA

The level of capital investment in PA varied from $55,000 to $189,000 (Table 5), which is typically at the medium to high end of investment for Australian grain growers. When expressed as capital investment per hectare cropped it varied by a factor of three from $14 to $44/ha. The estimated annual benefits from PA ranged from $14 to $30/ha and consequently the investment analysis showed that the initial capital outlay was recovered within 2-5 years of the outlay, and in four out of the six cases within 2-3 years.

Table 5: Summary across six farmer case studies of capital investment in precision agriculture technologies, estimated annual benefits and year when initial investment is recovered.

Farmer	Size of cropping program (ha)	Capital Investment in PA		Annual estimated benefits to PA*	Years to break even
		total $	$/ha	($/ha)	
Forrester	2,600	90,000	35	21	4
Fulwood	5,800	189,000	33	22	2
McAlpine	3,400	65,000	19	21	2
Smith	1,250	55,000	44	30	2
Heath	3,430	95,000	28	24	3
McLaren	4,000	56,000	14	14	5

** EXCLUDING CAPITAL COSTS*

Benefits to variable rate fertiliser

For all farmers we were able to quantify benefits to variable rate fertiliser management, ranging from $1 to $22/ha across the six farms (Table 6). On a per paddock basis, benefits ranged from -$28 to +$57/ha/year. This wide range can be explained in part by two factors. Most farmers varied starter fertiliser as well as nitrogen topdressing, however one farmer (McAlpine) only varies topdressing and the benefits to VRT were lower for him than the other case studies. The degree of within-paddock yield variation also contributed to differences among farms in the benefits to VRT (Robertson et al 2006). The degree of within-paddock variation was noticeably less in the case of McLaren where VRT benefits were on average $7/ha, compared with Smith or Forrester where benefits were >$20/ha. The difference between the average yield of the pre-determined high and low zones was always positive and substantial, suggesting that growers were successful in identifying zones of that perform differentially across seasons.

Table 6: Summary across six farmer case studies of benefits ($/ha) to precision agriculture technologies, in total and separated into categories.

Farmer	Total	Reduced overlap	Fertiliser management	Less soil compaction	Fuel savings	Other
Forrester	21	5	16			
Fulwood	22	13	7			2
McAlpine	21	12	1		4	4
Smith	30	8	22			
Heath	24		20	4		
McLaren	14	7	7			

McLaren was the only farmer who had a deliberate strategy of reducing fertiliser inputs overall upon moving to a VRT situation, whereas others either maintained or increased fertiliser use. In the case of McLaren the reduction of fertiliser P rates was due to a history of P build-up before the adoption of VRT and this necessitated lower rates of P especially on medium and low yield potential zones of his paddocks.

Where VRT benefits were able to be estimated across a run of seasons for a given paddock, it was noticeable that benefits, albeit diminished, still accrued in below average years, such as the 2002 drought. This suggests that, once zones have been defined, benefits from VRT will occur in most seasons.

There were no clear trends for differences in benefit due to crop type, with canola and wheat (McLaren), wheat and lupins (Forrester) performing similarly. In the case of Smith, chickpea gave lower returns to VRT than wheat because of less nitrogen applied on the former.

The methodology for estimating the benefits of VRT requires further testing on paddock-scale data where yields and fertiliser rates are recorded for uniform and VRT-managed strips. Where such studies have been conducted (e.g. Isbister *et al.*, 2005) the benefits recorded are in line with what we have estimated from farmer records.

Other benefits

Benefits due to reduced overlap of spraying were typically in the order of 10% savings on spraying costs. Other benefits nominated by farmers and estimated by us were less fuel use, soil compaction, and hired labour, and timelier sowing (Table 6). Intangible benefits listed by farmers were: the ability to conduct on-farm trials, increased knowledge of paddock variability, increased confidence in varying fertiliser rates, and better in-crop weed control due to shielded spraying. It was noted that no farmer nominated pest management, grain marketing or nutrient budgeting as benefits from the use of PA.

Characteristics of adopters

A clear impression gained through interviewing each farmer is that they were all highly literate in the use of computers, GPS technology, and variable rate controllers, routinely soil tested and kept good farm records. All invested considerable time in setting up their system in the beginning (with considerable teething problems in some cases), but on-going labour demands were minimal. Some did not use a consultant, while others placed heavy reliance on consultants for zone definition, yield map processing and variable rate map production. We also found that, while a number of farmers are trialling VRT in test strips within paddocks, it seems that very few have taken the jump into full commercial implementation of VRT on their farms.

CONCLUSIONS

This study is the first of its kind to estimate the economic benefits of precision agriculture in a commercial context. It demonstrates that Australian grain growers have adopted systems that are profitable, are able to recover the initial capital outlay within a few years, and also see intangible benefits from the use of the technology. While the results here will go some way towards informing the debate about the profitability of PA, it also illustrates that the use of, and benefits from, PA technology varies from farm to farm, in line with farmer preferences and circumstances.

ACKNOWLEDGMENTS

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Remote Sensing Applications in Peanuts: the Assessment of Crop Maturity, Yield, Disease, Irrigation Efficency and Best Management Practices using Temporal Images

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ABSTRACT

The measurement of infrared reflectance from peanut crop canopies via multispectral satellite imagery has been shown to be an effective method for identifying the spatial variability in crop vigour, as well as producing high correlations with peanut yield (r= 0.91**) and pod maturity (r= 0.67**). For peanut growers this information is essential as less than optimum harvest timing can lead to lower quality produce, harvest losses, reduced grain filling and associated lowering of kernel grades, and high aflatoxin infection in years conducive to the contamination, all of which can substantially reduce grower returns. As well as the accurate yield prediction of individual crops, a significant correlation (r=0.82**) was identified between the pod yield of 115 dryland crop sample locations with that of the corresponding normalised difference vegetation index (NDVI) values calculated from satellite imagery for each site. This result is of major benefit to regional, state and even national marketers as currently there is no in-season method available for accurately forecasting the total production of Australian peanuts. This technology has also been effective in identifying irrigation deficiencies, crop disease and now with a four year library of images over intensive peanut cropping regions in south east Queensland, we are able to assess whether the spatial variability identified within any block is inherent or the result of an in-crop constraint.

Keywords: peanut, crop maturity, yield forecasting, multi-spectral satellite imagery, irrigation and disease monitoring.

INTRODUCTION

Within non-stressed vegetation, the spongy mesophyll and palisade tissue leaf structures reflect up to 60% of infrared (IR) light upward (reflected energy) or downwards (transmitted energy) and therefore any limiting factor that may reduce plant health and ultimately the turgidity of these tissue structures, will result in reduced levels of IR reflectance (Campbell, 1996). This variation in IR reflectance, or ultimately plant health, can be measured by a number of remote sensing technologies including multi-spectral satellite and aerial imagery. For peanut, multi-spectral imagery provided by the American owned QuickBird satellite has been used to accurately predict pod yield and maturity within both dryland and irrigated crops (Robson, 2007; Robson et al. 2006; Wright et al. 2005). This information has enabled growers to formulate better harvest regimes in order to maximise quality and yield, whilst minimising the risk of aflatoxin, a toxin produced by a naturally occurring soil- borne fungi *Aspergillus flavus* or *Aspergillus parasiticus* under end of season drought conditions.

As well as the prediction of yield and maturity of individual peanut crops, additional remote sensing applications are being investigated that include the determination of inherent spatial variability that may affect particular paddocks across years, irrespective of the crop grown. Most growers are aware of consistently under performing regions within individual paddocks, whether it is the result of poor soil type or nutrition etc. However, without a method of quantifying the actual area or the ability to form an accurate monetary estimate of the loss of production resulting from cropping within these areas, they still tend to be included in crop rotations. It is hypothesised that remote sensing can provide more accurate prediction of those areas that are inherently poor performing. In addition, with coordinated ground sampling, it is also possible to assess to what degree production is affected and the potential monetary loss of cropping these regions in high risk years. With this information a grower can potentially alter his cropping management to include the planting of more tolerant or short duration cultivars in those under performing regions, or alternatively if the regions are deemed totally unviable, accurately remove them from the cropping system. Another advantage of having a sound understanding of the inherent variability of a particular paddock, is that low vigour anomalies that may occur within a growing season can be easily identified, such as those arising from foliar or soil borne diseases or from less than optimum irrigation. It is further hypothesised that remote sensing, through in season satellite and aerial imagery, may be a viable option for the spatial monitoring of disease ‘hotspots’ or assessing direct plant response to irrigation efficiency.

Australian peanut processors currently estimate total peanut production via the amount of seed they distribute at the start of the season. Although in some years this may provide a reasonably accurate estimation it does not take into account yield and quality fluctuations that may arise from variations in seasonal conditions. It is therefore hypothesised that with the aid of satellite imagery an accurate prediction of total peanut cropping area, as well as an accurate prediction of peanut yield variability can be determined that would provide a more accurate estimate of total peanut yield within intensive cropping regions. This information supplied prior to harvest would be highly advantageous to regional and national marketers for planning decisions regarding end of season handling and forward marketing of product.

MATERIALS AND METHODS

Acquisition and analysis of satellite imagery

QuickBird satellite imagery was selected due to its high pixel resolution of 2.4m and its multi-spectral format (blue 450- 520nm, green 520- 600nm, red 630- 690nm and near infra-red (NIR) 760- 900nm), and was acquired over four years (11 April 2004, 19 Feb 2005, 17 Mar 2006, 2 Mar 2007) near the S.E. Queensland townships of Wooroolin (151 49’05E, –26 24’24S). For this study the images were not corrected for atmospheric variation, however this would be recommended if this application was to be adopted on a commercial scale. All multi-spectral imagery did have a Normalised Differential Vegetation Index (NDVI= (NIR- red)/ (NIR +red), where QuickBird band 4 correlated with NIR and band 3 with red) applied, so as to remove noise errors such as those associated with soil reflectance and shading.

For the determination of inherent variability within specific paddocks, selected blocks were sub-setted from each annual image and segregated into five classes of NDVI value using an unsupervised classification. The classes were then colour coded with Red indicating a high NDVI value and therefore larger crop vigour, followed by Yellow, Green, Blue and then Black indicating low vigour or bare soil. The classifications were then compared to identify if any consistent spatial trends occurred across years and crop types. The annual image data set of Wooroolin was also used for the regional prediction of total dryland cropping yield. Ground samples collected over the last 4 peanut seasons, including 115 samples from crops with 5 different varieties grown in eight separate dryland blocks, were correlated against the NDVI value at each sample location. A supervised angle mapper (SAM) classification was applied to a composite 5 band (red, green, blue, IR and NDVI) layer stack in an attempt to estimate the total peanut cropping area within the confines of the image. This technique extracted all pixels that displayed the same spectral values as those selected from known peanut crop training sites.

For the prediction of yield and maturity via satellite imagery a number of irrigated peanut crops were selected from an additional QuickBird image acquired near the township of Texas, Queensland (central point of image- 151 16’44E, -28 59’49S) (20 Feb 2007). This image was also transformed by NDVI before each individual irrigated crop was sub- setted, classified into the five regions of NDVI and ground sampled as described below.

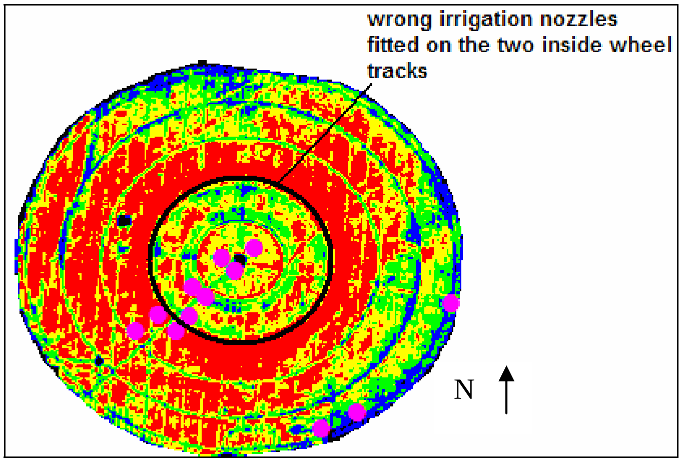
Field validation of QuickBird images

From the classified images, pod samples locations were selected to represent each colour class and located on the ground with a non- differential Garmin GPS (Geographics WGS-84). To compensate with the GPS accuracy of 5 metres, each sample location was selected within a > $20m^2$ area of homogenous colour zone. Three replicate samples were taken per colour zone and consisted of intact peanut bushes and pods from two adjacent 1m lengths of peanut row (i.e. $1.8m^2$). The samples were dried for three days at 40ºC, before pods were harvested using a stationary peanut thrasher. A 200g pod sub-sample was taken and shelled to measure the percentage of pods having a black (i.e. mature) pericarp using the ‘shell out’ method (Mackson et al. 2001), which was then used as an index of crop maturity. The maturity and yield values from each sample location were then correlated against the corresponding NDVI values to identify if any relationship existed.

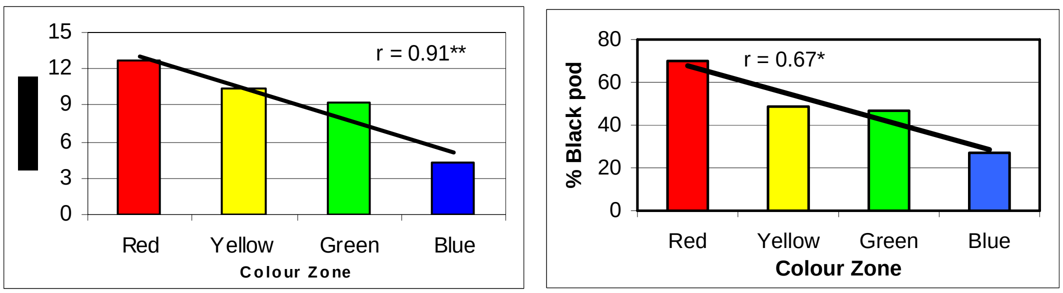
RESULTS AND DISCUSSION

Maturity and yield prediction, and monitoring of irrigation efficiency from individual peanut crops

The ground sampling of an irrigated peanut crop (cv. Holt) (Figure 1a) produced a highly significant correlation between yield and the NDVI value corresponding with sample each site (r= 0.91**, P = 0.000) (Figure 1b). The regions of the crop displaying higher IR reflectance or crop vigour (Red zones) produced a higher yield, in this case over 12t/ha compared to 4t/ha in the Blue zones, a result that is consistent with those previously reported by Robson (2007). For pod maturity, a significant correlation (r=0.67*, P=0.015) (Figure 1c) was also identified with a greater percentage of mature (Black) pods in the Red zone (70%) compared to the Blue zone (27%), a finding that contradicts results previously reported by Robson et al. (2007). Robson et al. (2007) hypothesised that peanut pods growing in low vigour (Black and Blue) areas within dryland and partially irrigated crops matured faster as canopies within these regions provided less shading, allowed more solar radiation to heat the soil resulting in a more rapid accumulation of heat units by the maturing pods. This hypothesis may however be negated in a fully irrigated system due to increased soil water availability and larger overall canopies minimising any variations in the amount of solar radiation heating the soil and hence nullifying the resultant thermal time accumulation effect.



a. Area = 21.9 ha (cv. Holt)



c.

Figure 1. (a) Unsupervised classification of a NDVI derived image of a fully irrigated peanut crop (cv. Holt), Red indicates a high NDVI value or high crop vigour, followed by Yellow, Green and Blue representing a low NDVI value and low crop vigour. The pink dots indicate the sample locations while the black circle encompasses the region where the wrong irrigator nozzles where installed, resulting in reduced crop reflectance. Correlation between measured pod yield (t/ha) (b) and pod maturity (% Black) (c) measured at each sample point against corresponding NDVI value. (* =P≤ 0.05, ** = P≤ 0.01).

By calculating the area encompassed by each classified region as well as the corresponding yield values as determined by the replicated hand samples, then an estimate of total production for each zone as well as for the entire crop can be made (Table 1).

Table 1. Average pod yield (t/ha) measured from the replicated hand samples, the area encompassed by each colour zone and the calculated yield (t/ha) produced by each colour zone. (Black zones weren't sampled as these mainly represented irrigator wheel tracks).

	Red	Yellow	Green	Blue	Black	Total
area (%) of pivot of each zone	38.8	31.5	20.5	7.8	0.3	100.0
area (ha) encompased by each zone	8.5	6.9	4.5	1.7	1.4	21.9
Yld (t/ha) (calc. from hand samples)	12.68	10.31	9.18	4.31	n/a	
Total Yld (t) per zone (area of each zone* hand sample yld)	107.79	71.17	41.33	7.34	n/a	227.64

Table 1 shows that nearly 39% of the crop within this irrigated pivot grew at an optimum level (Red zones) which had an estimated yield of 12.68 t/ha and equated to 107.8 tonnes produced by this zone alone. This production nearly equalled the sum of the other three zones, in which 61% of the pivot only produced 139.8 t. This variation when expressed in monetary terms emphasises the potential loss in production from those regions with less than optimal growth (Table 2).

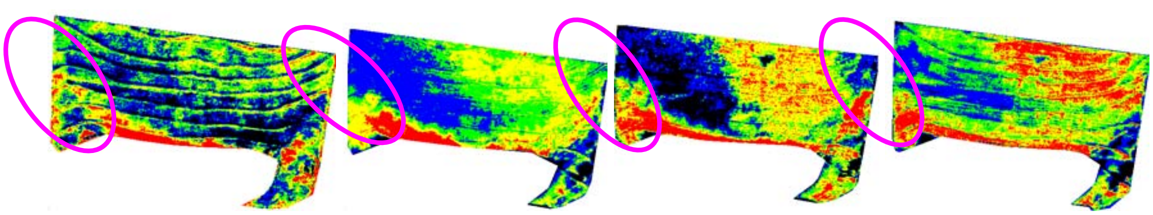
Table 2. Cost estimate on the potential loss of production by those zones showing less than optimum growth

Total Area of Pivot	21.9 (ha)
Total predicted yield from all colour classes	227.64 (t)
Average yield for all colour classes	10.4 (t/ha)
Average yield for Red colour class	12.68 (t/ha)
Total predicted yield if pivot all Red	277.7 (t)
Yield Difference	50.1 (t)

From Table 2, it can be seen that if the entire crop had optimum growth (Red) then the predicted total pivot yield would have been 278 tonnes, or more than 50 tonnes more than the total predicted yield based on the measured variation within each colour zone. In monetary terms, this represents a potential loss of $50,000 (at $1000 per tonne) from under performing regions within the crop. The predominantly Green areas located at the northern and south- eastern areas of the pivot (Figure 1a) are likely to be associated with a poorer soil type, and with the aide of this image to coordinate soil sampling, an agronomist could easily identify the deficiency and offer remedial action. This technology also offers a grower the opportunity to quantify the potential losses experienced by the incorrect fitting of the two irrigation nozzles located closest to the centre of the pivot (Figure 1a), and if appropriate, pursue those responsible for the monetary losses.

Temporal assessment of the inherent spatial variability of paddocks

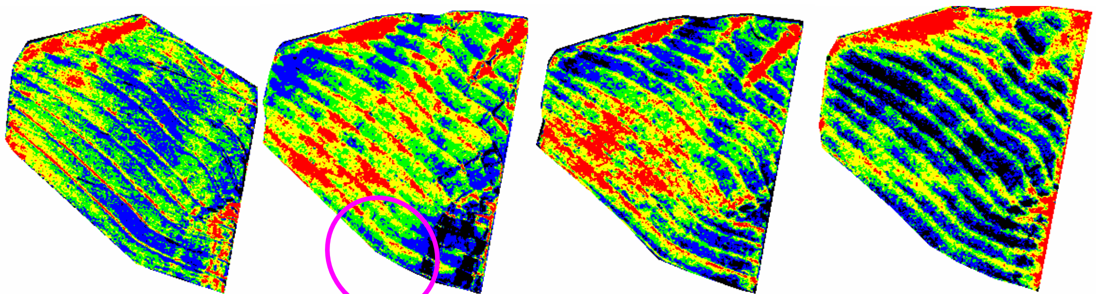
The acquisition of four years of multi-spectral satellite imagery over the intensive peanut growing region of Wooroolin has enabled across season image analysis to be undertaken on specific paddocks for the identification of inherent spatial variability. The left hand side (pink circle) (Figure 2) of the following rainfed block is shown to be consistently underperforming (Blue- Black), most likely a result of poorer soil type, irrespective of whether the crop being grown was peanuts or maize. This information could enable the grower to modify their farming practices by possibly planting a short duration variety in the region more prone to stress, to reduce the amount of time that the crop is exposed to potential yield limiting conditions, or alternatively removing this area from the cropping system altogether if yields are extremely poor. Also, poor performing regions such as that displayed in Figure 2, have been shown to more prone to aflatoxin contamination (Robson, 2007, Robson et al. 2006), so in years where the risk of infection is high, a grower can opt to segregate the harvest, delivering those peanuts that are of a higher risk of being infected and likely to attract a financial penalty, separately to those that may be aflatoxin free.



2007 (peanut) 2006 (maize) 2005 (peanut) 2004 (maize)

Figure 2. A four year (2004-2007) classified NDVI comparison of a rainfed paddock near the South Burnett township of Wooroolin. The pink circles indicate a consistently underperforming region of the paddock that occurs in both peanut and maize rotations.

By having a firm understanding of the spatial variability displayed by a particular paddock, a grower or agronomist, with the aid of in- season imagery, can easily identify any additional stress that may occur within a specific crop during a growing season. This is demonstrated in Figure 3, where the classified image of the 2006 maize crop displays a large area of low vigour (pink circle around Black area) that is not apparent in the images of the same paddock across other years. Following further investigation it was identified that this region of very low vigour was associated with an area of severe erosion brought on by a heavy rainfall event that had washed away germinating plants.



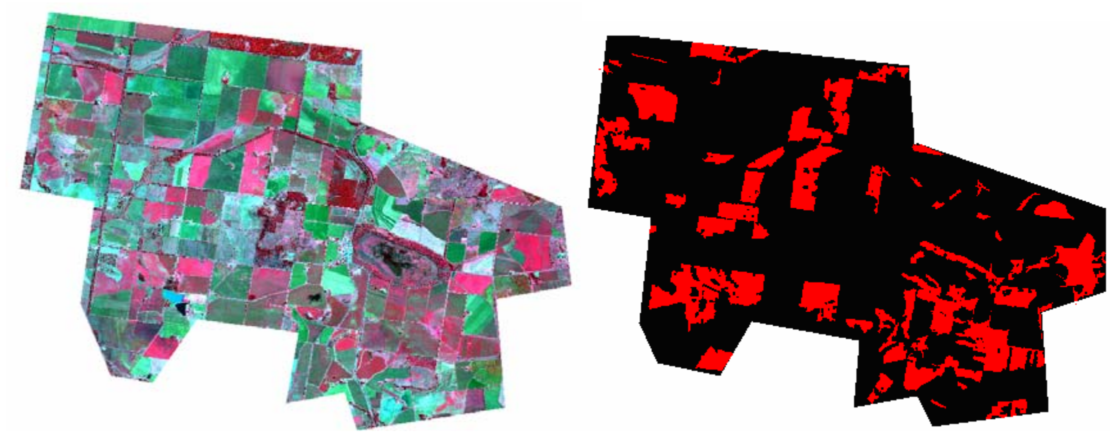
2007 (peanut) 2006 (maize) 2005 (soy beans) 2004 (maize)

Figure 3. A four year (2004-2007) classified NDVI comparison of a rainfed paddock near the South Burnett township of Wooroolin. The pink circle indicates a large region of low vigour that only occurred within the 2006 maize crop and was later identified to be a result of erosion.

Although this low vigour event was the result of erosion and therefore would have been visually obvious to the grower, this technology can provide an exact estimate of the area affected, allowing for decisions such as the feasibility of re- planting to be determined. Similarly positive results have also been identified following foliar disease outbreaks, pest invasion, salinity and even lightening strikes (Robson, 2007).

Regional prediction of peanut cropping area and yield forecasting

Within the rainfed regions of intensive peanut cropping areas of Australia, the peanut canopy displays equal or greater IR reflectance than most other crops in the later stages of the growing season, owing to its lack of maturity related senescence, unlike that displayed by other summer crops (Figure 4a). This feature means that late season acquired images, particularly through the peanut pod-filling stage, can be used to distinguish peanut from surrounding crops and therefore used to accurately measure the total cropping area. This is demonstrated in Figure 4b where a spectral angle mapper (SAM) supervised classification technique applied to the 2004 Wooroolin multi-spectral image highlights (in red) only those pixels that have NDVI values consistent with those predetermined to be representative of peanut crops.



a. b.

Figure 4. (a) False colour image acquired 11 April 2004, of the intensive peanut cropping region near the township of Wooroolin; the bright pink paddocks indicate peanut crops with high IR reflectance. (b) Resultant SAM classification showing peanut crops as red and all other land cover as black.

From the resultant SAM classification, an estimate of total peanut cropping area within the extent ($64km^2$) of this image was 2747.1ha. When multiplied by an average pod yield of 4.3t/ha, based on yield samples from the six crops sampled during the 2003-04 peanut season, the total peanut production for this region was estimated at 11,923 tonnes of peanuts. Although this estimate does suffer some inaccuracy due to some mis-classified pixels and the use of an average yield value, it does provide a more accurate estimate of total yield compared to currently available methods. This prediction may be improved with more specific classification software, as well the replacement of the averaged yield value with values that more accurately represent the spatial variability of each crop.

From ground samples collected from the 2004 to the 2007, peanut crops at 8 separate dryland locations and encompassing five peanut varieties, (cvs. Streeton, VB-97, NC7, Conder and Deakin), a highly significant correlation was identified between pod yield and the corresponding NDVI value for each sample location (Figure 5).

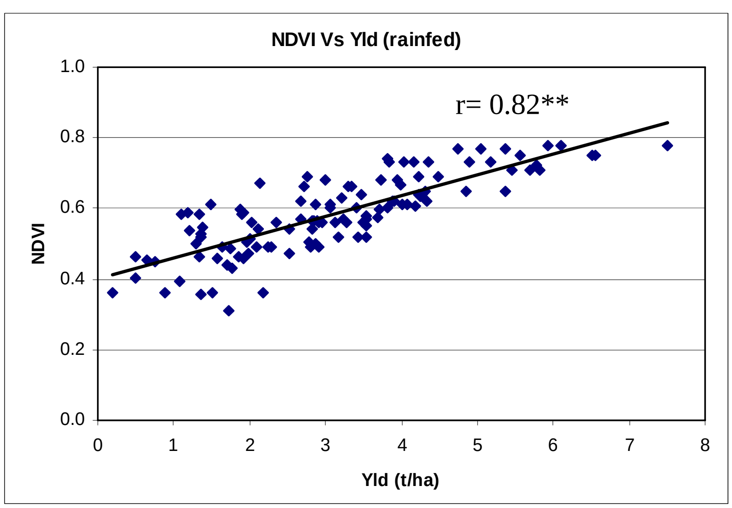


Figure 5. Correlation between 115 ground sampling points encompassing 5 varieties across 8 locations and four growing seasons, and the corresponding NDVI value for each sample point. (** = P≤ 0.01).

This high correlation when combined with the cropping area predictions may enable more accurate regional and even national yield estimates from satellite imagery to be developed. On a regional scale yield forecasts up to 8 weeks prior to harvest could allow better decisions to be made regarding issues such as likely supply, staffing requirements and import needs, while on a national and international scale this application could enable government agencies to establish estimates of likely surpluses or deficits and form food reserve estimates which could ultimately influence decisions relating to trade and emergency aid.

CONCLUSION

The results presented in this paper indicate a number of possible applications that remote sensing and subsequent image analysis offers to the peanut industry as well as other cropping systems. Such applications include: the accurate prediction of pod maturity and yield variability across individual crops, as well as a cost analysis of possible lost production from under performing areas; a total production estimate for an intensive cropping area; the identification of a paddocks inherent spatial variability of crop growth, and the in- season identification of irrigation inefficiencies, and other limiting constraints such as foliar diseases. This information has been well received by peanut growers, agronomists and agribusiness representatives.

ACKNOWLEDGEMENTS

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Does Controlled Traffic Have a Place in High Rainfall, Undulating and Difficult Environments?

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[3]Western Australian No-Till Farmers Association, Northam.

KEY MESSAGE

We have demonstrated the potential for controlled traffic farming (CTF) systems in undulating and dissected terrain, such as occurs in the Avon Valley of Western Australia. While compromising some of the objectives of CTF, a system based around 'multi-width tramlines' is relatively cheap and easy to implement and has benefits in terms of timeliness, efficiency and facilitating zone management. There has been no evidence of water erosion or run-off along tramlines running parallel to the slope to date. Work is continuing to quantify these impacts further and to determine the impact on long-term sustainability.

ABSTRACT

The sustainability of high production farming systems in the high rainfall Avon District of Western Australia is being investigated as a collaborative project between the Department of Agriculture and Food, Curtin University of Technology and the Western Australian No-Tillage Farmers Association. Paddock 30 at Curtin University's Muresk Institute has been selected as the development site for this study with the approach of "putting the system back together".

A CTF system based on 'multiple width tramlines' was adopted in 2005 following initial paddock benchmarking and analysis conducted the previous year. Detailed soil testing, radiometrics and analysis of previous years' yield maps have been used to identify zones of production. A tramline approach is seen as innovative in the district by local growers due to perceived constraints of topography, diverse soils and a medium to high rainfall environment.

Investigations at the site currently focus on the practical elements of the cropping system in this environment. The limitations to yield, the consequences of high production farming on the system and the impacts of management options on production, profitability and sustainability are being examined. In this paper, the progress of the first two seasons at Paddock 30 is described. Practical issues with the implementation of CTF and future activities planned for the site are discussed.

INTRODUCTION

Crop yields in the shires of the central agricultural region's high rainfall (400 to 550 mm) "Avon Valley" zone are historically low when compared to the water use efficiencies achieved by growers in the medium to low rainfall districts to the east (Russell, 2005). In many instances yields are about 60 to 70% of the water limited potential. Some growers in the district are able to achieve yields closer to 80 to 90%, but these are in the minority. In general, shire yields of cereal crops average about 2 t/ha when there is the potential to achieve 4 to 5 t/ha based on French and Schultz (1984) yield estimates.

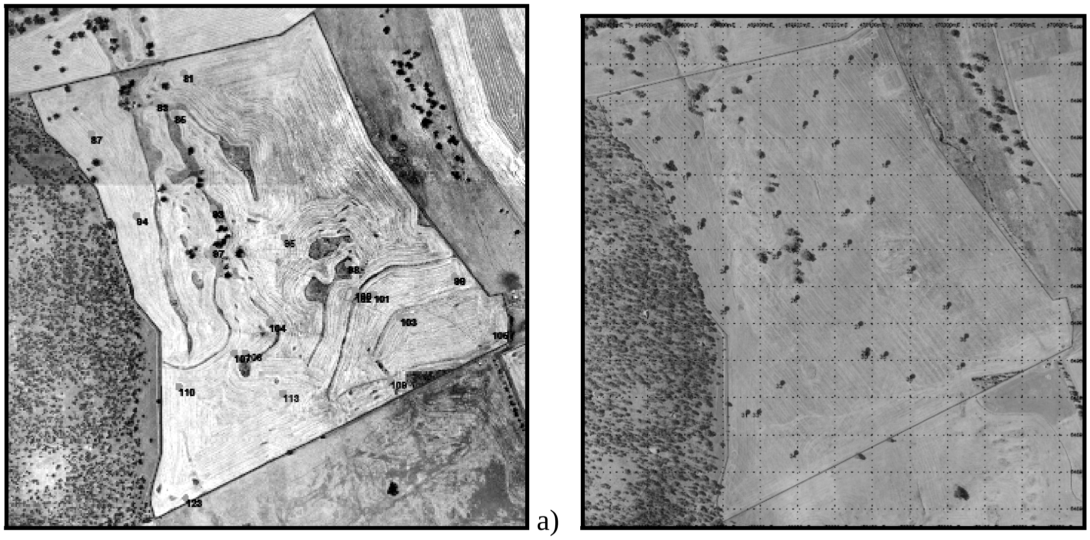
The Avon Valley zone has an area of just over 1.1 M ha of loamy valley and hillside soils. However, being a dissected landscape it suffers from issues such as extreme topography limitations of slope and rock and waterlogging of low lying areas. Farm sizes are also generally small compared to the state averages with the majority being less than 1,000 ha (Russell, 2006). On these farms cropping usually accounts for about 25 to 30% of the landuse, while pastures account for 40 to 45%, yet cropping delivers about 55% of the value of production for the typical farm. Constraints in the size of the farming operation are seen as limiting crop productivity in the district. In addition to this the Avon River itself is a major watercourse that flows into the Swan River. So the Avon Valley can be considered to be an environmentally sensitive region with downstream impacts possible for the urban community in the city of Perth.

CTF systems have not been widely adopted in the Avon Valley. Issues arise with the need for this to be compatible in the physical environment. Constraints are imposed on the adaptability of machinery with the standardising of wheel widths, along with operating stresses and machinery size and the costs of implementation. A possibility to overcome this is to develop landuse priorities for paddocks – those specifically suitable for cropping and those for grazing livestock based on the physical topography and operational size. In the case of cropping, gains in efficiencies of between 5-10% are considered to be made through controlled traffic in seeding and spraying (Webb et al. 2004).

Staff from the Department of Agriculture and Food, Curtin University of Technology and the Western Australian No-Tillage Farmers Association are involved in a collaborative project to assess the sustainability of high production farming systems in the Avon District. The use of CTF is viewed as one component of the system's methodology being used to achieve the aim of lifting crop productivity in this environment. The adoption of contemporary agronomic practices and the diagnostic amelioration of soil constraints to improve soil health are others. As such this is viewed as a test case for this practice of 'putting the system together'.

METHOD

Paddock 30 at the Muresk Institute, Northam was selected to investigate the practical elements of a high production cropping system (Fig 1). It met criteria covering accessibility, had a recent continuous cropping history and detailed records of paddock operations and yield mapping were available. The total paddock area is 89 ha with an estimated 81 ha considered arable. It has a slope mainly down to the north with a slight area sloping down on the south western edge. A water way also runs down to the northwest end of the paddock. Soils are mixed, light loam on the western edge with the balance being loam to clay. Rock heaps are also more prominent on the upslope areas of the southern half of the paddock. Since its cropping history made it likely to have built up a grass weed seed bank, TT canola (*Brassica napus*) cv Stubby was grown in 2004 as a cleaning crop to set the paddock up for the following year. In 2005 and 2006 the paddock was cropped to wheat (*Triticum aestivum*) cv Calingiri. In 2007 the paddock was sown to barley (*Hordeum vulgare*) cv Baudin.



a) b)

Figure 1. Aerial photographs of Paddock 30. a) Pre 2005, showing soil test sites marked for use in an earlier project. The location of now removed contour banks and non arable areas can be seen. b) Early 2006, with additional sampling sites and tramlines now established.

Detailed soil testing had been conducted at a number of sites (Fig. 1a) in the paddock during 2002 by Georgina Warren. as part of the CPSTOF project to develop 'Collaborative planning support tools for optimising farming systems', which was financed by the Australian Research Council (ARC-Linkage programme, LP0219752). These sites plus others were sampled in detail in March 2005 to make up 39 data sites (Fig. 1b) within the crop as sampling locations within the paddock.

In January 2005 a geophysical survey of the paddock was conducted by Geoforce. Terrain, EM31, EM38 and radiometric images were produced. The contour banks that were located up the slope at the southern and south eastern parts of the paddock (Fig. 1a) were removed in April 2005 as were the larger piles of rocks.

Tramlines running northwest–southeast down the longest slope were installed in May 2005. Two guidance systems were used—one in the seeder and the other in the boom spray—a borrowed steering assist programme and a ZYNK GPS, respectively. An ‘A B line’ was set-up to commence operations on the paddock. A variation of ‘multi-width tramlines’ (Webb et al 2004) was created by the best matching of the wheel tracks around the centres of the machines. The widths of the tractor tyres were 1.84 m, the seeder bar 3 m and the boom sprayer 2.4 m. The width of the boom (18 m) being twice that of the seeding bar (8.8 m) allowed for trafficking of every second seeder run. The harvester, while having tyre centres of 2.9 m, was offset as it had a comb width of 6.6 m and so was left out of the system (Fig. 2).

Machinery upgrades have occurred during the normal course of farm operations and a new tractor was purchased having dual wheels in 2007, so the effective width of the tramlines is now 1.4 m each (Fig. 2). This would be in keeping with many of the existing farming operations used in the Avon district and serves as a demonstration to neighbouring farmers as to how to adopt similar transitions.

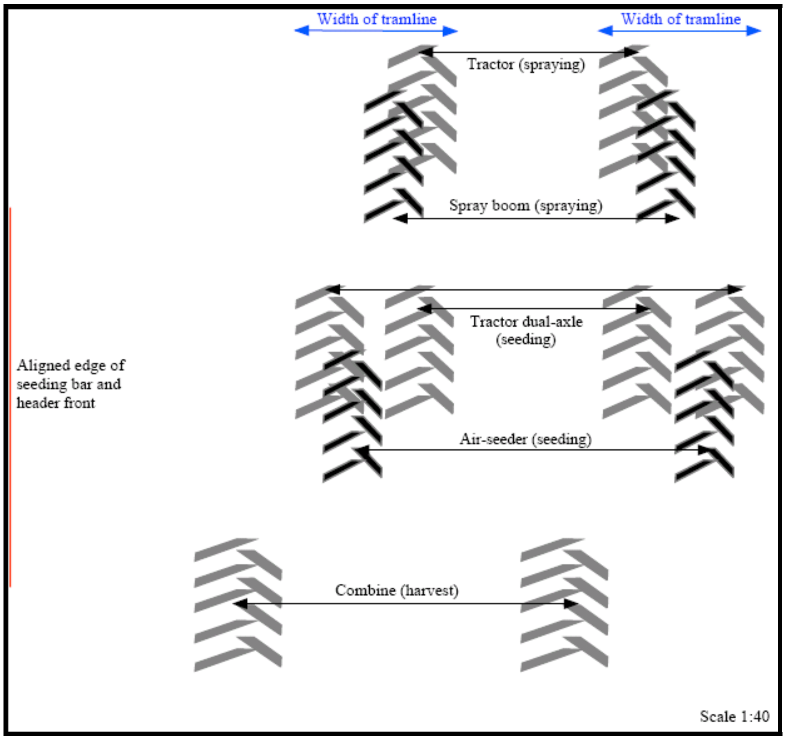


Figure 2. Schematic diagram of the multi-width tramline controlled traffic system being used on the paddock in 2007. Seeding and spraying operations are aligned centrally to allow for a reduction in the width of the tramlines with proposed adaptations to machinery. The combine harvester is not included in the system due to incompatibility of widths of the comb and seeding bar.

During 2005 and 2006, Paddock 30 was used as a teaching resource for Muresk's agribusiness students. Practical field work activities were conducted several times through the year and contributed to the collection of baseline information required in helping to ascertain soil properties, weed dynamics on the paddock and agronomic measures from the 39 sampling locations within the paddock.

Yield maps for the paddock have been made at harvest since 1996. In 2006 these data and the radiometrics information were dispatched for analysis to "SilverFox Solutions" from which management zones for the paddock were determined.

RESULTS

A detailed soil map developed from the 2005 radiometric survey showed a complex mosaic of seven soil types (Fig. 3). There is no one dominant soil type, though some are more prominent in certain areas of the paddock.

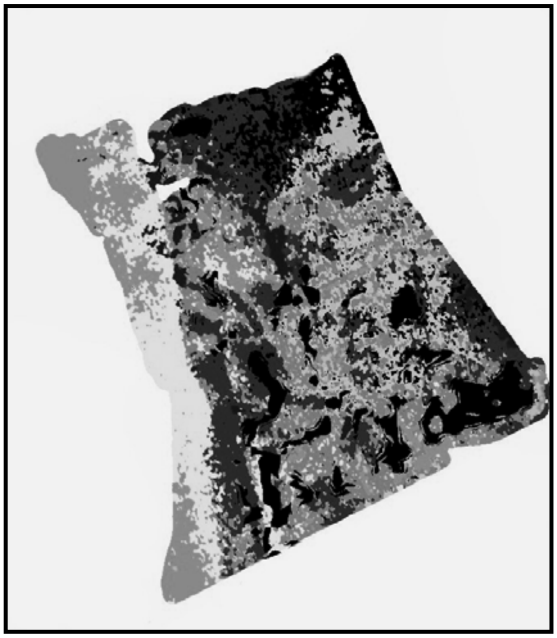


Figure 3. Soil map of Paddock 30 derived from radiometrics showing a complex soil type distribution.

Near average conditions prevailed for the 2005 season. May to October growing season rainfall was 327 mm. The crop was sown on multiple width tramlines (Fig. 4.) on 6 June and yielded about 2.76 t/ha as a paddock average. This is a production equivalent of about 8.4 kg/mm. In 2006 the paddock yields were much lower, despite a similar sowing date (12 June), due to an extremely dry growing season totalling 179 mm. The paddock average yield was recorded as 1.06 t/ha. Giving a production equivalent of 5.9 kg/mm. These yields were calculated from the tonnage of grain collected by conventional machine harvesting of the paddock.

Harvest estimates calculated from hand harvested samples taken from the 39 data sites gave a wide range of yields in both years (Table 1). The paddock averages derived from these data were much greater than the machine harvested values (probably due to errors associated with the estimated grain size used when calculating yield from the hand harvest samples). Three potential management zones were identified based on the radiometric and yield map data and related biomass imagery (Fig 5).

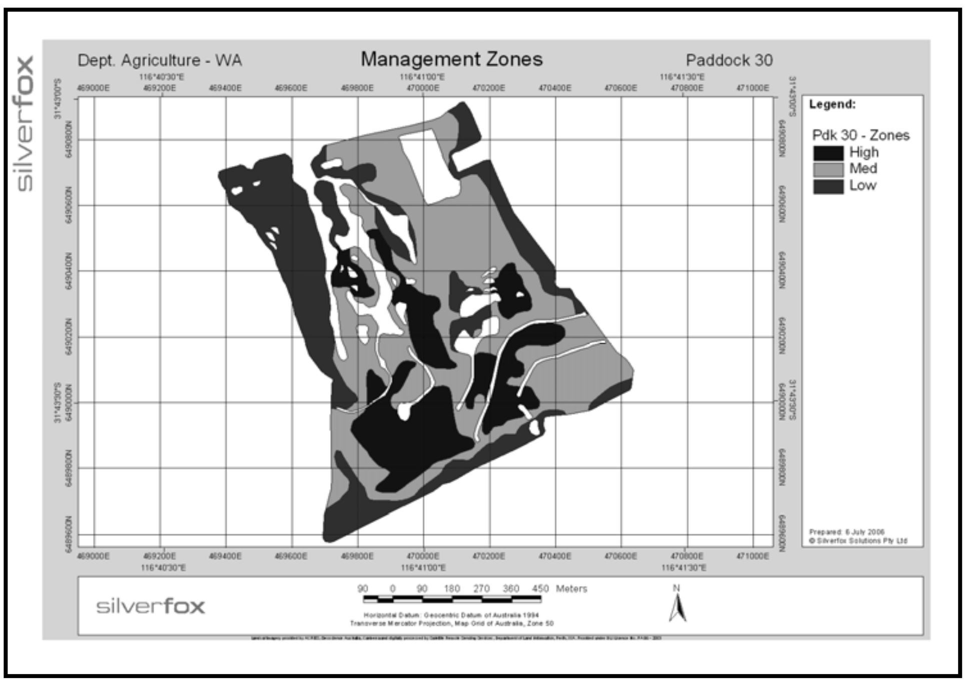
A number of qualitative and quantitative benefits have been identified to date. A small increase in area of about 4 ha has been measured due to the removal of the contour banks, rock piles and establishment of tramlines. The farm manager estimated that the time for seeding was about 40% faster than usual. As there was less overlap, use of fuel, time, seed and fertiliser, an overall estimated 10% increase in efficiency has been achieved.

a) b)

Figure 4. Crop establishment on multiple width tramlines in a) July 2005 and b) June 2007 with the new dual wheel tractor

Table 1. Wheat yields estimated from hand harvested samples

Year	**Lowest**	**Highest**	**Median**	**Average**
2005	1.818	6.591	3.864	3.989
2006	1.580	4.451	2.669	2.745



Fgure 5. Management zones determined for Paddock 30.

DISCUSSION

Despite still being under development and having only been used in two completely different seasons, the site has demonstrated some important practical issues and potential benefits of a CTF system in undulating, dissected terrain. The stepwise transition and upgrading of machinery is a realistic and pragmatic approach when considering the development of a system that can be used across a farm in such an area. With the current configurations of the machinery 0.32 ha is trafficked for each hectare cultivated (about 27 ha over the 85 ha now arable). This could be reduced to about 20% trafficked by reducing the wheel widths of the airseeder and boom spray and removing the outer duals. However, such changes need to be compatible with all paddocks on the farm, some of which require greater traction. While identification of cropping and pasture areas is possible, there needs to be flexibility in machinery to enable switching between these enterprises according to seasonal and economic considerations. In addition, there will always be mixed farming paddocks in such areas. The small increase in cropping area at this site was mainly due to the removal of obstacles. Similar small gains are likely to be replicated across paddocks in such terrain due to the removal of previously uncropped areas as a result of the change in the direction of tillage. Estimated increases in efficiency at the site are encouraging, but are not sufficient evidence of the benefits of a CTF system. These figures will be quantified in 2007 using a similar sized cropping paddock that is being cultivated according to current farm practice as a comparison.

The extremely variable environment is highlighted by the soil map derived from the radiometric survey and the range of yields from hand sampled locations across the paddock. This range of yields indicates the potential for additional benefits to be derived from zone management. Three management zones were identified but, due to the dry season, zone management was not implemented as planned in 2006. In 2007, it is planned that post-seeding fertiliser applications will be based on these zones.

The multi-width tramlines were created around the centres of the machines to enable reduction in the width of the tramlines over time as adaptations in machinery enable better matching of widths between machines. One issue that will require thoughtful consideration in the coming years will be how a CTF system is implemented with hay production. Hay production in the Avon Valley has become an increasingly important industry in recent years. Crop sequences are now often focused around hay as the main crop in a 1 in 3 to 1 in 5 rotation. Hay production requires more paddock traffic than cropping, representing a challenging situation to developing a CTF plan in a multi-pass system.

Background information on the paddock has been collected from Muresk records and these are currently being documented in greater detail to give a general overview of the history of the paddock. These, together with the detailed soils data collected by Warren, will serve as a useful benchmark upon which to match changes to soil properties in future years. After heavy rain in 2005 there was no evidence of run-off down the tramlines. Additional information on surface and sub-surface water and soil biology to be collected from 2007 will help to monitor environmental impacts of agronomic practices aimed at high productivity in this environment.

ACKNOWLEDGMENTS

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A Manufacturer's Perspective on Commercialising Technologies

Anthony Ryan, AGCO Australia, Melbourne

INTRODUCTION

What is the next stage in technology for the farming community? We all know what we have now, what is available to us today and what will be available shortly, but have you thought about what will be available in 5 or 10 years? Where is technology taking us and what should we expect?

Machinery manufacturers have already had to think about this, as this it takes 5 to 10 years to take in idea through the development phase and make it available to customers. Unfortunately it is not as easy as thinking of a great new idea or technology, and then implementing it onto machines tomorrow. It is just not that simple.

Identifying what to create for future products is the hardest question in developing new products and services. We all know how to build things, but we need to be able to decide what to build. It is easy to follow the technical opportunities that come along and hope that technology we create will find a market need. However this is high stakes gambling. This can produce innovative products, but many more great new technologies don't go anywhere, and end up wasting precious research and development dollars.

A much better approach is a user-centered process, not a technology-centered one. This starts from an understanding of users and finding a technology to serve them, rather than the other way round.

CASE STUDIES – HOW LONG EXISTING TECHNOLOGIES HAVE TAKEN TO GET TO THE MARKET AND WHERE DID THEY COME FROM.

Existing technologies have not just been thought up and added overnight. They have taken extended periods to go from a thought to actually a purchasable item. Here is an example of some. More detail to be shown in the presentation.

Vario Transmission – First developed in 1970, not put into production until 1996 due to restraints in technology to run the transmission efficiently in machinery.

Challenger Rubber Track Tractors – first development began in the late 1970's and included articulated wheel tractors, resulted in release of the Challenger 65 in 1986.

Beeline **-** hands free steering of Ag machinery first tried in 1994, not developed commercially until 1998
Fieldstar Yeild Mapping – first modern yield map produced in 1985, not made commercially viable until 1996.

WHAT ARE THE NEXT STAGES OF TECHNOLOGY WE ARE WORKING ON?

Here is a taste of some of the future technologies we see as important to the growth of Agriculture. These will be elaborated on and added to during the presentation. This is obviously sensitive information and not all our projects can be explained.

- Heads up virtual display
- Telemetry
- Alternative Power for machinery
- Machinery that does not require operators.

Seeking Profitability

Simon Tiller

Simon Tiller grain grower from east of Esperance WA, Total cropping enterprise consisting of wheat, barley, canola, lupins and field peas. Farming with wife Felicity and mum and dad. 25 years old, started farming in 1997 in South Australia at a time of low wool prices and in our particular area, low rainfall. Sold up in 1999 and moved to Esperance WA, put in our first crop in 2000.

Rain fall in our area is 429 mm annually of which 57% falls in the growing season. Thus leaving us with 185 mm falling out of season when our crop is not in the ground, bearing in mind that these are just averages. Faced with this in our first season we did the only thing we knew how, purchased an offset disc and chopped up what ever the seeder wouldn’t go through, sprayed what we could and still considered our chemical bill to be too high. After a few more seasons in Esperance talking to a few of the locals we began to feel a little more comfortable with summer spraying and we moved to no till and sold the discs. This gave instant results as we began to reap the benefits of moisture conservation and no till chemical farming. Not only did we see improvements in yields but also in profitability.

As we began to know our soil better and improve our farming techniques, some of our constraints became more evident. These included non wetting sands, salinity, compaction and summer weeds. Non wetting needed to be tackled first, clay spreading was the obvious choice, and a lot had already been done in the area. This practice however was extremely costly and with the amount of area that was non wetting on our farm, we couldn’t justify factoring in large areas in our budget. Even borrowing the money to clay spread large areas was still a long term option. Delving up clay from under the surface was trialed by a neighbor on a small scale. This was ironically noticed whilst checking a mob of sheep through the fence. After a bit more research it turned out that the delver would mean the end of the sheep on our property. On the majority of our non wetting problem areas our delver which we built ourselves, brought up more tones per hectare of clay for less dollars out laid. The job was quicker than clay spreading, could be done in varying conditions and cleaned up all of our compaction as an added bonus. Overall a quicker more effective way to tackle a big problem. Some areas still needed to be clay spread where the depth to clay exceeded 600mm. These areas only consisted of about 10% of the area of the total non wetting area.

Salinity was some of our own doing; we were unknowingly making this problem worse. Non wetting sand hills that were sprayed of during the summer would “shed” water after big summer rains and water would lie in the hollows, sometimes for a few months, sometimes up to a year. These areas eventually turned saline and could have threatened our livelihood had they been left to spread and get worse. To fix this problem we planted a mixture of saltbush and native trees to suck up the excess water that was hanging around. A combination of this and fixing the non wetting hills put a stop to any more of these areas spreading or reoccurring.

With these problems dealt with the summer weeds were next on the list. The paddocks were a more uniform soil type now and had a lot better moisture holding capacity, especially in the top 200mm. This meant now on an average we could receive three to four rain events during the summer months. If this rain fall pattern eventuated on our improved soils it would mean that some and not all of our top soil could have the ability to stay moist for the majority of the summer. Excellent for early seeding opportunities, not so good for the chemical budget. The yields were definitely there with this style of farming but the chemical imputes were a concern, as are all the inputs.

We began to look at ways to reduce inputs without cutting into our productivity, adjusting fertilizer rates, variable rate technology, etc. A base station gave us instant savings on chemical, fertilizer, fuel, labor, and generally made the whole farm more efficient. We had installed the base station in 2002 and it's paid for itself five times over by now. There were small gains to be made in VRT by shaving fertilizer costs, but this sometimes proved more trouble than it was worth. Banding flexi n was adopted, adding Impact®, copper, and trying to mix just about anything we could with it to try and get a yield response. These were all good adoptions but the chemical usage was still high. We were on the hunt for the next big thing to save some money.

A Weedseeker had been mentioned to me by a friend in the area. It seemed too good to be true. A machine that could spot spray weeds at 20 km/ph, 120 ft wide. Little did we know that the technology had been around for 10 years. After more research I found that farmers in the eastern states had this technology up and running on a broad acre scale. We needed to know if it would work here. Not long after with a bit more enquiry from other people around the state a demo of a weedseeker was offered by crop optics. This was an impressive demo and very successful. All broadleaf weeds 8cm in diameter or more were not only controlled, but blown away. This was achieved by using a much higher rate of chemical than usual, with huge savings made on the demo area working out to be around 13% of the area sprayed, and total broad leaf control.

In the background to all this our farming business was still growing, thus making our figures on buying a weedseeker more attractive each year. It took two years to bite the bullet, and the decision has been nothing short of a success. This machine has halved our summer spraying costs, given us more available moisture to push yields and turned back the clock for resistance in many broad leaf weeds. Other useful things we have done with the weedseeker are product application maps, we have used these maps to log weeds. These areas come up on a map the same as a yield map, these maps can be ground truthed at a later date to see why the weeds are thicker in different areas. This will ultimately give us a better understanding of our weeds and the soil types that they inhabit. Product application maps can also be linked to EM survey maps to better understand relationships between weeds and soil types.

The weedseeker is not only a profitable investment but a reliable one, with over 25000ha sprayed on our farm in its first season, there wouldn't have been more than about 3 hours of down time, and maintenance wasn't an issue. In times of rising inputs the weedseeker is a tool that we definitely couldn't afford to overlook.

As for the next big thing we made the decision to go to control traffic 2 years ago and we are probably still 2 years away. Control traffic farming will improve on every thing we are already trying to do, I believe that will be the biggest improvement since no till was introduced. It will preserve our delved country, improve soil health, and once again improve our ability to retain the ever important h20. We believe that we can make the move to control traffic on a broad acre scale without compromising on efficiency, thus improving our productivity. All these things in a nut shell are trying to keep ahead of the rising costs of modern farming and remain profitable and sustainable for the future.

Why Controlled Traffic Farming?

J.N. Tullberg, CTF Solutions

INTRODUCTION

The object of this paper is to summarise what we know about the science and practice of controlled traffic farming, and draw attention some of the things we don't know. The basics are straightforward. We know that wheel traffic can cause major soil damage. We know that driving on compaction-damaged soil is more efficient. Perhaps the most surprising aspect of CTF is that it has taken us so long to practice what we have always known: "plants grow better in soft soil, but wheels work better on roads”.

Research in the USA and Europe demonstrated the problems of random field traffic over 50 years ago, but large-scale adoption of controlled traffic by first world farmers has occurred only in Australia, and then only since the mid-1990s. Controlling field traffic is, however only the first step in a much more profound system impact, which goes well beyond dealing with soil compaction. Controlling traffic is the key to the improvements in efficiency, timeliness and soil structure necessary to reduce the waste of inputs and natural resource degradation inherent in conventional farming.

Controlled traffic farming-- CTF -- is a system to achieve greater productivity and sustainability from crop production in soil uncompromised by wheel traffic. Improvements in soil structure, field efficiency, or fuel use might still be an important motivator for adoption, but the outcome can be a truly revolutionary change in farming systems, providing major benefits to the economics of farming and to the broader environment.

The science tells us something about the magnitude of the soil damage inflicted by random traffic. It can tell us about the improvements we can achieve by controlling traffic. Unfortunately it can't tell us much about the system benefits, such as improved timeliness. Controlled traffic farmers tell us that CTF pays a large dividend in productivity and efficiency. It almost certainly pays a significant community dividend in terms of reduced pollution. I believe it is also the key to improving our greenhouse performance.

Controlled traffic systems of one sort and another are believed to be in place on more than 2Mha in Australia now. It would be great to get more information on just what this means, in terms of systems and outcomes, so we can do a better job of telling people what they can expect.

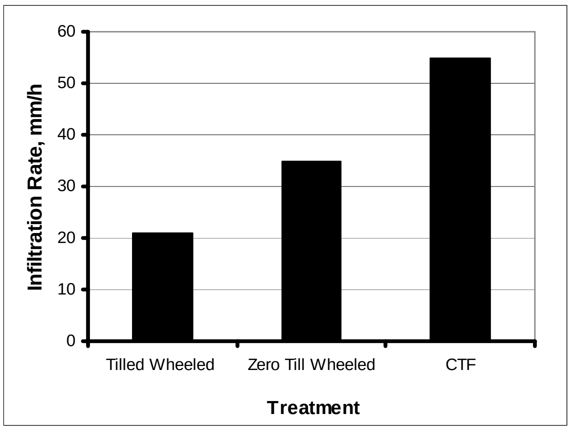
KNOWN SCIENCE

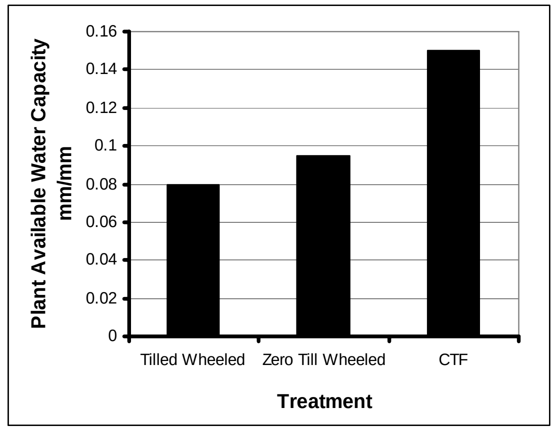
Soil in optimum condition for plant growth is relatively weak and permeable. When a wheel or track rolls over that soil, it must compress or compact it until the soil is strong enough to carry the load. The processes of transmitting surface loads down the profile is not straightforward, but it is generally accepted that tyre pressure is the most important factor affecting surface soil damage, but total axle load is a more important influence on subsurface damage, and the depth to which damage penetrates.

In most soils, natural processes of wetting, drying and biological activity will eventually repair this damage. Repair is usually rapid at the surface, but it is much slower further down the profile. At a depth of 20cm, for instance the time the scale of repair is in years, even on "self-ameliorating" soils. These natural processes, or tillage, can hide the surface damage quite quickly, but the subsurface damage persists.

Moisture

One of the major effects of wheel traffic damage is on soil moisture. Tillage reduces infiltration of rainfall by destroying the surface's residue protection. Wheel traffic reduces infiltration by reducing the rate at which water can move down into the profile. Both these mechanisms increase runoff and soil erosion, particularly in high-intensity rainfall events, while reducing the total water getting into the soil. Wheeled soil has a larger proportion of small pores and holds on to moisture more tightly than non-wheeled soil, so a smaller proportion of this moisture is available to plant roots.





a) Infiltration rate during 80 mm/hour rainfall event **b) Plant available water capacity (0 - 30 cm after two years CTF.)**

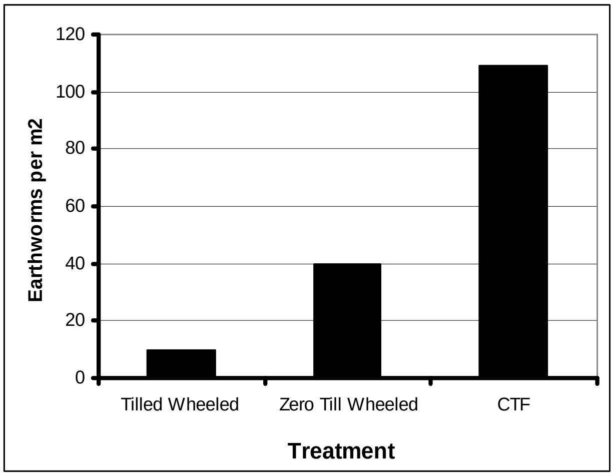
Figure 1.The impact of tillage and wheeling on infiltration rate and plant available water.

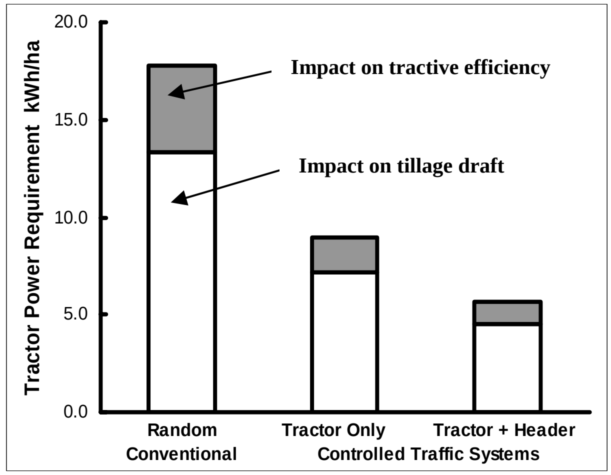
The impact of tillage and wheeling (1pass/year by 2t tractor wheel) on infiltration rate and plant available water is illustrated in figure 1, where conventionally farm soil (tilled and wheeled) is compared with zero tillage and random traffic and also with CTF (neither tilled nor wheeled). This data comes from Queensland's black vertisols, but broadly similar outcomes have been found in totally different soils in Victoria, in Western Australia, and other parts of the world. For all practical purposes, wheeled soil absorbs less rainfall and produces more runoff. It is more likely to get waterlogged, but is capable of storing less moisture in plant-available form.

Soil Health and Energy

Most soil organisms do not enjoyed being dug up or squashed. Biological activity of all sorts -- from earthworms down to bacteria and fungi -- is much more plentiful in soil which has not been tilled or wheeled. The effect of one annual 2t tractor wheeling on earthworm numbers (mean, monthly samplings of top 15cm over two years) is illustrated in figure 2a. There have been no exhaustive tests, but soil organic matter levels have generally increased in CTF. There is nothing surprising about the idea of soil health and organic matter levels changing in tandem, and this might be the reason for the improvement in plant available water capacity.

The good bit is that these improvements in soil condition come as a result of spending less money on fuel for the tractor. Zero tillage itself is a great step in this direction, but you still need to drive over the paddock several times. Controlled traffic provides more efficient traffic and traction, and the soil disturbance of planting will require less energy when you don't have to stir compacted soil.





a) Impact of tillage and wheeling on earthworm numbers **b) Traffic effects on tillage/planting energy requirements.**

Figure 2. Wheel traffic effects on soil biological activity, and power requirements of field operations.

The reduction in energy (or power) for planting or tilling non-wheeled soil, and the improvement in tractive efficiency on permanent traffic lane are both illustrated in figure 2b, which compares the total tillage power requirement of random conventional traffic with that of controlled traffic systems, with just the tractor, and then both tractor and grain harvester "in the system" (ie confined to permanent traffic lanes). Impacts of tractive efficiency change (permanent lanes) and decreased tillage draft are shown separately.

KNOWN PRACTICE

In uncontrolled “random” traffic systems heavy wheels drive over at least 50% of paddock area per crop, causing damage at 30cm depth and below, so root zone damage is almost universal in cropped soils. People can accurately claim they see no clear evidence of damage from heavy wheels—because the whole paddock is already damaged! Soil damage occurs instantly, on the first wheel pass. Second and subsequent wheel passes over the same soil do little further damage. On dry soil the surface damage is less severe, but the extreme wheel loads of larger grain harvesters penetrate a long way down the profile.

Natural soil repair processes of wetting, drying and biological activity work from the surface down through the profile. At depths of 20 -- 30 cm, this occurs on a timescale of years. CTF growers report improvements in their soil after one year's controlled traffic, but improvements at depth continue for at least five years -- with positive yield effects from increased plant available moisture.

Under the right conditions, deep tillage has occasionally been shown to have positive effects (in WA sands, particularly), but the cost is often not justified by the results. Beneficial outcomes have been reported only where deep tillage has been used to deal with clearly identified problems, and carried out under the right soil moisture conditions. Tilled soil is always weaker, so a wheeled tilled soil is often in worse condition than it was before tillage. The most important step is to keep wheels off -- so nature and crop roots can do the work for you.

In our water-limited cropping environment, it is amazing that some of our major problems come from excess water. Controlled traffic farming facilitates better water use efficiency by providing more opportunities for using available water for cropping. If soil is moist and plant growth is possible, cover crops are more valuable than weeds. Controlled traffic farming also provides a new approach to runoff management, getting rid of excess water rapidly and safely. A properly designed permanent traffic lane layout can ensure that runoff remains distributed across the whole paddock, rather than concentrating into erosive flows. Good layout ensures drainage which, combined with an undamaged soil profile, can prevent waterlogging in most conditions. Raised beds provide a positive insurance policy for the high-rainfall situation.

WHAT'S UNKNOWN

We still don't know enough about the broader system effects, simply because nearly all our agronomy -- whether derived from research or practice -- is based on the issues of cropping damaged soil. Traditional research is good at picking up the impact of changes in system components -- but it is not good at assessing the impact of system change. Whatever else they might have achieved, "farming systems" have not done much to quantify the effects of system change.

Grower surveys should tell us something about system impact but most do not distinguish between a grower operating a complete CTF system, and a grower who has simply purchased a guidance system. Both can make some claim to be controlling traffic, but only one is getting the full advantages. What are the system benefits, and what impact might they have?

Timeliness: Controlled traffic farming eliminates many of the time wasters. CTF growers, for instance, can get back on the paddock two days or more before growers in non-CTF zero till, and there is general acknowledgement that timeliness is extremely important. Unfortunately, we still have only the most approximate estimates of its impact. These estimates are usually between 0.5% and 2% yield loss for every day of delay in planting or harvesting, but there have been few attempts to measure the effects directly.

Harvesting and planting timeless effects can sometimes be cumulative. Rainfall at harvest time usually costs money in terms of crop downgrading, but for CTF growers the loss will be smaller -- because they will be harvesting again more rapidly after rain. In many Australian environments, moist soil at harvest time also represents a planting opportunity. Getting another crop established is always a better option than tilling out header ruts and then spraying weeds.

Zero tillage compatibility: Timeliness of spraying is probably even more important than timeliness of harvesting and planting -- but again we have no quantitative information. There is little doubt, however that timely spraying is an essential component of effective zero tillage cropping. Controlled traffic and zero tillage are a perfect match.

Precision: Controlled traffic farming means that inputs can be applied more precisely at the time they are needed, and the place they are needed. Permanent traffic lanes allow access to growing crops without causing crop damage, and 2 cm guidance allows precise positioning of inputs -- physical or chemical. We can achieve significant input economies when chemicals can be band-applied, and fertiliser precision drilled at the right time.

Environmental impact: Controlled traffic farming provides a major environmental dividend, because it facilitates the use of less energy, maintenance of more residue, and active crop production for a greater proportion of the year. We also know that a significant proportion of nitrogenous fertilisers are lost simply because they are placed in wet soil, long before now required by the crop. In controlled traffic farming, with precision guidance, fertiliser can be drilled in the interrow, or provided in liquid form when and where it is needed. Another valuable outcome of this strategy is a simpler, more residue-friendly planter, uncomplicated by the need to apply fertiliser long before it is needed.

WHAT'S NEEDED

The full implications of CTF have still not registered on the institutional research radar. We are all still too busy and too comfortable investigating the old problems of soil compaction etc to notice the system opportunities of better access to undamaged soil with precisely positioned tools. Controlled traffic farming will provide new opportunities in plant breeding, fertiliser management and weed control.

There are also opportunities to produce machinery to exploit improvements in precision and control and allow cheaper, lighter equipment to provide:

- Depth control independent of load-bearing wheels, without parallelograms on everything.
- More accurate implement guidance with drawbar equipment.
- An integrated, multi-bin "commodity cart" approach for all field materials handling.

CTF allows information to replace brute force, and precision to replace bulk steel.

Research institutions might eventually address some components of this challenge, but current indications are that these system issues will have to be sorted out by farmers, individually and in groups.

I believe this should be a major role for the Australian Controlled Traffic Farming Association.

CTF and Global Warming

J.N. Tullberg, CTF Solutions

INTRODUCTION.

Improved tillage systems are generally "environmentally friendly", particularly in terms of their potential to reduce on-farm energy use, runoff and loss of nutrients and crop chemicals to the environment. There are however confusing claims about the potential of improved systems to reduce agriculture's contribution to global warming and the possibility of farmers earning money from "carbon trading".

Agriculture contributes a significant proportion of Australia's greenhouse gasses, and this paper attempts summarise what we know now, and what we still need to know about the impact of improved systems.

GREENHOUSE GASES AND CROPPING

First a brief explanation of agriculture's greenhouse gases:

Carbon Dioxide (CO_2), the major greenhouse gas, is produced when fuel is used directly in farming. More is used indirectly to produce fertilisers and pesticides, and when organic matter decays. Biofuels are a greenhouse positive because the CO_2 released on burning biofuel was absorbed in growing the fuel crop.

Nitrous Oxide (N_2O) and Methane (CH_4) are also significant greenhouse gases. They are produced in smaller quantities than CO_2, but have a much more powerful greenhouse impact. N_2O, for instance produces about 300 times the global warming effect of CO_2, and also involves a loss of fertiliser from cropping soils. Animals produce large quantities of these gases from digestive processes and/or from manures.

Cropping agriculture can reduce its contribution to global warming both by reducing the emissions of greenhouse gases and by increasing the amount of carbon dioxide tied up in the soil (carbon sequestration). The general ideas are explained in figure 1.

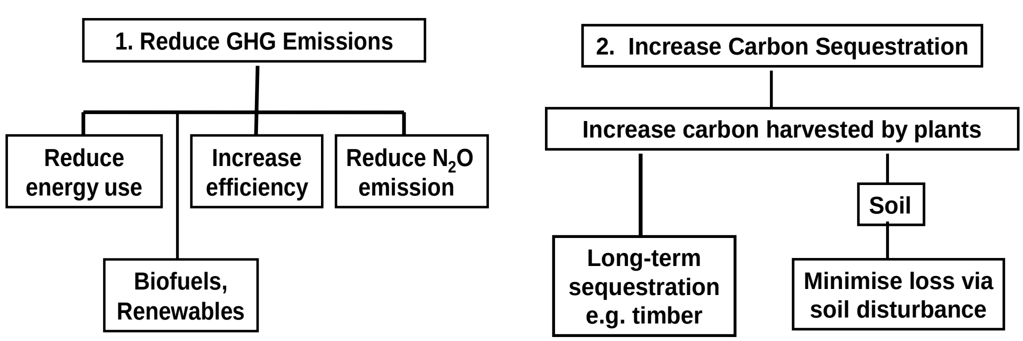


Figure 1. Reducing the greenhouse impact of farming.

THE IMPACT OF CTF

Controlled traffic farming reduces greenhouse gas emissions directly and indirectly, by reducing energy inputs, facilitating zero tillage and increasing fertiliser efficiency. Summarising these effects:

1. **Fuel Energy**. Compared with conventional, tillage based agriculture, tractor fuel requirements of uncontrolled traffic zero tillage (ZT) and controlled traffic zero tillage farming (CTF) are reduced by approximately 40% and 70% respectively. The CTF effect is a result of improved tractive efficiency and reduced draft at planting, reduced rolling resistance at harvest and spraying operations, and the total elimination of tillage. (Non-controlled traffic zero tillage will still sometimes need to eliminate wheel ruts after a wet harvest). There is good research and anecdotal evidence of these effects.

2. **Herbicide Energy**. The literature includes a variety of estimates of herbicide energy requirements in zero tillage, but none of these examine the reduction in herbicide requirement achieved by CTF. The reduction is a function of more timely spraying from permanent lanes (trafficable sooner after rain), and a further reduction occurs in those situations where agricultural chemicals can be applied in precise narrow bands. Anecdotal evidence indicates an overall mean reduction of perhaps 25%.

3. **Fertilizer Input**. Fertiliser (and seed) are generally not applied to permanent wheel tracks in CTF, reducing fertilizer costs by 10 -- 15% for narrow-spaced crops, while yield increases by about the same amount. Nitrogen fertilizer manufacture represents the biggest single energy input to many crop production systems, so CTF reduces this by 15 -- 30% per unit of production.

4. **Nitrogen Efficiency**. Research and anecdotal evidence of increased yield with less fertilizer coincide with expectations that nitrogen efficiency should increase with reduced soil compaction and improved soil biological activity in CTF. Nitrogen efficiency is generally believed to vary between 40% and 80%, so there is considerable scope for environmental and economic efficiency.

5. **Nitrous Oxide**. High concentrations of nitrogenous fertilizers are normally placed in a moist compacted seed zone at planting time, where poor internal drainage might be expected to increase denitrification and N_2O production. CTF reduces seed zone compaction and waterlogging. It also increases the practicability of aligning N supply better with crop demand by split fertilizer applications, reducing denitrification.

6. **Soil Carbon**. CTF reduces soil disturbance and improves the potential for cropping to mimic natural vegetation in maximising dry matter production (and water use) by double cropping or cover cropping. Increased soil biological activity and soil organic matter levels have been demonstrated in different environments, so increased soil carbon sequestration might be expected.

It is interesting to note that all these reductions in greenhouse gas emissions occur because controlled traffic farming improves the efficiency of management inputs -- energy, fertilizers and crop chemicals. Although we know a lot about the energy saving aspects of CTF, much less is known of its influence on fertiliser efficiency and carbon sequestration. These are important topics that require urgent investigation.

CONCLUSION

Controlled traffic farming is the key to a significant reduction in greenhouse gas emissions of broadacre crop production. Soil carbon levels should also be greater under CTF than under alternative systems. This improvement in agriculture's global warming performance can be achieved without financial penalty while simultaneously reducing costs and increasing production.

REFERENCE

The Potential of Conservation Agriculture for the Clean Development Mechanism. Report commissioned by the United Nations Asia-Pacific Centre for Agricultural Engineering and Mechanisation. (available at: http://www.unapcaem.org/admin/exb/ADImage/ConservationAgri/CA.pdf)

CT Farming Patchewollock

Peter Walch

My farm is situated in the Mallee region of North West Victoria. The soil type consists of mainly sandy loam to sand and the annual rainfall is 325mm, with the GSR at 220mm. The rotation is mainly cereals for example, W-W-B-W and I commenced tramline farming in 2003. The system is designed on 3m wheel tracks.

More operations are now occurring because of different farming technology and techniques, for example 4-6 spraying events per year. Auto steering and CT farming are a perfect fit. After repeated operations on your paddocks the logical step of matching your equipment size is obvious.

MATCHING MACHINERY FOR CT FARMING SYSTEMS

A module size should equal the header front eg 13m front, 12m seeder & 36.9m spray

12m-air seeder bar with 300mm spacing
The tractor currently being used in seeding operations has dual wheels, however looking to place the tractor on 3m-wheel spacing in the future. A 12-ton air seeder cart is also on this spacing.

24.6m urea boom
The urea boom is home made, which is towed behind the air seeder cart. This enables the use of variable rate control.

36.9m boom spray
A new axle was installed on the boom spray to increase the span to 3m. An articulated tractor had 4 wheels removed and the remaining 4 wheels moved out to 3m.

13m harvester
The 13m-harvester front from Midwest Fabrications [www.midwest.net.au] was mounted on the center of the machine, which led to problems with the auger length, chaser bin width and residue spreading. A Redekop residue management was installed [www.redekopmfg.com] which spreads chaff and chopped straw the width of the module. The harvester's wheels are also on 3m-wheel spacing.

Chaser bin
The chaser bin is on 3 m wheel spacing and the top of the bin has been widened to 4.5m it travels 95per cent of the time on tramlines except when emptying the harvester.

Fertiliser cart
A fertiliser cart was added to the seeder this year to enable me to place trace elements, fungicides and nitrogen in a more suitable way. Pre-emergent chemicals are planned to be applied in the future in front of the seeder

PRECISION GUIDANCE/STEERING SYSTEMS

For the previous 4 years I have been using a 10cm guidance system and recently changed to RTK this has changed my tramlines.

STUBBLE MANAGEMENT AND SEEDING

Straw is better managed with the combination of CT and auto steering; the direction of travel should be the same for the seeder and the harvester.
Tall stubble can be managed using auto steering and inter-row seeding, which speeds up the harvesting operation and reduces the need to spread large volumes of straw (less power requirements).
Taller straw creates better protection for the soil and there are fewer issues for the next year's crop

It is very important to have the harvester on tramlines, as I believe it is the machine that does the most damage. In the drought of '02 the crops did not grow on the previous header tracks (unsure about duels on the harvesters)

Choosing the direction of the tramlines is confusing: some research indicates E-W and others N-S. In my case, I have looked at where trucks can efficiently access the paddocks to determine the direction. As a result I have made some mistakes

Farm layout: plans should have been made with the image of no fences in mind perhaps consider employing a consultant prior to commencing CT.

Tend to become more aware of your soil, for example digging, probing, and looking for the build of the mulch.

You start to realise the importance in the operation efficiency.

Less fuel use and possibly the reduction of hp needed.

Enables you to spray insecticides and fungicides later in the season whereas historically a plane would be used.

If your next purchases are made with a CT plan in place, the costs should be minimal and the gains potentially enormous

Controlled Traffic and Precision Agriculture at Scaddan, Western Australia

Mark Wandel, Willawayup, Scaddan, WA.

INTRODUCTION

We are a family farming operation in the mallee region of Esperance Western Australia. The farm is in partnership with parents Neil and Mary Wandel, brother Scott and myself. We farm two properties covering a total area of 15,600ha. One farm is at Mt Ridley and its area is 10,400ha and has an annual average rainfall of 350-400mm. The other farm is at Scaddan and its area and average annual rainfall are respectively 5,200 ha and 425-450mm. Both farms are continuously cropped. We also have a grain handling business in Esperance, Esperance Quality Grains, which comprises a 3,500 tonne elevated storage capacity with drying and cleaning facilities.

I manage the Scaddan operation with my wife Hayley and our 3 children. The soil types are mainly loams through to grey clays. Surface soil pH ranges from 5.5-8.0 and its depth ranges from 10-30cm. The subsoil is clay. The cropping rotation consists of a standard rotation for our region of;

- Legume crop (either faba beans, field peas or vetch)
- Wheat
- Canola
- Wheat
- Barley

CONTROLLED TRAFFIC SYSTEM

Controlled traffic operations were begun in 2004. At the time we saw controlled traffic as the next step to improving our profitability and sustainability. We could not see the point of driving all over the paddocks and damaging all the soil structure that we had worked hard to build up through no- till crop establishment practices. The system that was decided on was the 9m width-3m track width system, which includes

- A 18m wide seeder which plants rows 300mm apart
- Boomsprays that are 36m wide
- A harvester with 9m front
- A 9m wide self-propelled swather with deck shift that allows swath rows to be laid 18m apart in the same direction.
- A combined 9m wide-row seeder and shielded sprayer (want to go to 18m width).
- Spreaders with 9m and 18m spreading widths, for spreading gypsum, lime and super
- All the machines are on 3m wide wheel centres
- All the steering is done with John Deere RTK Base Station that has 2cm accuracy

FARM PLANNING

We were very lucky that all the blocks of land were surveyed on a north-south orientation, and so we came up with the plan of having one set of run lines for the whole 5,200ha at the Scaddan property, which is set on 180 degrees. This ensures workings are simple for operators, there is need to change run lines between blocks and mistakes are eliminated. Most of our laneways are east west through the farms which works well for access, and we drive on these during all operations. Some we have even realigned to ensure they run directly east-west.

RESULTS

We have been very happy with the results, and the improvements gained have occurred quicker than was first imagined. Some benefits are:

- The soil has become softer, more uniform and easier to work.
- Less horsepower and fuel are needed to pull implements.
- The soil appears to have an increased water holding capacity.
- There is substantially improved traffic-ability in wet conditions.
- Inter-row seeding has improved trash handling and crop establishment.
- We now have an increased number of opportunities to control weeds during the growing season.
- Our header trails every 18meters are burnt, and the tramlines act as fire breaks.

Controlled traffic has opened up many more opportunities to improve our farming system and I think there are a lot more to find. For instance, controlled traffic has given us (i) the opportunity to establish crops on less rainfall, and (ii) the ability to do operations exactly where we want to do them, and this improves overall efficiencies.

PROBLEMS

As with everything, controlled traffic farming has its problems. Some that we have encountered are:

- Getting the old man’s head around it so it can all happen;
- Ryegrass weed infestation in tramlines, BUT this is reducing as tramlines get more compacted and hostile for plant establishment and growth;
- Rutting and water ponding in tramline depressions or in wet areas of the heavy clays.
- Improving the management of what is now uncontrolled traffic on our headlands;
- Trying to get everything to fit on tramlines for the minimum amount of expenditure;
- Swathing barley with the direction of seeding and trying to stop it from collapsing in to the space between the rows (we used to go at 45degrees to seeding direction); and
- Educating casual staff on what we are trying to achieve (i.e. don’t drive everywhere, drive only on the tracks).

Some of the tactics we have applied to overcome these problems are:

- *Ryegrass in tramlines:* We have fitted shields on the front of sprayer to separately knock out the ryegrass in tramlines while spraying rest of paddock.
- *Controlling the traffic on headlands:* We are in the process of setting up run lines on the headlands so we will also have tramlines on the headlands in every block.
- *Swathing barley:* Seeding barley in the inter-row space of previous year's wheat stubble leaving so that the standing and largely undisturbed stubble supports the swaths.
- *Rutting:* At this stage we are continuing to drive straight through them. (We are still working on a solution to this problem.)
- *Educating casual staff:* We now have a 'code of conduct' that explains what and how operations are done in particular ways and why.

WHERE TO FROM HERE WITH CTF ?

The on-going improvements we plan are:

- Increase the width of the shielded spraying unit to 18m;
- To configure the spray nozzles to allow on-row and inter-row spraying with 150 mm nozzle spacing;
- Catching weed seeds out the back of the headers and place them on the tramlines where we know they are and can be managed; and
- Try and spread straw uniformly over an 18 meter span.

Wide row agronomy of Faba Beans

Dad has been growing Faba Beans since the 1980s at Scaddan they are good legume suited to the clay soil types and higher pH values particularly of our subsoils. We have had good and bad results with faba beans over the years. Our major problems occur after canopy closure, when good control of diseases and broad leaf weeds has proved to be very difficult. However, our best wheat yields have been obtained after faba bean crops.

We wanted to continue growing beans in a profitable way and were noticing that where plants grew without close neighbouring plants they set more pods and had less disease. This got us thinking about the viability of seeding faba beans in widely spaced rows.

In 2004 a wide row seeder and shielded sprayer was put into the farm operating plan. Out came the welder and it was built. It consisted of 750mm row spacings over a 9m width. An area of 400 ha was planted with this machine in the first year. Our goals when we first started with this system were to:

- reduce disease occurrence and incidence;
- improve podding by allowing more light to penetrate the crop canopy;
- reduce the need to use grass-selective herbicides; and
- improve the efficiency use of fungicides and other pesticide inputs.

Now, after 4 years our wide row system consists of seeding an 800ha program of beans seeded at 900mm row spacing. We have converted our Deep Blade Seeder® (DBS) with a second air seeder hose system which requires lifting two of every three tines out of the ground. We are using a 9m shielded sprayer and are looking to purchase a 18m wide one. Currently, 73% of the paddock is being sprayed between the rows: 40% is being sprayed over the row. Harvesting with a 9m flex front. Our management stratagie is as follows:

i) Seed in or as soon as possible after the 3rd week of April at 80kg/ha.

ii) Six weeks after seeding, spray for grasses over the rows, with glyphosate between the rows.

iii) Spray fungicide, insecticide and trace elements over rows using banding nozzles with our JD4920 self-propelled sprayer.

iv) When the first flowers appear, which is normally 3- 4 weeks later, spray fungicide over the row with three nozzles at 120 l/ha of water and glyphosate, or Sprayseed® gramoxone between the rows.

v) Four weeks later, or before a rain event and canopy closure, spray broad acre with the JD4920 sprayer, applying fungicide at a minimum of 200 l/ha water rate.

vi) Again, 3-4 weeks later, depending on weather and growth conditions, spray broad acre with fungicide and insecticide at a minimum water rate of 200 l/ha.

vii) Pre-harvest, spray-top beans with gramoxone.

viii) Harvest as early as possible, in cool weather.

Experience has taught us that by applying fungicides earlier and via band spraying they are more cost effective. This successfully keeps diseases pressure down. We apply fungicides earlier before we see any sign of disease because they are really preventative, not a curative in their actions, and the high water rates are used to get superior coverage to protect the leaf.
Our wide rows and improved agronomy for faba beans has increased our average yields, mainly by taking the bottom out of the yields. It has also:

- Improved flower set, through more light penetration as flowers face towards the sun
- Helped them finish in dry springs probably because they can access moisture between rows
- Reduced disease pressure, through improved efficiency and effectiveness of fungicides
- Improved weed control through an increased in weed control options
- Decreased pressure on grass selective herbicides because of option to use knock down herbicides between the rows (but this has increased the pressure on knock down herbicides)
- Increased our average gross margins

ELECTROMAGNETIC SURVEYS

Managing sodicity

EM surveys are being used to map soil types across the farm. We have EM surveyed 20% of the farm at this point in time and are still discovering and working with what we can do with this information. Our first and most easy application from this data has been to map our exchangeable sodium percentage (ESP). We have found that as our EM reading increases the sodicity level in the profile is increasing, and this is a strong relationship with a R squared value of 0.81.

Through soil coring and soil testing we have mapped areas according to their gypsum requirement. These range from areas that need no gypsum through to some that require 20t/ha to correct the sodicity level.
In the past we would normally spread 1.0 to 2.5t/ha of gypsum every 5-6 years based on an average value for the soils in particular paddocks. Now we have divided the paddocks into around 6 zones and determined the rates of gypsum needed to correct the sodicity over time through the use of variable rate control on the spreader. Most rates vary from 0.4 to 5.0t/ha and we believe it will take 4-5 applications to achieve our outcomes. So, for us, gypsum applications are giving us the quickest return on investment in this technology.

Managing weeds

We have also been able to map the soil types on which ryegrass is more prevalent, such as buck shot gravel country, which has a shallow topsoil and a sodic clay subsoil. In consequence, it becomes wet very quickly and dries-out quickly. This rapid wetting and drying behaviour seems to favour ryegrass as populations on these are high. This year these areas have been targeted by applying higher rates of herbicide in a canola crop, and the level of weed control achieved has been excellent.

Future use of EM surveys

In the future, I believe EM surveys be done of the whole farm to map soil types according to their water holding capacity, nutrient requirements, soil constraints, weed problems and whatever else we can think of to gain efficiencies in managing the farm as soil-type-zones rather than paddocks.

Biomass NDVI imagery

The use of biomass NDVI imagery is an area that I feel has a fit for in-crop management of inputs. I am currently looking at different ways to cost effectively access these data when we need them, whether by satellite imagery to 1m resolution, Green Seeker® sensors, aerial imagery, or other real time sensors when operations are being carried out in the paddock. I am keen to improve on zone specific management for:

- applications for nitrogen, and manganese and zinc deficiencies;
- the control of waterlogging and water deficit stress;
- Faba bean biomass to yield ratio (I believe that when some of our beans grow too much in some seasons and forget to pod, there may be some gains to be had by applying variable rates of growth regulators).

CONCLUSIONS

Gathering zone specific information, ground truthing it and then obtaining an interpretation of it that translates into practices that work in the paddock are the main challenges confronting farmers contemplating an investment in this technology.

Controlled traffic farming has been a rewarding and challenging transformation of our farming practices. We are still refining it and finding more innovative ways to use it. Our next step is into precision agriculture and zone farming, which I see as an evolution that is as challenging, if not more so, than CTF. It will require ground truth surveys, computers, data analysis programs and a great deal of intelligence and experience in putting all the information into a usable form that get it into the field and working.

Applying PA Techniques for Better Decisions

Michael Wells, Precision Cropping Technologies

INTRODUCTION

The successful incorporation of Precision Agriculture techniques into the farm management system has some fundamental requirements. It is very much dependant on the degree of within-field variability that exists and also our ability to accurately measure and map this. The challenge then is to build an understanding of the nature of this variability and the consequences it has on management and productivity. If this can be achieved then the likelihood of generating successful outcomes from differential management over a uniform whole field approach will be greatly enhanced.

Today an increasing range of sensors are being combined with high accuracy GPS to collect large amounts of geo referenced information of how a particular attribute varies over a given field area. Information can be gathered on variations in elevation, soil conditions, yield, and crop health amongst others. With the addition of GPS assistance to many farming management operations the farmer now has the ability to collect some of these important datasets. The challenge he/she then faces is how this and other information can be managed in such a way that it realises its potential benefits.

This paper aims to demonstrate, by way of a case study, how a farmer planning to manage water-logging issues has used Precision Agriculture techniques to build his knowledge about within field variability and use this to make a more informed decision on soil amelioration and designing of surface drains.

CASE STUDY : PADDOCK 290A

Overview

This project was conducted on a field in the Esperance District of WA. The paddock is centred at a converging point of a larger catchment area that feeds naturally into the Neridup Creek. It is characterised by gentle undulations and slight ridges which trap sheets of water that combine with heavy clay subsoil to cause chronic water-logging in wet seasons. This was quite evident in winter 2005 when field work could be carried out on the adjacent paddocks but the problem paddock was clearly un-trafficable with uneven canola emergence.

Due to the farmer's experiences with raised beds on this type of country he believed much of the gain they produce in improved drainage could be delivered to this paddock through strategically located surface drains. Though beds may deliver a little extra overall benefit across all soil types this would not compensate for the complications he had encountered at harvest with chaser bin entry and when wind-rowing barley for grass control.

The farmer chose to use Precision Agriculture techniques in his planning of remedial activities for water-logging. Firstly he wanted to identify where the main issues were in the paddock and then focus his investment in those areas as opposed to a whole field broad-brushed approach. He was concerned that the whole field approach would result in money being spent where it was not needed and not enough work being done where it was actually required. Secondly he planned to construct the surface drains on his own and felt that designing a complex system of drains using lasers alone, on-the-go in the field, would be almost impossible as well as placing his investment at risk. With the information and maps generated through PA techniques he believed he would be able to see more clearly where drains should go and the area of catchment that would feed each drain.

There were also plans to apply gypsum, especially to the worst of the areas, to work in combination with the drains to reduce the water-logging risk. The farmer was aware that there were different soil types but the actual surface soil similar. Therefore it was not an option to visually patch out the problem areas with gypsum.

COLLECTING THE REQUIRED INFORMATION

The first stage of the process was to collect the relevant data from the field. Given that the issues with water-logging had in part been both topography and soil type related it was necessary to measure the changes in elevation and apparent soil profile conditions over the paddock. To do this, three sets of information were required.

An EM38 survey was conducted in vertical dipole mode coupled with a Starfire RTK GPS system. The survey, completed at 20m swaths, allowed the collection of high accuracy elevation and measurements of apparent soil profile change simultaneously. From here the sets of information were initially managed independently before being integrated at a later stage to assist with decision making. The third set of information required were the soil cores with laboratory analysis.

MANAGING THE INFORMATION

Soil

The EM38 data was processed in AGIS software to create a map showing apparent variation in the soil profile conditions through the changes in bulk electrical conductivity detected by the EM38. To interpret the nature of the variability and to better understand more specifically the actual soil properties that are varying, soil cores were collected at selected and known locations.

The soil cores were subject to laboratory tests and defining of texture through analysis of particle size distribution which determines the proportions of sand, silt and clay. The subsequent analysis of these soil-test results with the EM38 data revealed some significant and useful correlations.

Electrical Conductivity dS/m	$r^2 = 0.82$
Chloride ppm	$r^2 = 0.79$
Clay %	$r^2 = 0.66$
ESP	$r^2 = 0.63$
Cation Exchange Capacity meq/100gm	$r^2 = 0.62$
Boron ppm	$r^2 = 0.94$
Ca:Mg ratio	$r^2 = -0.82$

With the exception of Ca:Mg ratio, as the EM38 measurement increases over the field it is inferring an increase in the above properties. The Ca:Mg ratio is decreasing as the EM increases. Of particular importance for the farmers plans to apply gypsum are the correlations between Clay % and Exchangeable Sodium % (sometimes referred to as sodicity) with EM data. This has allowed the building of a map that infers where the sodicity condition varies over the field even though not visible on the surface. This provided the basis for a VRT gypsum plan that was implemented by a local contractor with higher rates applied to the problem areas.

Elevation

The elevation data collected in the survey was processed using AGIS to create a Digital Elevation Model (DEM). On its own this has limited application for the farmers planning. Given that surface drains were the chosen option over a raised bed system the elevation map was processed further with a focus on generating information about potential surface water movement.

The first of these layers were the elevation contours at 10cm increments. The field was then segregated into natural Watershed areas. These are like mini water catchment zones which are best described in that water would have to move uphill at some point to cross the line into the next watershed area. These can be used as a guide for assessing the size of the area from where water would shed into a prospective drain.

For each Watershed area in the paddock there will be a final culmination point for the flow of water for which a mark was located that can be over-layed on any other maps of the paddock to highlight the low points of where water flow will terminate. These points can be linked together with a surface drain.

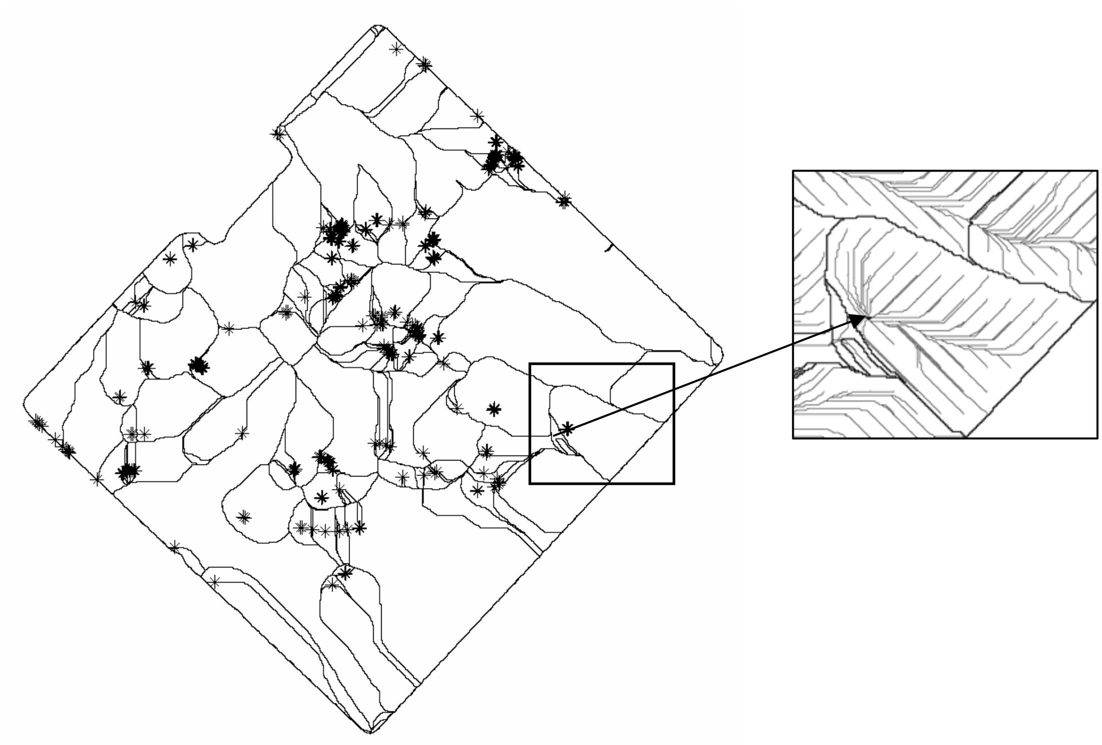


Figure 1: Drain Points over-layed on Watershed Boundaries. The exploded section shows the Water Grid layer which identifies the natural water flow lines of laterals into a main within each Watershed Boundary area. The farmer found this useful in choosing pathways for drains.

BUILDING NEW KNOWLEDGE

To this point we had identified the areas most requiring gypsum and this had been implemented in a variable rate application fulfilling the first of the farmer's objectives. However water-logging risk was also influenced by changes in the surface topography.

The topographic information layers described so far provide a useful insight of the potential behavior of surface water movement and will prove to be very useful for the farmer when it comes to design the drains and importantly implement them in the field. They do not though fully satisfy the objective to direct the design of surface drains to the most problematic regions. This could mean the areas that through water-logging suffer nutrient loss, harbor weeds or cause trafficability problems. They could also be defined as those areas that suffer significant yield loss in wet years. Yield loss areas can be identified beyond a simple visual appraisal through comparative analysis.

Yield maps were created from data collected in drier seasons (2002, 2004) and a wetter year (2003). AGIS was used to build an Elevation Error Surface. This is used as a guide of where water is more likely to pond or shed according to the subtle, localised variations in elevation. In the graphs using Elevation Error below, positive values refer to likely water-ponding areas and negatives values indicate potential water shedding areas. The yield maps with the EM38 and Elevation Error surfaces were analysed in AGIS to generate following information about the major causes to yield variation in different seasons.

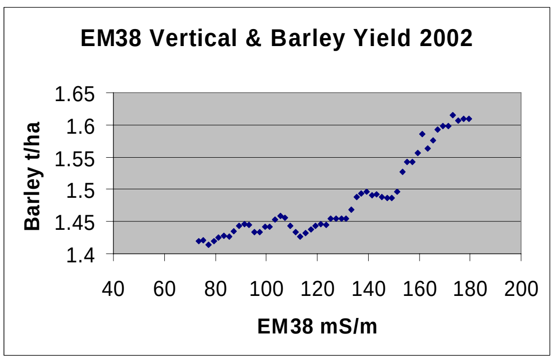


Figure 2

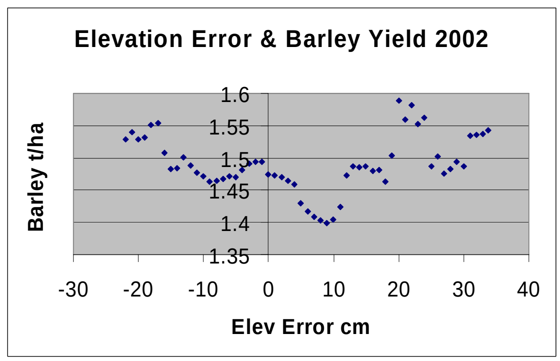
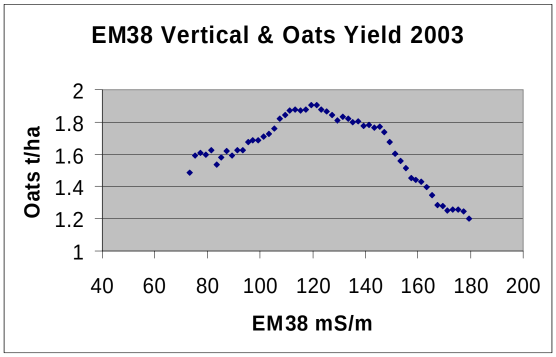


Figure 3

In AGIS we have asked "as the EM38 value increases over the paddock what happens to the barley yield". Season 2002 was dryer with barley averaging 1.46t/ha. Figure 2 indicates a steady trend of yield increasing as the EM38 value increases over the field. Soil-test information indicated higher clay content as the EM value increased. Apparent improved water holding capacity is supporting more yield. Figure 3 suggests no meaningful trend between yield and the paddocks surface ability to pond or shed water. The graphs suggest that in 2002 the changes in soil had more of an influence on yield than did potential water-logging.



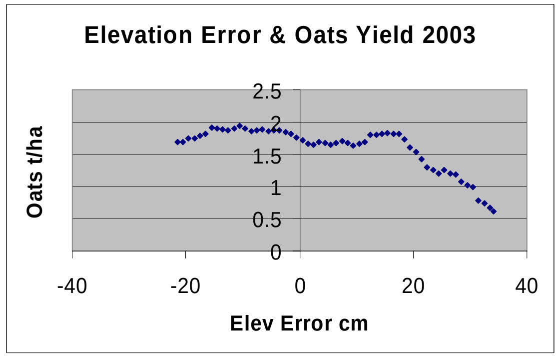


Figure 4

Figure 5

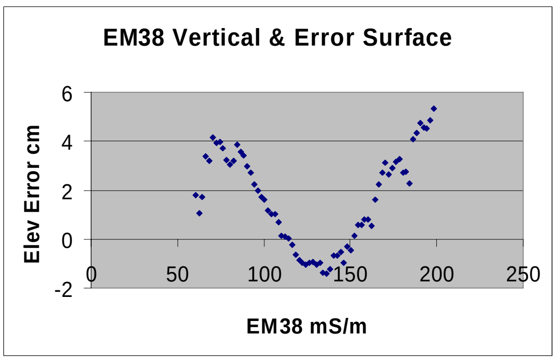


Figure 6.

2003 was a wetter year with oats averaging 1.75 t/ha. The trend between EM and yield starts the same as in 2002 but when the EM exceeds approx 120mS/m the yield declines as the EM increases. Poorest yields are in the heavy soil regions with some low yields in the lowest EM areas. Figure 5 indicates the areas with greater water ponding yielded the least. Figure 6 Indicates the low EM areas (dense gravelly profile) and high EM areas (heavy clay) have the greatest water-ponding potential which may explain the trend between EM and yield in 2003. The topography and soil change appear to be combining to create different growing environments which reduce yield in wet seasons.

To visually assess for the most problems areas, the Drain Points were over-layed on the yield map for 2003. It was evident they were mostly located in the lowest yielding areas. Gross margin affects of this could also be assessed to build confidence further of which areas to prioritise for drains.

Using the outcomes of soil analysis and the farmer's observations, the EM38 data was used to divide the paddock into 4 major soil zones. Each soil zone can be assessed for how potential water logging had affected yield and therefore gross margin.

Concerned only with assessing the productivity loss in the low lying areas of each soil class, the yield in Elevation Error zone of -15cm was used as the benchmark to compare with yield performance in the water-ponding areas. This was chosen as the benchmark as areas with an Elevation Error value higher than this were considered likely to suffer some degree of water-logging in extended wet periods or heavy rainfall events. In Figure 7 the Soil Zones are in sequence from the lowest to the highest EM38 survey values.

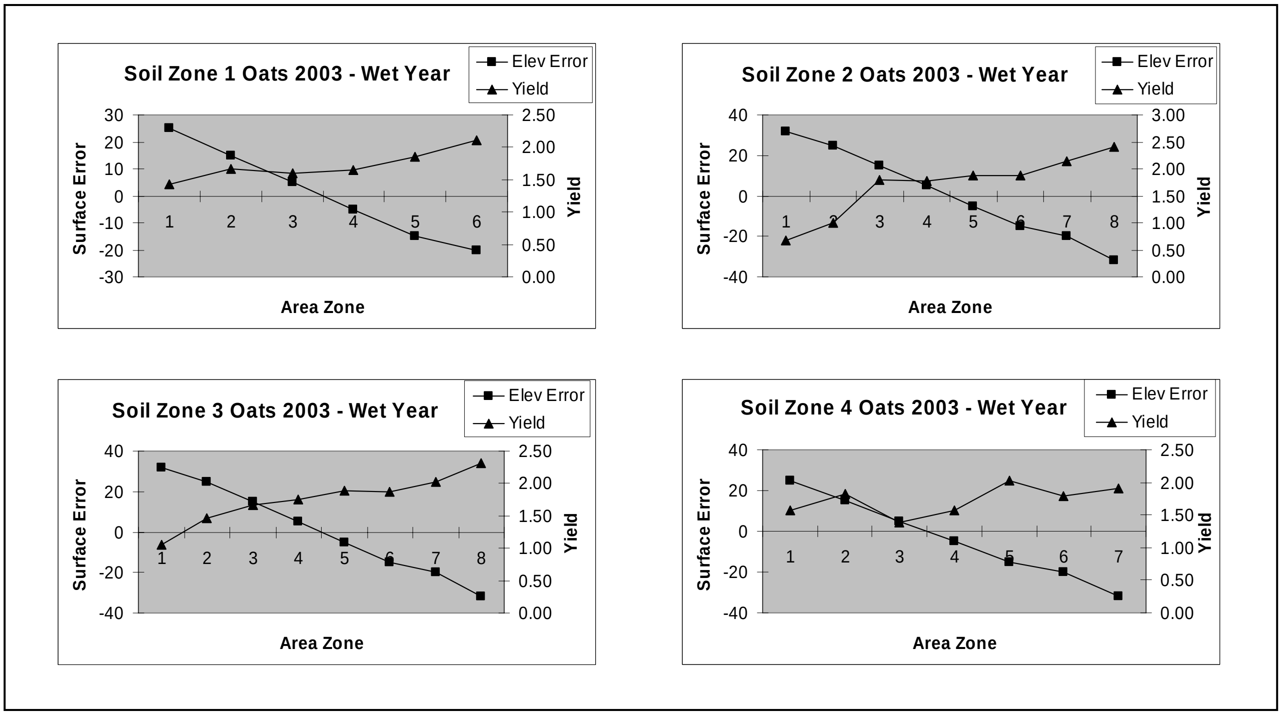


Figure 7: shows that in each soil zone there is a trend of yield increasing as the surface changes from water-ponding to shedding.

Table 1: Zone 1 dense gravel profile and Zone 4 heavy clay had the highest loss attributable to water ponding

Elev'n Error cm	Loss Zone 1	Loss Zone 2	Loss Zone 3	Loss Zone 4	Total Loss
-32		-$13.67	-$3.07		-$16.74
-25	-$5.17	-$19.12	-$10.59	-$2.59	-$37.47
-15	-$50.18	-$42.57	-$67.42	-$40.11	-$200.28
-5	-$547.29	-$387.57	-$391.90	-$1,290.29	-$2,617.06
5	-$160.55	-$13.42	$39.85	-$475.10	-$609.22
15	$0.00	$0.00	$0.00	$0.00	$0.00
20	$11.94	$22.49	$14.18	-$0.75	$47.87
32		$1.43	$3.56	$0.83	$5.82
	-$751.25	**-$452.43**	**-$415.39**	**-$1,808.01**	**-$3,427.08**

DESIGNING AND BUILDING THE DRAINS

Using both visual and GIS analysis the farmer was confident of which areas he should prioritise when designing the surface drains. In the Viewpoint software all the layers generated for this project were displayed and geo-referenced. This allowed the farmer to trial different drain pathways and then finalise the location of the main drains which supported a series of laterals. Having been created in Viewpoint the drains had their own geo-referencing. This meant they could be transferred to the field using Mobile DLog software allowing navigation to their exact location. Other layers like the Drain Points, Water Grid and Elevation Contours could be taken to the field in the same manner and would prove useful for making on-the-go alterations. Similarly any changes that were made in the field can be recorded and loaded back to the office computer in Viewpoint. He also used printed maps.

The farmer also had the option to have the drain design built to a more advanced level before transferring to the field. Each drain could be designed with controlled slope, direction and depth and this information also being geo referenced allows it to be taken the paddock for ease and precision of drain construction.

Farmer comments

> "The fact that I was doing it myself meant it would be a lot easier to work out where to do them from the PA maps than to try to master the fine art of in the field drainage planning. Wherever possible I set the drains either parallel or square to the working direction, so that machinery such as the sprayer didn't have to negotiate a lean one way then the other to get through the drains. Sometimes that was not practical so an angled drain was cut. This is not so important with the shallower drains. The auto steer on the tractor was good as I could preset the parallel and square angles, and placed the parallel ones at the edge of the boom spray swaths. That way both the sprayer and seeder tractor stay on good ground. Cutting the drains square or parallel also gives me the option of installing beds later if needed, as it is difficult to put beds through angled drains".

> "To design the drains so that the tractor would not be running along them I set the first A_B line at the fence. It was a simple case of finding the nearest track to the "valley" and then locking on. In some cases a "staircase" drain was cut (to avoid angles) with each parallel segment matching in with the tramlines".

> "Using the surface maps as well as my yield maps from a wet year helped me work out which low areas had to be drained, and which ones cope OK without drains".

SUMMARY

With specific objectives in mind the farmer has used information from different sources and his own accumulated of the project area to help with his planning. Yield data from his own yield monitor and high accuracy field data from the EM38 and elevation survey have been combined with soil analysis to provide him with intimate knowledge about the variation in the physical environment of the project area.

The Geographic Information System, AGIS, had a significant role in bringing together the various types of information, processing it properly and presenting it on a single platform so that it could be used to its best potential. The subsequent analysis of the information guided the farmer to where the problems areas existed and gave him confidence that the gypsum applications and surface drains were being directed where they would provide the best effect. With the aid of Precision Agriculture techniques he has been able to design a management plan that satisfies his goals and then implement this in the field on his own.

ACKNOWLEDGEMENTS

Mick and Marnie Fels 'Melaleuca', Esperance, WA – for their kind permission for use of information.

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Management of Overland Flow in CT Systems in the Northern Agricultural Region, W.A.

Peter Whale, Lyle Mildenhall and Paul Blackwell. Department of Agriculture and Food Western Australia, Three Springs and Geraldton Offices.

INTRODUCTION

Surface water management may offer benefits in cropping systems that use relatively downhill and parallel cropping directions with controlled traffic. We still need to know more about the erosion risks of these systems, but experience to date for low slopes (<2%) has been relatively encouraging. Improved soil structure with better water infiltration rates from no-till and CT (controlled traffic) systems are generating less run-off, and in-furrow flow separation by relatively downhill and parallel working appears to reduce flow concentrations. Where adverse conditions have produced very low levels of ground cover and markedly reduced furrow depth, and this is combined with high intensity short duration summer storms, uncontrolled overland flow has occurred and caused visible soil erosion. Surface water control structures would still be recommended to minimize erosive overland flow in circumstances with poor traffic control, low levels of attached cover and set-stock grazing. Low crest broad-based grade banks which allow for continuous downhill operation, are being developed and trialled.

The increasingly widespread use of techniques such as tramline farming, controlled traffic, and autosteer, combined with very wide equipment means that working on the contour, and between grade or contour banks, is often not practical. Broad acre farmers have moved to achieving the longest straight and parallel working runs which are now measured in kilometres. Structures such as contour and grade banks that interrupt the long runs have been removed. It has been argued by many farmers that these structures are no longer necessary because of the observed reduction in run-off as a result of the adoption of minimum tillage and stubble retention practices.

A project was initiated with funding from NLP in collaboration with the Liebe Group to research the level of erosion risk that farmers face in the adoption of long run mainly downhill, parallel cropping CT systems. The aim is to provide information on ways to minimize the risk of erosion via a technical manual, field days and presentations; and in particular web-based information.

FIELD OBSERVATIONS

These were undertaken at 4 sites: Riverside (Porter's) – 40 km N of Binnu; Mallee station (Groves) - 50 km north of Yuna; Pindar (Kerkmans) - 30 kms E of Mullewa; Buntine (Fitzsimmons) - 20 km East of Buntine; Sermon Road (Chappell's) – 30 km NE of Morawa.

The observations used the following methods:

a) Rainfall recording using a tipping bucket rain gauge to provide information on rainfall intensity and the duration of events.

b) Estimates of vegetative cover using quadrat counts.

c) Visual assessments of ridge stability - soil movement into furrows - surface wash and rilling or gullying - evidence of wind erosion - evidence of soil deposition.

d) Photographic records and physical measurements of rill and gully depth

e) Aerial photography analysis to establish water movement patterns after heavy rainfall events.

Rainfall simulation: (This was used as a technique for assessing maximum infiltration rates under storm conditions, rather than realistic simulation of natural rainfall). We used two methods:

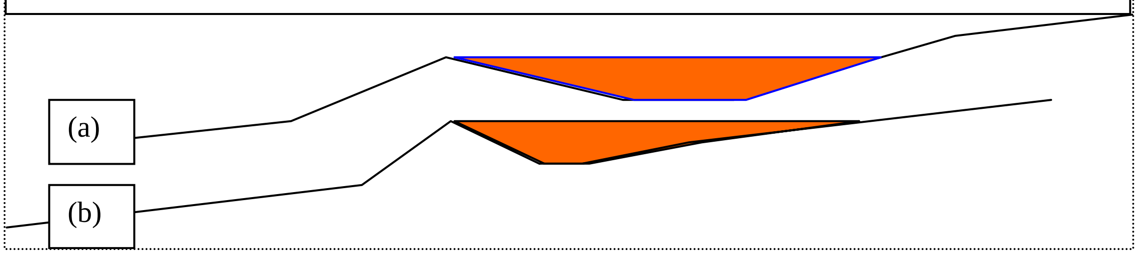
1. Collaboration with Landloch consultants from Toowoomba, Queensland in February 2006 measuring water runoff from simulated 100mm/hr rainfall events on paddock sites at Pindar and Buntine using a 2 m by 5 m area under an oscillating boom.
2. Use of a DAFWA mobile rainfall simulator with a 2 m x 2 m oscillating boom at Pindar, Buntine, Mallee Station, Riverside, and Sermon Road in May 2007, to help relate infiltration behaviour to soil structure and develop a simple visual indicator to predict maximum infiltration rates.

INSTALLATION OF TRIAL BROAD-BASED ROLL-OVER BANKS

[A broad-based roll-over bank is a low profile earth structure, surveyed on a gradient, with a wide flat channel that enables farm operations (seeding, spraying and harvesting) to be carried out at right angles to the direction of the bank. The bank would discharge into a grassed waterway. The main features are minimal interference with long run, downhill CT farming and no loss of arable area.]

Using design criteria originally developed in Queensland – the first trial at Buntine involved the modification of an existing grade bank to form a broad-based bank, and the second at Pindar was a new structure. The broad-based bank has a channel increased to between 4-5m compared to a conventional grade bank with a channel width of 1-2m. The bank construction straddles about 20 to 25m but now the whole bank area can be sown to crop. The bank was traversed by air-seeder in the planting operation with ease, but operation of a spray rig was more difficult and slower.

Comparison in shape and size between (a) new broad-based bank and (b) original grade bank at Buntine



Issues arising from cropping operations over the broad based bank in the 2006 winter growing season were:

1. Poor depth of seeding control on the crest of the bank, despite some capacity of the seeder to follow ground contours (DBS design).
2. Poor crop growth on the crest of the bank, probably due to poor crop nutrition in the ‘sour’ soil exposed from the centre of the original bank.
3. Difficulty traversing the bank with the spraying equipment (‘whip’ at the ends of the spray boom); it would be even more difficult at approach angles other than 90^{o}, depite slowing down.

4. Impracticality of harvesting the crop parallel to the direction of sowing; harvesting was done parallel to the bank alignment.

These issues have highlighted the need for more machinery design and development work.

Figure1. Air seeder unit traversing broad-based bank at Buntine 2006.

QUEENSLAND EXPERIENCE AND RESEARCH

Controlled traffic in broadacre farming has been applied in the cropping areas of Central Queensland and the Western Downs since the early 1990's mainly on land with slopes of less than 2%. There were uncertainties relating to potential runoff and soil erosion levels that prompted researchers to investigate the implications of the widespread adoption of CT farming in relatively downhill and parallel cropping directions. The following are some outcomes.

Li et al. (2001) found that "the steady infiltration rate for non-trafficked soils was 4 to 5 times greater than for trafficked soil regardless of cover levels but the presence of cover led to increased infiltration rates for both states". Tullberg et al. (2001) conclude that "an important issue is the reliability of having high cover levels present. If cover cannot be retained due to drought, tillage or other reasons, then the soil erosion risk is increased". Titmarsh et al (2004) write that "there is a consensus that contour banks are still required (on sloping country) regardless of traffic lane orientation. Where the layout requires farming over contour banks, the banks require flatter batters and higher maintenance. CTF field layouts (farming practices) that combine maintenance of soil cover with reduced tillage are very effective in this endeavor" (i.e. give the best combination of runoff and soil erosion minimization). "Further, it has been shown that traffic lane orientation influences runoff and soil erosion with lower gradient orientations resulting in less runoff and soil erosion". (Titmarsh et al point out that the field studies have been undertaken during low rainfall years)

OBSERVATIONS / RESULTS

Rainfall for the 2005-2006 seasons in the Northern Agricultural Region has been the lowest for years with areas in the north and east being declared drought affected. Field observations registered extremely low levels of cover, with the site at Riverside having significant wind erosion, and Mallee Station with heavy grazing pressure, which reduced furrow ridge heights to almost zero. This had dramatic effects at Riverside where a high intensity summer storm caused large scale overland flow and significant topsoil movement - the reduced capacity of the downhill furrows was not able to contain the rainfall volume (see Figure 2).

Runoff was measured with a simulated 100mm/hour rainfall event (collaborative effort between Landloch Consultancy and DAFWA) in paddocks at Pindar and Buntine with stubble cover levels of 5-10% in

February 2006. The greatest runoff rate was from the tramlines in a downhill working system (slopes 1.5 - 3%), and the least runoff from a deep cultivated soil between the tramlines, where the compaction had been removed. As the tramlines cover only 15 – 20% of the overall paddock area, there was less runoff from the downhill working than a cross slope system provided the soil was not compacted.

Further simulation work, using similar rainfall intensity, was undertaken at all of the five sites in May 2007 – similar results were observed with the effects of further reduced cover levels producing increased run-off rates across all sites.

Figure 2. Riverside site after 46 mm in 30 min. rainfall event in December 2006

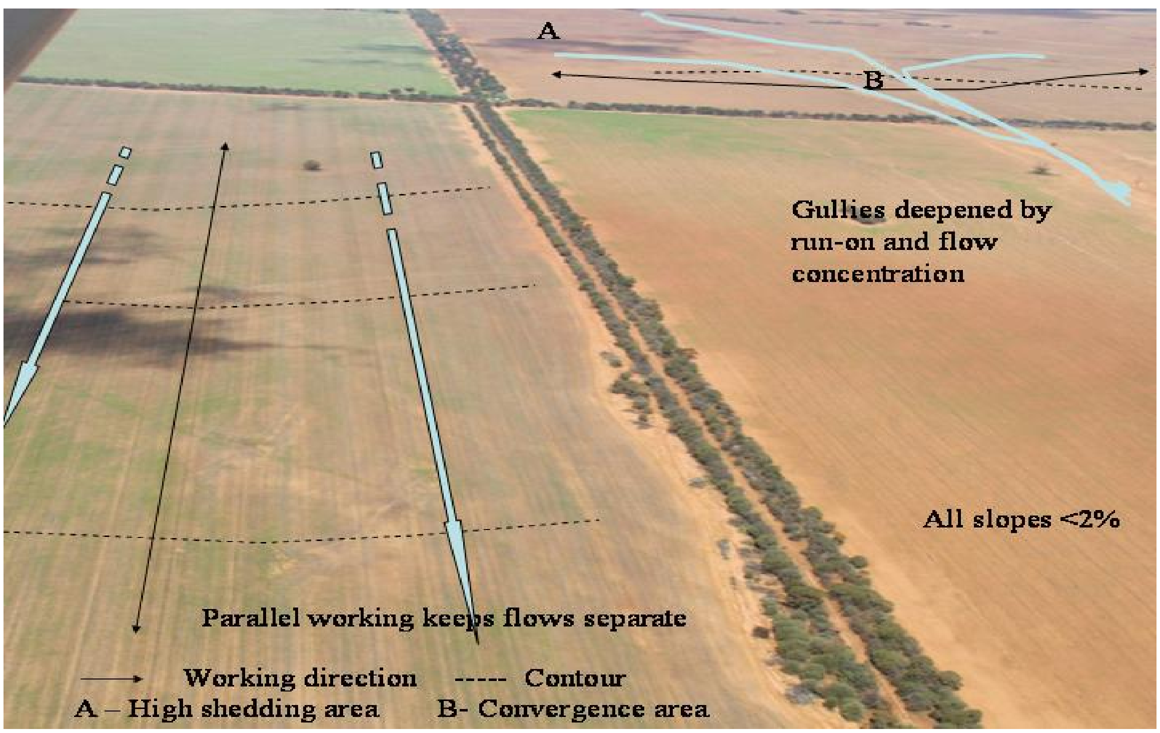


Figure 3- Aerial photograph (May 2005) of Sermon Road sites - contrasting effects of working up and down, and across the slope. Bottom left stable site in full cover and ungrazed; top right unstable site with low cover, run-on from high shedding area and flow concentrations by cross slope working.

Table 1: Summary of observations made over 3 years linked to potential risk and the main drivers/features that modify the risk level.

Case Study	Observation from Rainfall simulation	Support for general concept	Erosion/ Runoff risk	Observation over 3 years	Key features
Sermon Rd Downhill	Less runoff between tramlines with good cover	NT+CT + no stock -low need for banks on slopes <2%	Safe	Some runoff esp. on tramlines	Good traffic control No grazing /stubble retention promotes infiltration – furrows stay intact for flow separation
Sermon Rd Ariel paddock Across slope	Flow concentration at low points	Cover in inter row	High risk in intense storms	Cascade down slope to form rills – gullying at main convergence	Furrows overflow at convergence points – upland run-on areas with high shedding capability.
Riverside	Stubble loss from wind - drought. Levelling of ridges - still more infilt. in inter-row	NT+CT + no stock. Root mass in furrow – still good infilt. Upland area slope >4%	Low on slope <2% Moderate to high- on upland	Cover loss from dry season and wind – ridges flattened – storm caused overland flow and top-soil removal	Good traffic control No grazing /stubble retention – bank needed to reduce flow velocity from upland area
Pindar	More runoff in areas with wide row spacing	NT+CT + no stock.	Low on slope <2% Moderate to high on upland	Stable	Good traffic control No grazing /stubble retention – bank needed to reduce flow velocity from upland area
Mallee Station	No cover No defined furrow/ridges - low infilt. rate	Heavy grazing (set stocked), and soil loosening	High risk in current condition	Unstable – Surface loose	Grazing regime needs serious review Consistent traffic control areas needed
Buntine	Ripped sandy soil - good infilt.	NT+CT Managed grazing	Low	Stable	Consistent traffic control areas needed

CONCLUSIONS

Soil erosion by water can be viewed as a direct product of runoff and soil condition – the better the soil condition the greater the infiltration which in turn generates less run-off. The gentler the slope the less erosive power for the runoff produced.

More downhill operations at low slope may not be as risky as first imagined; however the risks are greatly increased by poor surface cover and low permeability soil structure. Where long working runs are used, broad-based banks (or other flow control measures such as filter strips across the slope) should be installed to manage flow length, cumulative flow volume and velocity.

To reduce soil erosion risk, it is vital that CT Farming layout and practices:

a) maximize rainfall infiltration by maintaining good soil structure, maximum traffic control and cover levels

b) have crop furrows draining to a safe disposal point with no reverse gradients or low spots

c) retain runoff generated within each traffic lane or furrow

d) maintain soil surface roughness in the crop area to increase erosion resistance

e) ensure that furrow gradients are considered when orientating the runs, to minimize any soil movement.

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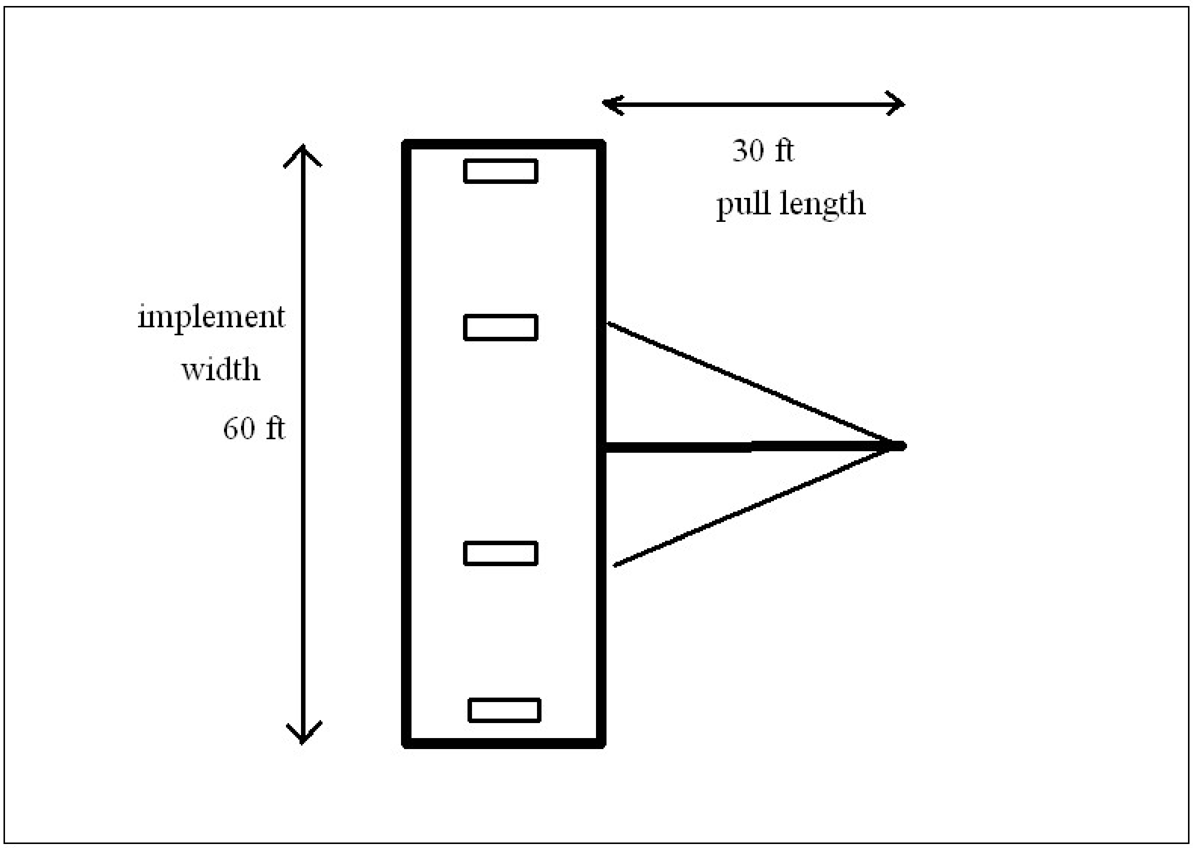
Factors Affecting the Tracking Performance of Implements

Brendan Williams, GPS-Ag Pty Ltd

For farmers considering implementing inter-row sowing selecting an implement that tracks well is very important. It is possible to modify existing seeders to improve their performance. The following is a guide for farmers to select implements that will have good tracking performance.

DRAWBAR LENGTH

a. General rule of thumb drawbar length should be half the implement width, e.g. 60ft implement needs a 30ft pull
b. Longer drawbars give more leverage and better tracking.



WIDTH OF IMPLEMENT

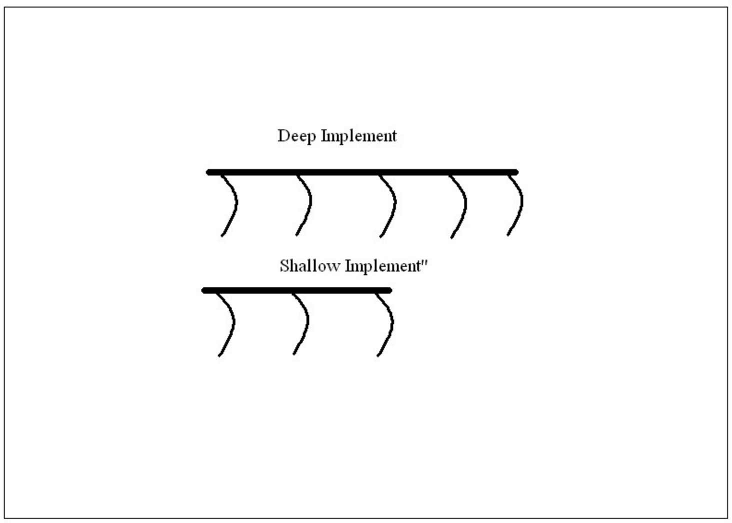
a. The wider the implement the worse the tracking because depth control and contour following capability is compromised as implements get wider.
b. 50-60 ft implements challenge tracking.

DEPTH CONTROL

a. Depth control across the implement is extremely important for good tracking, an implement that digs in more on one side than another will skew and track poorly
b. Having a level implement is very important for tracking
c. Independent depth control tynes like parallelograms solve this problem.

DEPTH OF IMPLEMENT

a. By depth of implement I mean the distance from the front rank of tynes to the rear rank of tynes.
b. Deeper implements will have a greater tendency to skew and follow last years rows.
c. Deeper implements are inherently less stable because of variations in depth control.



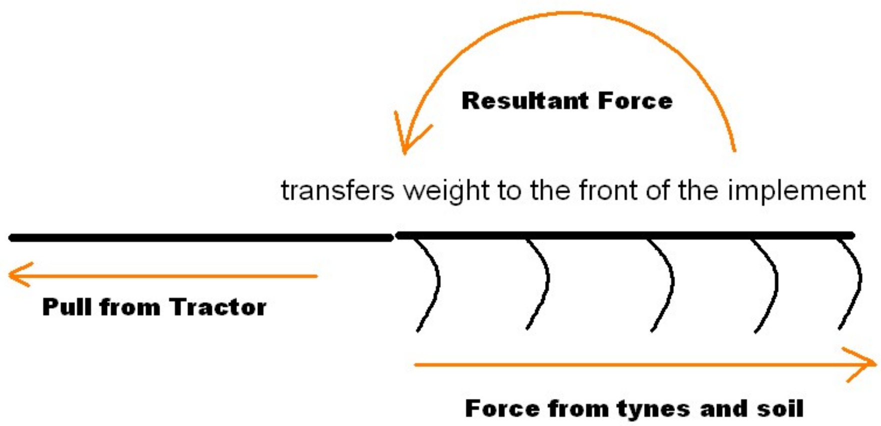
TYNE LAYOUT

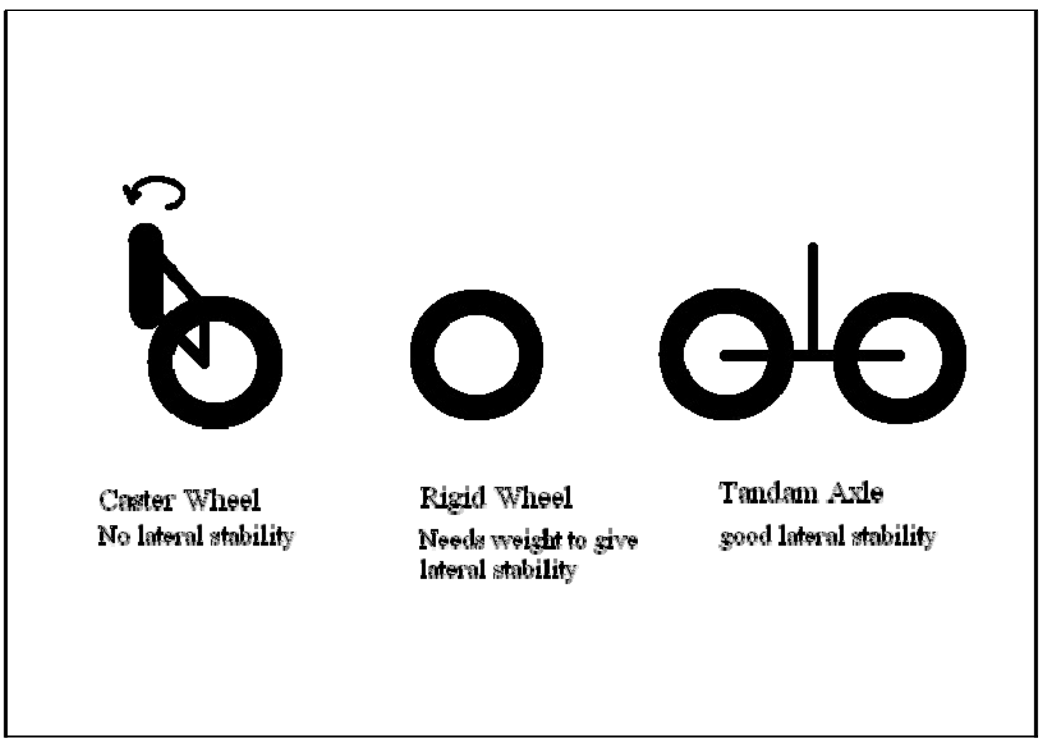
a. Tyne layout is important in that we need to have an even tyne layout, the layout needs to be symmetrical around the centre of the machine.
b. For example the lead tyne on the right side should be the same position on the left.
c. This gives equal loading left and right to balance the machine.

WHEELS AND TYRES

a. Caster (free steering) wheels offer no lateral stability so are less stable
b. Caster on the front on implements can often carry a lot of the load especially in heavy pulling situations (implements tend to rotate forward). So the rear tyres can carry little weight and so offer little stability.
c. Single axle wheels offer little stability

d. Tandem wheels offer more lateral stability than single wheels (lot more difficult to pull a tandem trailer around a sharp corner than it is a single axle trailer). Tandem axles want to run straight.
e. Non-caster single axle wheels front and rear of the implement are the most stable (but they are difficult to turn).
f. Remember wheels at the front tend to carry most of the load and hence offer stability.





SEEDER BOX - PULL BEHIND *VS* PULL BETWEEN

a. A "well designed" pull behind box will offer better tracking than a pull between box. By well designed we mean a box that has front steerable axle. Pull behind means the implement is nearer the tractor and so more closely follows the tractor.
b. A poorly designed pull behind boxes will be offer worse performance – those with non steerable axle. The box in this situation will tend to slide down slopes and pull the rig off line. So boxes with only one axle or that have front caster wheels will offer poor performance. Select a 2 axle box with the front steerable axle connected to the pull so as the box drifts down the slope the steer wheels point up the slope.

PREVIOUS PASSES

a. The worst situation for tracking arises when you may have had some tracks that run in the general direction but say not very straight or slightly unaligned with this years row this often is the case if the farmer has swapped from one steering system to another or has been using marker arm and now wants to use autosteer.
b. The implement runs for some time in last years mark, then eventually the run is far enough off line to jump out of last years run, the result is this is repeated up and down the paddock so you get a saw tooth type pattern created.
c. What can be done about this?
    i. Cultivate the paddock to get rid of old marks?
    ii. Work the paddock from a different direction – work at least 30 degree angle from previous marks.
    iii. Ensure you have a very stable implement – narrow, balanced with long drawbar.

TERRAIN

a. Undulating terrain and side slopes make accurate tracking more difficult
b. Try to work up and down slopes not across slopes
c. If working across slopes try to work in the same direction each time.
d. Undulations and Gilgai formations often mean the implement does not maintain an even depth and hence the load on the implement is unbalanced and causes the implement to skew.
e. Parallelogram / independent individual tynes alleviate this problem.
f. Shorter drawbars are probably better if you are working on side slopes.
g. If you have this type of country then narrower implements are better.

CTF and PA Tools – the Perfect Match

Don Yule and the CTF Solutions Team
www.ctfsolutions.com.au

ABSTRACT

The paper briefly reviews the basics of CTF and the benefits for farming systems, and the available PA Tools and their value in CTF systems. The paper examines the platform created by CTF to improve the triple bottom line and the complementary use of PA Tools to provide the next steps for CTF. Highlights include understanding productivity drivers, causes of variability and management opportunities; automated record keeping and measure to manage; on-farm R&D for system improvement; and building partnerships for achieving goals.

THE BASICS OF CTF

CTF specifically recognises that cropping is mechanised, wheel compaction is good for wheeltracks but bad for crop growth, and wheeltracks are spatially distributed.

The Basics of the CTF system defined by our experience so far are:

1. Property management planning. The PMP is based on natural resource identification and suitability, goals and needs analysis, and infrastructure.
2. Designed paddock and farm layouts for water management and infrastructure. Paddock layouts consider surface water flow and drainage, waterlogging, soil types and properties, wind direction and erosion, access and efficient transport, and logistics.
3. Controlled traffic or permanent wheeltracks to manage compaction, increase infiltration, and provide access and timeliness, accuracy and efficiency. All tractor and harvester wheels are on defined wheel tracks. Wheel tracks are typically 3 m wide (to suit the harvester). Low cost machinery modifications are available.
4. Matching machinery and auto-steer = precision. Machinery should be reduced to planter, sprayer and harvester with chaser bin. 9, 11 and 12 m units are grain options. 2cm RTK GPS auto-steer is recommended, particularly for marking at planting.
5. High cover levels - zero tillage. Controlled traffic makes accurate, efficient, effective and flexible herbicide applications possible.
6. Farmer/adviser/supplier partnerships – a team approach. Each farmer/farm combination is unique. CTF systems are developed through partnerships between land managers and technical advisers.
7. Measure to manage for continuous improvement, record keeping, on-farm R&D and problem solving. Many new technologies are available, and they all work better with CTF.

The theme of this paper is **"everything works better with CTF."**

The farming system impacts from these few basics all seem to be positive.

1. Optimum resource allocation and use – natural and purchased
2. Natural resource quality, manage resource degradation (compaction, water and wind erosion, waterlogging, deep drainage and salinity)
3. Access, efficiency, effectiveness, flexibility and most of all timeliness
4. Precise row, inter-row, wheeltrack management
5. Higher water availability and crop water use, i.e. productivity
6. Opportunities for dynamic, innovative management and continuous improvement.

In summary, CTF is a comprehensive and strategic systems approach; it is aimed at sustainability; it is triple bottom line; and it provides the essential spatial framework for most new technologies. We have CTF solutions for grain, cotton and cane, horticulture is still a challenge. The challenges for CTF are to achieve maximum profitability (how to maximise our NRM and machinery) and maximum performance and personal benefits (automated record-keeping with appropriate processing, reporting and actions).

APPLYING THE BASICS

1. **Improved agronomy.** CTF improves the soil physical and chemical fertility and our agronomy must use this to produce higher yields and increased incomes. Soil water relations are optimised, the fundamental driver of dryland farming. Growers have stated their goal as "**PRODUCTIVITY IS LIMITED ONLY BY LACK OF WATER**". Much on-farm research is needed to determine how best to farm the non-degraded soils that CTF produces. Conventional research approaches (varieties, crops, herbicides, etc) must also use CTF as the base to produce relevant information. Machinery issues are critical and team approaches are needed to progress planters, sprayers and harvesters to optimise CTF systems. Growers have done on-farm R&D that can provide a base and direction for the future.
2. **Auto–steer, 2 cm GNSS.** Growers with auto-steer report that this was the best investment they ever made. With CORS networks and much reduced prices, RTK auto-steer is now a must, the first investment to make in CTF, for accuracy, reduced driver fatigue and all drivers perform equally well.
3. **On-farm R&D.** The controlled traffic system with yield mapping facilitates strip experiments. Grower managed trials within the farming system ensure that results are applicable and quickly adopted.
4. **GIS computer based farm record systems.** CTF systems support automatic recording of farm operations and measurements, and incorporation of all information into a GIS based system for all spatial data.
5. **Use remote sensing.** Remote sensing such as multi-spectral aerial or satellite imagery offers cost effective, high resolution data to measure farm performance and responses to treatments. It links with yield monitoring and the spatial accuracy of CTF and does not interfere with farm operations.
6. **Use efficiencies as performance indicators.** Efficiencies reduce the year to year and season to season variability. Measures such as water use efficiency, machinery efficiency, and financial efficiency are useful.

PRECISION AGRICULTURE TOOLS

PA tools are digital, spatial, temporal and measure something (collect data).

Digital means computer ready.

Spatial means accurately located in space (you know where you are), and in the computer we can overlay data. Space has 3 dimensions – x, y and z. Time is also recorded.

Sensors measure yield, spectra, radiation, electrical properties, etc. The most common spectral data are multi-spectral – colours, infrared, thermal, etc. and now hyper-spectral (256 or more bands) are available. Radiation (gamma, magnetics and radar) is widely used in geology. EM is an example of electrical properties. These PA sensors provide information about landscapes, soils and crops and their spatial distribution.

Other important measurements, e.g. soil sample analyses and soil water, salt and pH are not well suited to spatial collection.

PA Tools are used to define and manage variability in crop yield, maturity and quality. Management options depend on the scale of definition. We manage wheel tracks, inter-row and rows with high resolution data; and soil types and management zones with coarse resolution data. Management should be based on understanding causes.

We want to manage paddocks uniformly, particularly at harvest time. Reducing variability is important, e.g. from machinery or waterlogging. Creating variability is bad, e.g. with contour banks, land leveling, roads and fences, and variable fertiliser inputs.

Successful PA tools include:

1. **Imagery.** Imagery is the powerhouse of PA tools, it can provide digital, spatial, temporal data from a range of sensors very easily at a low cost. Imagery can be satellite, aerial or proximal (close to the target, e.g. hand held or on a machine) and each has a place depending largely on the area of interest. Each can deliver 1m^2 pixels or less. Many sensors are available but these are in-direct measures of yield and biomass. So, we must evaluate the value of the data.
2. **Yield monitors.** The most basic measure of farm performance. Fundamentally the data quality depends on having a full comb all the time to ensure reliable and credible data. Yield maps should be "ground truthed" each season to remove known errors. Pixel size is about 400m^2.
3. **Topography.** With RTK GNSS, topography to 5cm resolution can be easily collected at a reasonable price. Topography is essential data for farm layout design and particularly for waterlogging management. Topography is typically related to soil types and a useful indicator of soil distributions. Topography pixels are about 200m^2. Growers with RTK GNSS can collect their own data.
4. **GNSS location.** The location log records where you are and where you have been when. These data are useful in GIS analyses to link an effect with prior actions.
5. **Soil properties.** These include EM (spatially measures electrical properties related to clay, water and salt content, pixel size about 200m^2) and soil sampling for PAWC and nutrients. Soil samples do not provide spatial data, the pixel size could be 100,000m^2.
6. **GIS Tools.** For data management and record keeping, for analyses and relationships among data layers, for identifying causes of variability, and for reporting as maps and graphs. These are

powerful tools but they depend on the quality of the data. If the data is variable, statistics can be used. This will hide the variability we want to understand and repair.

LINKING CTF AND PA TOOLS

CTF imposes a defined spatial distribution on all farm machinery activities, and defines variability by where it is and what caused it, e.g. wheel compaction. CTF ensures that one operation can be carried out in exact relation to past or future operations. CTF ensures quality data from yield monitors and the value of GIS analyses. When CTF is designed to reduce variability, particularly caused by waterlogging, erosion, compaction, fences and rocks, crops grow more uniformly and PA Tools work better. CTF supports collection of spatial, digital data in computer ready formats.

Imagery at small pixels is the key linkage with CTF because CTF aims to manage uniformly at about this scale, e.g. wheel track compaction, row and inter-row management. Therefore the variability created by random traffic is removed and other variability identified. The only value in high resolution imagery in non-CTF paddocks is to show why CTF is needed.

Imagery is also a proven agent of change. It shows what farmers know but in a way that can be understood and acted upon. Solutions become obvious. It is possible to drain low spots or move rock heaps, because then CTF will work much better. These in-efficiencies can be "managed" with random traffic.
Imagery is the tool but the driver of this change is the partnership between grower and adviser asking "what can we do with this information?" Many growers say "you have shown me what I already know", but "If you know everything, it's very hard to move forward".

Yield monitors. CTF ensures a full comb all the time, and this allows automated analysis of yield data, only the headlands are "fuzzy". The reliability and credibility of the data is assured and can be used with confidence. Yield maps no longer need to be stored for 5 years to find some consistency in the "fuzz".

Topography data are crucial for CTF layouts and identify solutions to waterlogging and drainage issues. The links to landscape properties and soil types are useful.

Pixel size. Our previous work harvesting single rows of crop identified large variability across the planter and due to wheel tracks. This led us to imagery with pixel sizes of $1m^2$, which has further identified a wide range of variability associated with random traffic, poor machinery performance, paddock histories and layouts, erosion and waterlogging, and weeds, pests and diseases. The causes were identified from the spatial distribution of the variability combined with the knowledge of the grower. This variability is caused by grower management and our priority is to reduce and manage it. As Neale and Chapman (these proceedings) have shown, this approach has been successful but in the GRDC PA Initiative we were the only team (of 12) routinely using high resolution imagery.

The common PA approach is to define management zones based on coarse data sets – yield monitors, EMs and Landsat imagery. The pixel size is greater than $200m^2$ and at this scale the variability and causes described above are not obvious. Management zones are typically related to soil types and landscapes, and managed by variable rate inputs.

GIS. High quality data, as CTF can provide, maximises the value of GIS and the confidence in the outputs. This allows automated data processing, rapid reporting back to growers and in-depth analysis. Statistical methods to smooth the data are not needed. Undoubtedly, handling the increasing volumes of data and information (we call this Information Rich Agriculture) is difficult with deficiencies in both software and support services. More software options are coming available but our GRDC project highlighted major deficiencies in support services across all PA tools.

Site Specific Management. The accurate positioning of CTF and PA tools allow management at very specific locations. Examples include inter-row management for stubble handling, weed control, fertiliser application; row management for pest and disease control, and foliar sprays; and wheel track management for weeds and compaction. Precise management also applies to layouts for drainage and runoff control.

USING PA TOOLS TO MAXIMISE CTF

Our goals with CTF and PA Tools are to maximise the efficiencies and effectiveness of farming systems.

We plan to achieve these by:

1. Maximising resource quality and use, both natural and purchased resources. CTF creates the platform and PA Tools support operations. These answers are generally known, but there is an enormous job to achieve adoption across industries and to train and maintain support services.
2. Measure to manage and managing variability. CTF reduces variability and provides the system where PA Tools are effective. PA Tools provide the data, processing and presentation. The PA Tools/CTF combination is the basis of forensic agronomy – how we identify problems, causes and solutions (see below).
3. Measure to market in terms of impacts and products. CTF and PA Tools should be marketed as a sustainable, environmentally friendly farming system. We should produce current and new products of very high quality and market them with a competitive advantage.
4. Continuous improvement through new approaches to on-farm R&D (see below).
5. Cooperation with independence. ACTFA was, in part, established to support cooperation among CTF growers. We have started a contractor's register but there is much to do to support adoption, marketing and R&D needs. CTF/PA Tools is not "on the radar" and much lobbying is required across the board. Other issues like mobile phone and broadband internet are of concern to CTF growers.

Forensic agronomy is about finding the causes of problems in the farming system. As mentioned here and described by Neale and Chapman, PA Tools in a CTF system allow in-depth analysis of crop and soil responses that can frequently identify both the causes of variability and possible solutions.

At 1-4 m^2 pixel scales waterlogging and erosion can be clearly identified and options identified with topography data; machinery performance is also obvious (compaction, overlaps, misses, inefficiency, trees and rock heaps); insect and disease damage quantified; responses to inputs (lime, fertiliser, manures, etc.) quantified. This remote sensing provides a new dimension to crop management.

High resolution data also add value to coarse data layers such as yield monitoring and Landsat imagery. GIS skills are essential, analysis is slow and involves large amounts of information. Automated analysis will be possible in the future but problem expression in each paddock could be different. This is a new concept and we have little experience.

Farm/Farmer R&D. The CTF platform and the measurement capabilities of PA Tools offer a whole new way to do on-farm research. Using strip trials as the basic approach, farmer/adviser teams can design, implement, measure and interpret a wide range of experiments. The basic unit would be a planter or sprayer/spreader width, so treatments are realistically large and practically within the farming system.

With a GPS controller, the plan could be loaded in and operations would continue as usual. This automatically marks the plots. Treatments related to any input are possible but also new crops, rotations, etc. Rate trials would be standard.

Crop responses are measured spatially with imagery and yield monitors, at data intensities far greater than research plots, e.g. IKONOS satellite imagery at $1m^2$ pixels, or 10,000 values/hectare. Other sensors could measure temporal changes.

The opportunity exists to analyse the data as treatment means but more importantly as response curves related to the background paddock variability as measured in the control strips. In one experiment, the responses across the whole paddock conditions are measured. Options to improve poor areas are identified and the good areas show potential yields and realistic targets. The interruptions to normal farm operations are minimal, and the results are relevant and easily adopted.

This approach requires considerable development. The farmer /adviser team involves new skills and roles, planning needs are totally new, implementation should be straight-forward but new analysis and interpretation methods are needed. The adviser role requires new applications of the usual R&D skills and close partnerships with growers. Other technical support may be required to make sure the tools work.

But the potential outcomes are worth it.

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