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**Crop Updates 2010 - Farming Systems**

Christopher R. Newman  
*Department of Agriculture and Food*

Jonathan England  
*Department of Agriculture and Food*

Stephen Gherardi  
*Department of Agriculture and Food*

Mohammad Amjad  
*Department of Agriculture and Food*

David Ferris  
*Department of Agriculture and Food*

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Authors

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Preserving phosphine for use in the Grain Storage Industry

Christopher R Newman, Department of Agriculture and Food, Western Australia

KEY MESSAGES

Incorrect use of phosphine since the 1950s, has led to escalating resistance in stored grain insects which threatens the continued use of phosphine at the farm level. Two weak resistance genes present in the insect population have combined to create strong resistance. This is common in eastern Australia and we have now had two outbreaks in Western Australia. Only fumigation in a tested sealed silo will slow the development of phosphine resistance in WA.

INTRODUCTION

Australia is one of the few countries in the world where phosphine is available to farmers to apply to protect grain in their own storages. The continued use of phosphine at the farm level in Australia however will depend on the ability to slow or arrest the development of phosphine resistance in all the major grain storage species present in the country.

Phosphine has been available to farmers since the 1950s when the label recommendations included the use of the product in unsealed storages and admixture to a grain stream. In 2008 that the label was changed and the two practices removed from the recommended use table. It is suggested the continued use of phosphine in this manner for many decades in Australia has led to an escalating resistance in stored grain insects.

In the 1980s Cooperative Bulk Handling abandoned the use of contact insecticides and created sealed storages in which to use phosphine exclusively for protection of export grain. This has placed even more reliance on phosphine for the profitability of the entire grain storage industry in WA.

INVESTIGATION INTO THE DEVELOPMENT OF RESISTANCE

As part of the measures taken to slow the development of phosphine resistance in WA samples of grain insects from farm and central storages have been taken from grain storages since 1985 and submitted for bioassay to determine tolerance to phosphine. This provides information on the status of phosphine resistance, providing feedback to the farmer and grain store managers that resistance discovered in their grain insects is an indication to improve the fumigation procedure.

The test used is the ‘discriminating dose test’ where the insects are exposed to an atmospheric concentration of the fumigant under controlled conditions that approximates to the amount needed to kill 99.9 per cent of the adult insects of a fully susceptible strain (Taylor 1986).

Insect resistance is classified as ‘weak’ or ‘strong’ and this distinction is applied from the research by Ebert et al. (2003) finding that the tolerance to phosphine in Rhyzopertha dominica is controlled by two major genes. One gene is responsible for ‘weak’ resistance but those insects with a stronger resistance have an additional gene which on its own has little effect but in combination enhances the effect of the other gene. Over a series of poor fumigations in poorly sealed silos the insects carrying the weak gene survive and as they increase in numbers there is greater chance they will mate with the carriers of the other gene resulting in the progeny expressing ‘strong’ resistance characteristics. A failure to effectively eliminate this strong resistant strain during subsequent fumigations will further select the most resistant individuals in the population with an ability to withstand a higher concentration of phosphine.

Since the commencement of the testing program there has been a steady escalation in grain insects showing a resistance to phosphine (DAFWA report 2009) (Figure 2). In WA the average across all species shows up to 48 per cent of insects tested have a ‘weak’ resistance to phosphine with a range of 15–70 per cent between species. The selection of grain farms for sampling is completely random, and the variability each year in the numbers found to have weak resistance is most likely the result of sampling intensity (Emery pers. comm. 2010). In the eastern states of Australia 70 to 100 per cent of
insects in the Northern GRDC region and 53–83 per cent in the southern GRDC region exhibit a weak resistance (Collins pers. comm. 2006). In 2007 strong resistance to phosphine had been detected in the Northern region but remained below 10 per cent of the 253 insect samples analysed. (Collins pers. comm. 2007).

When the test results of individual insect species are tabled for WA (Table 2) (Emery and Chami pers. comm.). Tribolium castaneum (Herbst) is showing the highest weak resistance and in two cases up to 2009 have been found to have ‘strong’ resistance. In both cases Tribolium castaneum (Herbst) is the dominant species making it more likely that a high proportion of the insect population contains the weak resistance gene and that there will be a cross fertilisation of the two major genes.

**Eradication of strong resistant strains**

To this point there have been two strong resistant strains discovered in WA As part of the on going campaign to reduce the development of phosphine resistance in WA it was decided by Department of Agriculture and Food, Western Australia (DAFWA) that eradication of strong resistant strains should be conducted. The aim was to demonstrate the procedures needed to the farmer so that the strain remains in check but also to understand the process needed to achieve eradication.

The procedure includes:

- Re-sample insects from the property and re-test in the laboratory for resistance factor and confirmation testing by the former Department of Primary Industry and Fisheries in Queensland.
- Confirmation of strong resistance initiates a farm visit to assess the scale of the problem and plan a clean up and fumigation with the owner.
- A further visit to the farm prior to harvest is required to ensure hygiene procedures have been completed and the silos sprayed internally with a contact insecticide. In addition contact insecticide is applied underneath and around the silos and in any former derelict grain storage areas that might provide safety for grain insects. Grain handling equipment is treated with contact insecticide particularly harvesters which are notorious for retaining harvest residue and providing a harbourage for grain insects. Silos are checked for gas tightness and rubber seals replaced as needed, oil in the pressure relief valves is topped up.
- After harvest and when the farmer has finished loading grain into the silos, DAFWA personnel revisit the property to fumigate the grain. This involves a pressure test of the silo and loading phosphine at the label rate of 1.5 g of Aluminium phosphide (AlP)/m³ into the headspace onto a wide tray that allows the AlP tablets to lay one deep and allow rapid release of the phosphine.
- The validation of the treatments is a work in progress and to this point we have tried ground traps baited with whole and crushed grains and sieving the grain in the silos. Future validation checks will involve headspace pitfall traps and intensive sieving of the grain at outturn.

**CONCLUSION**

The lower level of phosphine resistance encountered in WA is most likely due to the ongoing GRDC funded extension campaign the sealing of the central storage system by CBH, and the response by silo manufacturers to seal transportable silos.

However, other mitigating factors may have played a part in slowing the development of phosphine resistance. For example, the smaller amount of grain held on farms for domestic trading compared to eastern Australia, the majority of grain grown is delivered direct from field to the central system and 85 per cent of grain held under high quality central storage conditions is exported.

With the dismantling of the centralised marketing system it is anticipated there will be more storage installed on farms, a larger amount of grain traded in small parcels and greater use of phosphine.

To ensure the grain meets customers specifications there will need to be more professionalism applied to farm grain management than in previous years. This includes more effective fumigation measures to avoid resistance selection.

**KEY WORDS**

farm fumigation, phosphine, resistance
ACKNOWLEDGMENTS
Thanks to Rob Emery and Michelle Chami for providing the data for Figure 2.

Project No.: DAQ 00158
Paper reviewed by: Rob Emery

REFERENCES

Demonstrating the benefits of grazing canola in Western Australia

Jonathan England, Stephen Gherardi and Mohammad Amjad, Department of Agriculture and Food, Western Australia

KEY MESSAGES

- Grazing a canola crop at a high stocking rate with young growing lambs is a valuable way to increase the potential returns from a crop.
- The gross margin for the grazed crop was $61/ha greater than that for the ungrazed crop.
- The two hybrid varieties (46Y78 and Hyola mix) appear to be more resilient to grazing with their yields being less affected than that of the open pollination variety (44C79).
- Grazing retarded flowering by around three to four weeks, which has the potential to push maturity past the frost risk period.
- The stage of development of the canola crop at the time of grazing, the period of grazing and the length of growing season post grazing can all have a significant impact on yield.

AIMS

To measure the potential benefits of grazing canola using South African Meat Merino (SAMM) x Merino lambs on a property at Dumbleyung.

METHOD

A demonstration was undertaken to compare the gross margin returns from a grazed and ungrazed canola crop in 2009. Three varieties of canola (46Y78—Clearfield hybrid late maturity, 44C79—Clearfield open pollination and Hyola mix—Clearfield/open pollination hybrids early maturity) were dry sown on 19 May in a 11.4 ha paddock (3.8 ha per variety). The row spacing was 25 cm at a seeding rate of 4 kg seed/ha.

Prior to grazing, five exclusion cages were placed equidistantly into each of the three canola varieties. Initial plant number observations were undertaken after establishment which showed a degree of variability in establishment within the plots as might be expected in a commercial planting. On 3 August, the paddock was stocked with a total of 395, four month old, SAMM x Merino lambs at a stocking rate of 35 lambs/ha. 218 of the lambs had previous experience of grazing canola, whereas the remaining 177 lambs had no experience and were weaned directly onto the canola crop. A random sample of 50 lambs from each of the two groups was weighed and condition scored prior to going onto the plots.

Following removal from the plots on 24 August, two random samples of 50 lambs, representing each weaning group were weighed and condition scored. The liveweight data was used to calculate the liveweight change over the grazing period. There was no additional fertiliser applied post grazing, but all plots were sprayed post grazing with a mix of 150 mL Lontrel and 500 mL Select, with 375 mL Intervix added to the mix for the two plots with the two Clearfield varieties 46Y78 and 44C79. The crop was then allowed to regrow and mature to the point of harvest.

A 50 cm x 50 cm area of ungrazed crop inside each of the 15 cages (five cages/variety) was hand harvested on the 11 November. The same area of grazed crop (along the same rows as the ungrazed crop) was hand harvested on the 24 November at a distance of 10 m from each of the 15 cages. At time of harvest the number of plants and stems were recorded for each of the 50 cm x 50 cm harvest areas. The samples were threshed and the yield of grain and harvest index determined for each of the samples.
RESULTS

Sheep liveweight and condition score

The mean liveweight and condition score of the SAMM x Merino lambs pre and post-grazing and the change over the 24 day grazing period is presented in Table 1. The results showed that the lambs that had prior experience in grazing canola grew faster than those that had no prior experience (282 g/day cf. 189 g/day). The results are confounded by the fact that those that had no prior experience were also weaned directly onto the canola.

Crop characteristics and yield

The number of plants, stems, stems/plant and yield for the grazed and ungrazed canola varieties is presented in Table 2. Grazing resulted in a doubling of the number of stems/plant for each of the varieties. The onset of flowering was delayed by around three to four weeks across all varieties due to grazing. Grazed canola plants can compensate yield by producing more stems or branches if spring and finish of the season are favourable. Grazing reduced the yield of canola for each of the three varieties which may be due to dry finish in 2009. The yield for the grazed crops was reduced by 33, 42 and 72 per cent for Hyola, 46Y78 and 44C79 varieties respectively. This was not unexpected considering the late time of sowing and resultant grazing of the canola varieties. Grazing commenced at about the time of stem elongation which is considered too late to avoid an effect on yield. The farmer was prepared to forgo the yield of canola because it allowed him to defer his pastures and saved him the cost of having to feedlot the lambs. The hybrid canola varieties suffered the smallest reduction in yield.

Table 1 The mean liveweight (LW) and condition score (CS) pre and post-grazing and the change in liveweight for the SAMM x Merino lambs with prior and no prior experience in grazing canola.

<table>
<thead>
<tr>
<th>Prior experience</th>
<th>No prior experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW pre (kg)</td>
<td>30.7</td>
</tr>
<tr>
<td>LW post (kg)</td>
<td>37.5</td>
</tr>
<tr>
<td>LW change (g/h/day)</td>
<td>282</td>
</tr>
<tr>
<td>CS pre (kg)</td>
<td>3.4</td>
</tr>
<tr>
<td>CS post (kg)</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Table 2 The average number of plants, stems, stems/plant and yield (per 0.25 sq metre hand harvested area) for the grazed and ungrazed canola varieties.

<table>
<thead>
<tr>
<th></th>
<th>46Y78 Ungrazed</th>
<th>46C79 Grazed</th>
<th>44C79 Ungrazed</th>
<th>44C79 Grazed</th>
<th>Hyola mix Ungrazed</th>
<th>Hyola mix Grazed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of plants</td>
<td>11</td>
<td>10</td>
<td>14</td>
<td>10</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>Number of stems</td>
<td>11</td>
<td>21</td>
<td>15</td>
<td>21</td>
<td>14</td>
<td>25</td>
</tr>
<tr>
<td>Stems/Plant</td>
<td>1.0</td>
<td>2.1</td>
<td>1.1</td>
<td>2.1</td>
<td>1.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Yield (t/ha)</td>
<td>1.38</td>
<td>0.73</td>
<td>1.88</td>
<td>0.53</td>
<td>1.73</td>
<td>1.17</td>
</tr>
</tbody>
</table>

Economic analysis

An economic analysis of the grazing trial shows that the total returns from grazing were higher than those for the ungrazed crop (Table 3). The gross margin for the grazed crop was $61/ha higher than that for the ungrazed crop ($770 cf. 709/ha). The opportunity exists with an earlier sowing ‘to have your cake and eat it too’ that is to achieve a similar length of grazing with a minimal effect on yield.
Table 3  A comparison of the gross margin ($/ha) for grazed versus ungrazed canola

<table>
<thead>
<tr>
<th></th>
<th>Ungrazed</th>
<th>Grazed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canola ($/ha)*</td>
<td>709</td>
<td>345</td>
</tr>
<tr>
<td>Sheep ($/ha)**</td>
<td>N/A</td>
<td>425</td>
</tr>
<tr>
<td>Total returns ($/ha)</td>
<td>709</td>
<td>770</td>
</tr>
</tbody>
</table>

Note: There are no allowances made for freight, commissions, levies, etc. in these analyses.
** Assumes dressing per cent of 45 per cent and a dressed price for lambs of 500 ¢/kg or 225 ¢/kg live. The return per ha is then total bodyweight gained during grazing/ha by the estimated live price.

CONCLUSION

Grazing a canola crop at a high stocking rate with young growing lambs is a valuable way to increase the potential returns from a crop.

This demonstration showed that gross margin for the grazed crop in 2009 was $61/ha greater than that for the ungrazed crop.

Grazing reduced the yield of each of the varieties with the hybrid varieties being less affected.

Grazing also retarded flowering of all of the varieties by around three to four weeks which has the potential to push their maturity past the frost risk period.

The stage of development of the canola crop at the time of grazing the period of grazing and the length of growing season post grazing can all have a significant impact on yield.

KEY WORDS

Grazing canola, hybrid canola varieties, liveweight change, condition score, canola yield

ACKNOWLEDGMENTS

Thanks to Growers, Dale and Terry Cronin for seeding and managing animal grazing trials at their property. Thanks to the seed companies including Canola Breeders, Pioneers Australia and Pacific Seeds for arranging seed for these trials and to Nufarm for providing Intervix for the spraying of the Clearfield varieties.

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Paper reviewed by: Alison Lacey, DAFWA, Narrogin
Buloke barley yield when pasture-cropped across subtropical perennial pastures

David Ferris, Department of Agriculture and Food, Western Australia
Phil Ward and Roger Lawes, CSIRO

KEY MESSAGES
A focus research site was established south-west of Moora in 2008 to collect detailed measurement on the performance of different pasture cropping systems. This paper presents grain yield results for the first crop sown across different perennial pasture species. Collective results (2009–11) will be used to update farming systems models, measure NRM outcomes and evaluate the profitability of different pasture cropping systems.

The type of perennial pasture and nitrogen rate (50 vs 80 N) appear to influence the performance of barley when pasture-cropped across subtropical species on a deep pale sand. All pasture cropping treatments yielded more than 2.4 t/ha. Some pasture cropping treatments resulted in a yield loss (nil to 14 per cent) relative to the control (barley crop without a perennial base, and 50 N).

For pasture cropping systems to be viable any loss in grain yield must be offset by an increase in livestock returns from grazing of extra green feed over summer and/or improved distribution and quality of feed resources.

It is important to note that perennial options other than subtropical species (e.g. native grasses, lucerne or even bluebush) might underpin pasture cropping systems in other agro-climatic zones in WA. Likewise, the suite of crop species and varieties suitable for pasture cropping systems in WA (for either grain or forage production) is still unknown.

AIMS
The EverCrop project in the Future Farm Industries (FFI) CRC aims to evaluate the viability of pasture-cropping systems in the medium rainfall zone of the Northern Agricultural Region in terms of profit, risk and NRM outcomes.

This experiment aims to evaluate the performance of crops (barley in 2009) when pasture cropped over different perennial species established on deep pale sands of the West Midlands region.

BACKGROUND
Pasture cropping is a grower-initiated farming system where annual crops are sown directly into summer-active perennial pastures. In NSW, pasture cropping has proved to be profitable in some situations (Millar and Badgery 2009). In their temperate climate the technology is generally based on native (C4) pasture species; and success is dependent on winter dormancy in perennial pastures, effective weed control, and adequate soil fertility and moisture (Badgery and Millar 2009).

In WA, the climate, soils and occurrence of native pasture species differ significantly from NSW. However, the low prevalence of native pasture species across the WA wheatbelt may not necessarily limit the opportunity to test pasture cropping in WA. Over the past decade a number of commercialized perennial species such as Rhodes, Panic, and Signal grass have proved successful on sand-plain soils across the northern and southern agricultural regions of WA (Moore et al. 2009). As these subtropical species are summer-active, the question posed by innovative growers who have adopted them is: ‘Can we pasture crop across subtropical grasses without limiting crop yield?’

Over the next three years the FFI CRC EverCrop team will work closely with growers and agronomists in the Northern Agricultural Region (through Local Adaptation Groups) to evaluate and refine pasture cropping systems in WA (see companion paper). This team includes officers from the Department of Agriculture and Food, Western Australia, CSIRO, UWA and Evergreen farming with expertise in systems research and development, biophysical and economic modelling, and group facilitation and extension.
**METHOD**

In 2008 a site was established south-west of Moora (391147 m E, 6593977 m N) on a deep pale sand to evaluate the viability of pasture cropping in the Northern Agricultural Region of WA. The site was set up to compare the profitability and NRM benefits of three general farming systems: Continuous crop, permanent perennial pasture and pasture cropping. Annual volunteer pasture was killed with a knockdown spray (August) prior to sowing perennial species (4–5 kg/ha seed) on 3 September 2008.

Ten cropping treatments were implemented in 2009 (Table 1) and four permanent pasture treatments (not reported here). Plots were 30 m long, 6 m wide (3 replicates per treatment), and sown with a disc seeder (36 cm row spacing) with trailing press wheels. Pasture cropping treatments had different perennial bases (Katambora rhodes, siratro, and Gatton panic at 72 cm and 36 cm row spacing).

Soil samples were collected (0–10 cm) on 19 May 2009 from the 6 plots where a perennial had not been established; soil was collected at 2 depths (3 positions per plot) and sent to CSBP for analysis. The overall chemical properties for the top soil at the focus site are given in Table 2.

### Table 1. Treatment description and codes

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Panic-PC80N</td>
<td>Gatton panic</td>
<td>36 cm row spacing</td>
<td>Pasture cropped</td>
<td>Buloke barley</td>
<td>80 kg N/ha</td>
</tr>
<tr>
<td>Panic-PC50N</td>
<td>Gatton panic</td>
<td>36 cm row spacing</td>
<td>Pasture cropped</td>
<td>Buloke barley</td>
<td>50 kg N/ha</td>
</tr>
<tr>
<td>W-Panic-PC80N</td>
<td>Gatton panic</td>
<td>72 cm row spacing</td>
<td>Pasture cropped</td>
<td>Buloke barley</td>
<td>80 kg N/ha</td>
</tr>
<tr>
<td>W-Panic-PC50N</td>
<td>Gatton panic</td>
<td>72 cm row spacing</td>
<td>Pasture cropped</td>
<td>Buloke barley</td>
<td>50 kg N/ha</td>
</tr>
<tr>
<td>Rhodes-PC80N</td>
<td>Rhodes grass</td>
<td>36 cm row spacing</td>
<td>Pasture cropped</td>
<td>Buloke barley</td>
<td>80 kg N/ha</td>
</tr>
<tr>
<td>Rhodes-PC50N</td>
<td>Rhodes grass</td>
<td>36 cm row spacing</td>
<td>Pasture cropped</td>
<td>Buloke barley</td>
<td>50 kg N/ha</td>
</tr>
<tr>
<td>Siratro-PC80N</td>
<td>Siratro</td>
<td>36 cm row spacing</td>
<td>Pasture cropped</td>
<td>Buloke barley</td>
<td>80 kg N/ha</td>
</tr>
<tr>
<td>Siratro-PC50N</td>
<td>Siratro</td>
<td>36 cm row spacing</td>
<td>Pasture cropped</td>
<td>Buloke barley</td>
<td>50 kg N/ha</td>
</tr>
<tr>
<td>Annual-CC80N</td>
<td>Annual</td>
<td>–</td>
<td>Continuous crop</td>
<td>Buloke barley</td>
<td>80 kg N/ha</td>
</tr>
<tr>
<td>Annual-CC50N</td>
<td>Annual</td>
<td>–</td>
<td>Continuous crop</td>
<td>Buloke barley</td>
<td>50 kg N/ha</td>
</tr>
</tbody>
</table>

* District practice, considered the control.

### Table 2. Soil chemical properties of the focus research site at Moora

<table>
<thead>
<tr>
<th>Depth</th>
<th>Ammonium nitrogen</th>
<th>Nitrate nitrogen</th>
<th>Phosphorus Colwell</th>
<th>Potassium Colwell</th>
<th>Sulphur</th>
<th>Organic carbon</th>
<th>Conductivity (CaCl₂)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>mg/kg</td>
<td>mg/kg</td>
<td>mg/kg</td>
<td>mg/kg</td>
<td>mg/kg</td>
<td>%</td>
<td>dS/m</td>
<td></td>
</tr>
<tr>
<td>0–2</td>
<td>11.2</td>
<td>34.2</td>
<td>31.6</td>
<td>96.2</td>
<td>18.3</td>
<td>2.9</td>
<td>0.16</td>
<td>6.2</td>
</tr>
<tr>
<td>2–10</td>
<td>4.4</td>
<td>13.8</td>
<td>8.7</td>
<td>32.3</td>
<td>4.5</td>
<td>0.9</td>
<td>0.06</td>
<td>5.0</td>
</tr>
</tbody>
</table>

A facilitated discussion was held with the EverCrop Local Adaptation Group (Moora). The group recommended aiming for a 2.5 t/ha crop and supplying 50 N, 12 P, 25 K and 12 S. The trial paddock was considered marginal for cropping due to non-wetting, erosion risk, and loss of organic carbon/fertility when cropped. Historically it has been cropped every 4–5 years and is volunteer pasture (e.g. barley grass) in pasture years.

In 2009, a knockdown (Spray.Seed 1 L/ha) was applied, and perennial pastures were slashed (height 5 cm) prior to seeding. Buloke barley (70 kg/ha) was sown on 3 June with a disc seeder (8 row, 180 cm spacing) with trailing press wheels across all cropping treatments. Agstar extra (80 kg/ha) was drilled at sowing; a blend of sulfate of ammonia (50 kg/ha), murate of potash (50 kg/ha) and urea (30 kg/ha) was topdressed across all treatments at the three leaf stage; and urea was also topdressed at two different rates (30 or 100 kg/ha) at the six leaf stage according to treatment. Broadleaf weeds and pests were controlled by spraying Barracuda (800 mL/ha) and Dominex (100 mL/ha) on 16 July.
Perennial pasture biomass was assessed by randomly cutting three representative quadrats (50 x 72 cm) per plot at a height of 5 cm. Samples were cleaned, oven dried and weighed. Grain was harvested using a small plot header from two 1.44 by 19 m strips per plot (i.e. 8 seeding rows).

RESULTS

Total rainfall recorded for 2009 at the Moora focus site was 431 mm (Table 3). 362 mm fell from May to September (inclusive). There were no significant rainfall events over the 2008/09 summer.

Table 3. Monthly rainfall (mm) at the Moora focus site in 2009 and long term average

<table>
<thead>
<tr>
<th>Year</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>16</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>42</td>
<td>78</td>
<td>107</td>
<td>90</td>
<td>45</td>
<td>16</td>
<td>29</td>
<td>0</td>
<td>431</td>
</tr>
<tr>
<td>Average</td>
<td>11</td>
<td>14</td>
<td>15</td>
<td>25</td>
<td>67</td>
<td>90</td>
<td>94</td>
<td>76</td>
<td>50</td>
<td>26</td>
<td>16</td>
<td>7</td>
<td>493</td>
</tr>
</tbody>
</table>

Crop establishment was uneven and plant density low (av. 83 pl/m²) (Table 4). This was likely due to the non-wetting nature of the soil and persistent shallow furrows that had formed 9 months earlier when perennial pastures were sown.

Barley sown in line with district practice (Annual-CC50N) yielded 2.8 t/ha with 8.9 per cent protein. Using this as a reference (or ‘control’) there appeared to be a yield penalty (nil to 14 per cent) for crops sown across perennial grass treatments (Table 4). However, the yield penalty was only significant for the crop sown across Gatton panic and fertilized with 80 units N (Panic-PC80N).

There was a significant yield boost (16 per cent) in response to additional nitrogen (80 v 50 N) for the ‘Annual-CC80N’ crop treatment (i.e. no perennial base; Table 4). By contrast the higher nitrogen rate tended to result in a greater yield penalty than the lower nitrogen rate for Gatton panic treatments; while barley sown over the sparse Siratro plots (< 5 pl/m²) produced similar yields to the control irrespective of nitrogen treatment.

Protein content tended to be greater for higher fertility treatments (Table 4) but only the ‘Siratro-PC80N’ treatment was significantly greater than the control (9.4 v 8.9 per cent). 1000 grain weight was slightly lower in the 80 N Gatton panic treatments compared to the control (40.5 av. vs 41.8). There were no significant differences between treatments for other quality attributes (average moisture content, 9.67 per cent; hectolitre weight, 68.7 kg/HL, and screenings < 2.5 mm, 4.9 per cent).

Table 4. Plant density, Grain yield and protein content

<table>
<thead>
<tr>
<th>Treatment code #</th>
<th>Crop density 14 July 2009 (pl/m²)</th>
<th>Grain yield (t/ha)</th>
<th>% of Control</th>
<th>Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panic-PC80N</td>
<td>78</td>
<td>2.42</td>
<td>86</td>
<td>8.9</td>
</tr>
<tr>
<td>Panic-PC50N</td>
<td>84</td>
<td>2.63</td>
<td>94</td>
<td>8.7</td>
</tr>
<tr>
<td>W-Panic-PC80N</td>
<td>71</td>
<td>2.58</td>
<td>92</td>
<td>9.3</td>
</tr>
<tr>
<td>W-Panic-PC50N</td>
<td>80</td>
<td>2.85</td>
<td>101</td>
<td>8.8</td>
</tr>
<tr>
<td>Rhodes-PC80N</td>
<td>94</td>
<td>2.66</td>
<td>94</td>
<td>8.9</td>
</tr>
<tr>
<td>Rhodes-PC50N</td>
<td>89</td>
<td>2.55</td>
<td>91</td>
<td>8.7</td>
</tr>
<tr>
<td>Siratro-PC80N</td>
<td>72</td>
<td>2.81</td>
<td>100</td>
<td>9.4</td>
</tr>
<tr>
<td>Siratro-PC50N</td>
<td>91</td>
<td>2.93</td>
<td>104</td>
<td>9.3</td>
</tr>
<tr>
<td>Annual-CC80N</td>
<td>86</td>
<td>3.27</td>
<td>116</td>
<td>9.8</td>
</tr>
<tr>
<td>Annual-CC50N *</td>
<td>83</td>
<td>2.81</td>
<td>100</td>
<td>8.9</td>
</tr>
<tr>
<td>l.s.d. (5%) ns</td>
<td></td>
<td>0.344</td>
<td>–</td>
<td>0.47</td>
</tr>
</tbody>
</table>

* See Table 1 for descriptions.
* District practice, considered the control.
The three perennial pasture species differed in their level of dormancy over winter (siratro>>rhodes>panic). Siratro became very dormant, yellowed and did not grow. Panic and rhodes grass produced some biomass; and panic resumed growth the earliest. By anthesis (September), the amount of pasture biomass in pasture cropped treatments varied from < 0.1 to 1.3 t/ha (Table 5). Individual Siratro plants ‘greened up’ in November but their low density (< 5 p/m²) limited overall biomass production.

There are some potential logistical issues to consider when seeding a crop into ‘live’ perennial pastures. Prior to seeding the crop, rhodes grass had spread by runners and produced considerable bulk (> 1.6 t/ha, Table 5). Nevertheless, the disc seeder passed through the sward without clumping. By harvest (24 November 2009) the perennial species had grown as tall as the crop in some places. Consequently, substantial green leaf material (esp. panic and rhodes grass) was cut and passed through the header; but this did not result in contaminated grain samples.

Table 5 Total green biomass from perennial species on select dates*

<table>
<thead>
<tr>
<th>Treatment code</th>
<th>Biomass – early autumn (DM t/ha)</th>
<th>Biomass – at anthesis (DM t/ha)</th>
<th>Biomass – mid summer (DM t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panic-PC80N</td>
<td>0.18</td>
<td>0.61</td>
<td>1.37</td>
</tr>
<tr>
<td>Panic-PC50N</td>
<td>0.25</td>
<td>0.65</td>
<td>1.26</td>
</tr>
<tr>
<td>W-Panic-PC80N</td>
<td>0.46</td>
<td>0.56</td>
<td>1.33</td>
</tr>
<tr>
<td>W-Panic-PC50N</td>
<td>0.28</td>
<td>0.36</td>
<td>0.82</td>
</tr>
<tr>
<td>Rhodes-PC80N</td>
<td>1.50</td>
<td>1.01</td>
<td>2.56</td>
</tr>
<tr>
<td>Rhodes-PC50N</td>
<td>1.65</td>
<td>1.30</td>
<td>2.61</td>
</tr>
<tr>
<td>Siratro-PC80N</td>
<td>0.26</td>
<td>&lt; 0.01</td>
<td>0.12</td>
</tr>
<tr>
<td>Siratro-PC50N</td>
<td>0.30</td>
<td>&lt; 0.01</td>
<td>0.25</td>
</tr>
<tr>
<td>l.s.d. (5%)</td>
<td>0.516</td>
<td>0.273</td>
<td>0.765</td>
</tr>
</tbody>
</table>

* Cutting height was ~5 cm; biomass above this height was collected and dried.

CONCLUSION

Pasture cropping systems might be used in WA to integrate perennials into farming systems to improve farm profits and provide risk management and NRM outcomes. The results from the Moora focus site (2009) suggested that, at least for Buloke barley, potential yield penalties associated with pasture cropping across perennials are less than 20 per cent; this is likely to reflect the limited capacity of deep pale sands to store moisture from summer rainfall events for crop production. The 2009 results also highlighted the potential for significant pasture growth after harvest to help offset any crop losses provided extra green feed over the summer-autumn period is converted into wool or meat.

Further experimental work (across a range of sites and seasons) is needed on the performance of pasture cropping, especially interspecies (crop and pasture) competition for water and nutrients, water use, feed production and livestock production. Systems analysis, credible demonstrations and case studies on farms that have / have not adopted pasture cropping will also be conducted by the EverCrop team to help resolve if pasture cropping has a role in WA.

REFERENCES


ACKNOWLEDGMENTS

Thanks go to our Technical staff: Julie Roche, Susan Robson and George Woolston (DAFWA); Shayne Micin and Chris Herrmann (CSIRO); the Geraldton Research Support Unit (DAFWA), Chris Vanzetti (Host Farmer) and EverCrop Local Adaptation group members (Moora).

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Paper reviewed by: Michael Robertson
Is pasture cropping viable in WA? Grower perceptions and EverCrop initiatives to evaluate

David Ferris, Tim Wiley, Perry Dolling, Department of Agriculture and Food, Western Australia, Philip Barrett-Lennard, Evergreen farming

KEY MESSAGES

- This paper provides an overview of potential benefits and constraints to the adoption of pasture cropping systems in WA as perceived by growers, and EverCrop initiatives to address the question posed. Companion papers present results from agronomic trials established by the EverCrop team to test the viability of Pasture Cropping in WA.

- A potential fit for pasture cropping is on marginal or problem soils, particularly poorer sand-plain soils across the northern and southern agricultural regions in WA, where summer-active perennial grasses have persisted (e.g. rhodes, panic and signal grass).

- Pasture cropping has two broad applications: For livestock dominant systems the crop could provide feed to supplement the perennial pasture, with crops ‘locked up’ and harvested only in years with excess feed. For cropping dominant systems, where feed is a secondary consideration, pasture cropping might stabilise fragile soils, improve soil health and prevent summer-weeds from growing.

- Improved soil health, green feed over summer and a double income stream are perceived by growers to be the main benefits of pasture cropping, and the potential for crop yield reductions and opportunity costs to establish perennial pastures as the main constraints to adoption.

AIM

To collate perceptions on the viability of pasture cropping systems in WA (potential fit, benefits and constraints) among innovative growers and agronomists interested in developing this technology in WA for the purpose of guiding future farming systems analysis and field research.

BACKGROUND

What is Pasture Cropping?

Pasture-cropping is a land management system where annual crops are sown into ‘live’ perennial pastures. This concept was initiated by Colin Seis and Daryl Cluff (NSW farmers) about 17 years ago. The system exploits a separation in the growth period of winter active crops and summer active grasses to maximise total production on some soils. The annual crops are used either for grain or forage while the perennial pastures are retained for grazing (Badgery and Millar 2009). In the Eastern States, this technology has been adopted across native perennial pastures (e.g. Redgrass) due to profit and NRM benefits.

What is EverCrop?

EverCrop is one of the research activities supported by the Future Farm Industries CRC to develop new sustainable farming systems and technologies that will improve the resilience of Australian broadacre agriculture to climate change, climate variability and drought while improving productivity and sustainability. EverCrop research is determining what perennials are specifically suited to mixed farming systems in different rainfall zones, their beneficial roles and how they can be adopted to make the greatest impact on farm at minimal cost.

Over the next two years, the EverCrop team will work closely with innovative growers and agronomists in the Northern Agricultural Region to evaluate the potential role and benefits of pasture cropping in WA. The central element of this project is on-farm adaptive research: A cycle of identifying issues, opportunities and research needs; trialling and refining technologies on-farm; and sharing results and experiences with the wider farming community.
METHODS

In February 2009, two Local Adaptation Groups were established in the Northern Agricultural Region to evaluate the concept of pasture cropping. These groups comprised innovative growers from Moora, Mingenew and Binnu; local agronomists and EverCrop facilitators. Facilitated discussions were held to identify and rank potential benefits, constraints and research needs. Each grower was asked to assign 3, 2 or 1 points to their top three issues, and collective scores were expressed as a percentage of the total number of points per group. There was some grouping of similar issues in Tables 1 and 2.

On-farm paddock trials were established by most growers in the Mingenew-Binnu Local Adaptation Group. Pasture cropping treatments (barley, lupin, oats or wheat,) were sown across paddocks that had previously been sown to a mixture of subtropical perennial grasses (panic, rhodes and signal grass). The on-farm trial implemented by Murray Carson (Binnu) was showcased at the Northern Agri Group spring field day (19 August 2009). A show-of-hands survey was used to assess the level of interest in pasture cropping systems among growers.

A 3 ha focus site with replicated pasture cropping treatments was established south-west of Moora (see companion paper). Local agronomists, NRM officers and extension staff were invited to a pre-harvest field walk and regional advisory group meeting that followed (13 November 2009). A facilitated discussion was used to gain feedback on the potential viability of pasture cropping systems in WA.

RESULTS

EverCrop Local Adaptation Groups

The main advantages of pasture cropping perceived by the Local Adaptation Groups had to do with soil health and livestock carrying capacity (Table 1). Improved soil fertility included increased organic matter, microbial activity and nutrient levels from recycling, and improved soil structure. A double income stream, increased water holding capacity and reduced non-wetting were also potential advantages perceived by the Mingenew-Binnu growers (Table 1).

Table 1 Ranked advantages of pasture cropping by each Adaptation Group

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Advantages</th>
<th>% of total votes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Moora</td>
</tr>
<tr>
<td>Soil health</td>
<td>Increased organic matter, microbial activity and nutrient level</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Reduced N leaching (capture and recycling)</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Increased water holding capacity or less non-wetting *</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Reduced lime requirement</td>
<td></td>
</tr>
<tr>
<td>Livestock</td>
<td>Greater carrying capacity</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Longer growing season</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Green feed over summer *</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Less supplementary feed</td>
<td></td>
</tr>
<tr>
<td>Enterprise mix</td>
<td>Two income stream (i.e. Crop and Livestock) *</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Tighter rotation</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Better pasture after crop</td>
<td></td>
</tr>
<tr>
<td>Weeds</td>
<td>Weed suppression (winter and summer)</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Herbicide tolerance of perennials</td>
<td></td>
</tr>
<tr>
<td>NRM</td>
<td>Carbon credits</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Ground cover (less erosion) *</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Beneficial Insect hosting environment *</td>
<td></td>
</tr>
<tr>
<td>Number of growers</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

* Factors raised by the Mingenew-Binnu group only.
The main disadvantages of pasture cropping perceived by the Local Adaptation Groups had to do with water availability (Table 2). Less stored moisture from summer rains and less moisture for crop germination were the key concerns. The possible impact of cropping on pasture productivity and persistence and additional costs to implement the system were also raised as potential disadvantages (Table 2).

Table 2 Ranked disadvantages of pasture cropping by each Adaptation Group

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Disadvantages</th>
<th>% of total votes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Some issues were identified but did not receive any ‘high priority’ votes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Moora</strong></td>
<td><strong>Mingenew-Binnu</strong></td>
</tr>
<tr>
<td>Water availability</td>
<td>Yield loss</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Less moisture at seeding (i.e. moisture from summer rain) #</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Crop germination compromised</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Grain quality decline (if tight season) #</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry inter-row (i.e. between perennials) #</td>
<td></td>
</tr>
<tr>
<td>Costs</td>
<td>Opportunity cost to establish perennial *</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Need to suppress perennials (herbicide resistance threat) *</td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>Less perennial growth over summer #</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Perennial decline #</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Perennial persistence compromise (due to crop water use) #</td>
<td></td>
</tr>
<tr>
<td>Livestock</td>
<td>Animal health issues (photosensitization) #</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Requires livestock #</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grazing strategy difficult due to paddock size #</td>
<td></td>
</tr>
<tr>
<td>Cropping logistics</td>
<td>Herbicide tolerance of perennial #</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Rough paddocks (poor trafficability if low perennial density) *</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Need for disc machine or tram lining (esp. rhodes grass)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contamination of grain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weediness of perennials (spread to better cropping soils) *</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uneven seeding depth *</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slashing required if no livestock *</td>
<td></td>
</tr>
<tr>
<td>Pests</td>
<td>Green bridge for disease and pests (e.g. aphids)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attraction of rabbits, kangaroos and mice *</td>
<td></td>
</tr>
<tr>
<td>NRM</td>
<td>Compaction from livestock *</td>
<td></td>
</tr>
</tbody>
</table>

* Factors raised by the Mingenew-Binnu group only.
# Factors raised by the Moora group only.

Northern Agri Group survey

A show-of-hands ‘straw poll’ conducted as part of the Northern Agri group spring field day (2009) suggested that one third of the growers attending believed pasture cropping could be viable in WA. Of the 90 people attending the event, 65 were growers; 21 growers indicated that they thought pasture cropping could have a role to play on their farm (a positive attitude) and 12 indicated that they are or plan to pasture crop in the next 2 years (a strong aspiration). On this basis there appears to be considerable interest in the concept of pasture cropping among growers in the Northern Agricultural Region, at least North of Geraldton.
Agronomists and NRM officers – Feedback

A facilitated discussion (Nov 09) with local agronomists (5), NRM officers (2), and extension personnel (4) invited to join the EverCrop-WA Regional Advisory Group suggested that marginal or problem soils were the most likely fit for pasture cropping systems in WA. Such soils were estimated to occupy 20–30 per cent of the total arable area in the West Midlands sub-region. Participants felt that the main benefits of pasture cropping were the potential to increase the frequency of cropping, provide out of season feed and better soil coverage. Major issues perceived for farmers were crop yield reduction, failed establishment of perennial pastures, the risk of grain contamination at harvest and increased complexity in deciding when to sow. The participants identified two different ways that pasture cropping systems could be used: For feed, by farmers with a livestock focus; and for grain production by farmers with a cropping focus. Participants believe that interest in the technology was gaining momentum but considerable research was still required to prove its viability in WA.

Participants indicated that there was a need for agronomy research, modelling of specific scenarios and extension activities such as field walks, case studies and economic analyses. This aligns well with proposed EverCrop-WA initiatives (Table 3).

<table>
<thead>
<tr>
<th>On-farm adaptive research</th>
<th>Agronomy research</th>
<th>Modelling research</th>
<th>Adoptability / extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives</td>
<td>Work with growers and agronomists to develop and test the viability of pasture cropping in WA.</td>
<td>Gain knowledge on the performance of pasture cropping systems in WA, from both crop and pasture perspectives.</td>
<td>Develop decision support tools for pasture cropping and the use of perennials in WA.</td>
</tr>
<tr>
<td>Products</td>
<td>Case studies comparing farmer experiences and data on the performance of pasture cropping.</td>
<td>Scientific articles and technical bulletins providing a realistic assessment of the viability of pasture cropping in WA.</td>
<td>Tools to assist with decisions about the productivity and profitability of pasture cropping across a range of circumstances.</td>
</tr>
<tr>
<td>What are we doing?</td>
<td>Evaluating the performance of crops sown across perennial pasture species.</td>
<td>Assessing the impact of cropping on perennial pasture growth and persistence.</td>
<td>Updating farming system models to include pasture cropping options. Validating biophysical and economic predictions against trial data and detailed user evaluations.</td>
</tr>
</tbody>
</table>

CONCLUSION

Is pasture cropping viable in WA? At this point in time there is no definitive answer. However, based on the level of enthusiasm, a growing number of farmers believe that the answer may well be ‘yes’. Over the next two years the EverCrop team will work closely with Local Adaptation Groups to evaluate the profitability of pasture cropping systems in WA. Activities will include paddock scale trialling to address logistical and integration issues. The experiences of innovative growers, together with timely results from agronomic research, bio-economic modelling and adoptability studies should provide a realistic assessment of the viability of pasture cropping systems in WA.
REFERENCES

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Paper reviewed by: Rick Llewellyn
Best-bet management for dual-purpose canola

John Kirkegaard, Susan Sprague, Hugh Dove and Walter Kelman, CSIRO, Canberra
Peter Hamblin, Agritech Research Young, NSW

KEY MESSAGES
Canola has been managed successfully as a dual purpose crop (graze and grain) on commercial farms in southern NSW since 2007 to improve profitability and flexibility of mixed farms. We highlight the best-bet management guidelines to ensure success and discuss the major risks involved in this new option.

BACKGROUND
Well managed dual-purpose cereal crops have provided opportunities to increase the profitability and flexibility on mixed farms by increasing winter stocking rates and providing income from feed and grain. Dual-purpose canola can generate similar benefits while providing a break crop for weeds and disease to clean up paddocks for subsequent cereals or for pasture establishment. In combination with grazed cereals, grazed canola can also spread the timing of operations and potentially extend the grazing window. Our research since 2004 has developed best-bet management strategies to maximise the chances of success. These have been successfully adopted on many commercial farms since 2007.

In summary, canola varieties sown 2–3 weeks earlier than normal (early to mid April) can be grazed in winter prior to bud elongation (usually providing 600–800 dse grazing days/ha) and recover with no impact on yield or oil. Thus an early sowing opportunity can be capitalised on in paddocks planned for canola on farms with suitable livestock operations providing grazing and hay or grain options while maintaining break crop benefits. Critical issues for success are summarised below.

BEST-BET MANAGEMENT

(a) Paddock selection and sowing time—Paddocks should be well prepared to capitalise on early sowing opportunities, have adequate stored water to ensure good even establishment and early biomass. Press wheels can improve establishment in dry conditions. Crops sown 2–3 weeks earlier than normal (early-mid April) produce significant biomass (1.5–3 t/ha) in the winter feed gap to allow the resting of pastures.

(b) Varietal choice—Most commercial varieties can be managed for successful dual-purpose use. The best results come from early sown, mid-late maturing types for the area, with high early vigour and good blackleg resistance (R rating) (see Table 1). Weed management is important in varietal choice given the early sowing and the withholding periods for some chemicals. Grazing increases blackleg severity in cultivars with a low blackleg resistance rating (<MS-MR). Cultivars with a high blackleg resistance rating (R) are required.

(c) Managing the crop—Strategies to increase early biomass for grazing include earlier sowing (but not too early!); varietal choice (hybrid > conventional > triazine tolerant), increased sowing density (at least 50 pl/m²), adequate N nutrition (beware of the nitrate poisoning risks for stock on recently fertilised crops). N topdressing and some weed control can be delayed until after grazing if necessary to ensure the crop has adequate nutrition to maximise re-growth and yield according to the season.

(d) Grazing management and stock health—Grazing can commence as soon as plants are well anchored, although generally the feed available or chemical withholding periods would preclude grazing until the 6–8 leaf stage which coincides with mid-June for early April sowings (> 1.5 t/ha biomass). Canola is palatable to livestock, has high feed value, and has produced good live-weight gains (210–300 g/day). No animal health issues were reported in 12 separate grazed paddock-scale experiments or 25 commercial paddocks in 2007/08. Guidelines for grazing brassicas should be followed. Most growers have achieved 600–800 dse grazing days/ha in the period mid-June to late-July with various animal classes (see summary of commercial grazing—Table 2). Growers should ensure they have adequate livestock on hand to capitalise on this high value feed. The choice of enterprise and class of animal will determine the profitability of dual-purpose use (e.g. cross-bred fat
lambs vs breeding merinos). The value of winter forage can vary from $80/t (agistment) to $200/t (fat lambs) based on current prices and feed conversion ratios so that typical feed removal of 0.5 to 1.5 t/ha can generate significant additional income.

(e) **Timing of stock removal is key!**—Removing stock before buds have elongated more than 10 cm has little impact on flowering time (2–3 days delay) (Figure 1), yield or oil (Table 1 – 2008). Grazing more advanced plants or grazing too late heavily delays flowering and can reduce grain and oil yield (Figure 1 and Table 1 – 2009). Crops with good grazing management have little yield penalties depending on seasonal conditions for re-growth.

![Figure 1](image-url)  
**Figure 1** Delay in flowering associated with grazing or defoliation at different growth stages.

(f) **Profitability and risk**—Assuming best bet management is achieved and yield penalties minimised, growers can evaluate the direct economic benefits from grazing according to the livestock enterprise they are running, but generally such high value forage is best utilised by meat enterprises. The feed value of later grazing must be considered in relation to potential yield loss. The paddock gross margins for dual-purpose canola are generally $100–$400 more than for grain only canola if yield penalties are avoided but this is price sensitive. Indirect benefits such as a reduction in crop height/bulk to facilitate harvesting, grass weed control, value of winter pasture spelling, earlier income and risk management, disease break, option for wheat streak mosaic virus and management flexibility are more difficult to quantify but have been listed by consultants and growers as definite benefits of the system.
Table 1  Grazing and grain production for dual-purpose canola at Young in experimental plots in 2008 (optimal grazing and good spring) and 2009 (later grazing and drier spring). In each year the yield of a later sown, un-grazed crop is shown for comparison (in bold). Note later grazing (after buds were elongated) in 2009 caused a yield penalty in most lines. TT lines generally produce less biomass and lower yield after grazing.

<table>
<thead>
<tr>
<th>Site/ Year</th>
<th>Sow</th>
<th>Variety</th>
<th>Grazing intensity (dse.d/ha)</th>
<th>Grazing time</th>
<th>Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>16/4</td>
<td>46Y78</td>
<td>Ungrazed</td>
<td>–</td>
<td>4.7</td>
</tr>
<tr>
<td>(2008)</td>
<td></td>
<td></td>
<td>700</td>
<td>2/7 – 30/7</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1300</td>
<td>2/7 – 4/8</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>16/4</td>
<td>Hyola76 (Hy)</td>
<td>700</td>
<td>2/7 – 30/7</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Garnet (Con)</td>
<td>700</td>
<td>2/7 – 30/7</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marlin (TT)</td>
<td>700</td>
<td>2/7 – 30/7</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>30/4</td>
<td>46Y78 (Hy)</td>
<td>crash</td>
<td>14/7 – 28/7</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skipton (Con)</td>
<td>crash</td>
<td>14/7 – 28/7</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beacon (TT)</td>
<td>crash</td>
<td>14/7 – 28/7</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>12/5</td>
<td>46Y78</td>
<td>Grain only</td>
<td>–</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46C76</td>
<td>800</td>
<td>30/6 – 16/7</td>
<td>2.3 (1.2)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hyola50 (Hy)</td>
<td>800</td>
<td>30/6 – 16/7</td>
<td>2.3 (1.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Garnet</td>
<td>800</td>
<td>30/6 – 16/7</td>
<td>2.5 (1.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hyola601RR (Hy)</td>
<td>800</td>
<td>30/6 – 16/7</td>
<td>2.5 (1.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46Y20RR</td>
<td>800</td>
<td>30/6 – 16/7</td>
<td>2.0 (1.6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TriumphpTT (Hy)</td>
<td>800</td>
<td>30/6 – 16/7</td>
<td>2.2 (1.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TawrifficTT</td>
<td>800</td>
<td>30/6 – 16/7</td>
<td>2.3 (0.5)</td>
</tr>
<tr>
<td></td>
<td>29/4</td>
<td>46Y78</td>
<td>Grain only</td>
<td>–</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>800</td>
<td>30/6 – 16/7</td>
<td>2.2 (0.6)</td>
</tr>
</tbody>
</table>

* Numbers in brackets in 2009 are minimum estimates of biomass removed by grazing.

SUMMARY OF COMMERCIAL GRAZED CANOLA CROPS IN 2008

In conjunction with consultants, we monitored commercial growers in 2008 to follow adoption and outcomes (Table 2). Growers used currently available spring canola cultivars, many opting for hybrids such as 46Y78 and 45Y77. Grazing was conducted on crops that were sown early from late March to early May on paddocks located from The Rock, south of Wagga to Canowindra in the north, Mandurima in the east (645 m asl) to Junee in the west. The outcomes demonstrate little or no impact on yield when best-bet management was followed and many have now grazed canola for several years. Consultants comments were:

‘Mostly positive response, and all growers will try again. Most achieved 4 weeks grazing @ 25 dse/ha and yield of grazed crops (2.4 t/ha oil 42 per cent) matched yields of ungrazed. Unexpected economic benefits also arose due to ease (and speed) of harvest of less bulky crops’. Tim Condon, Delta-Agribusiness Harden-Young, NSW.

‘Generally positive results but variable, some yield penalties on crops grazed late. Canola will become a standard option in the feed-base. The concept has moved from the experimental to operational’. Peter Watt, Elders Cowra, NSW.

‘An opportunity to clean up grass weeds arising from a phase of grazing cereals so that pastures can be cleaner and more productive. The system benefits are the main attraction’ Tony Good, Harden District Rural Advisory Service.
Table 3 Summary of commercially grazed canola paddocks in NSW in 2008

<table>
<thead>
<tr>
<th>Location</th>
<th>Cultivar (sow date)</th>
<th>Grazing</th>
<th>Class of stock</th>
<th>Dse d/ha</th>
<th>Yield (t/ha)</th>
<th>Grower response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junee</td>
<td>46Y78 (22/3)</td>
<td>4/6–20/6</td>
<td>merino ewes</td>
<td>350</td>
<td>0.6</td>
<td>Very pleased, yield similar to grain only crops</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7/7–21/7</td>
<td>merino maidens</td>
<td>252</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>31/7– 8/8</td>
<td>merino ewes</td>
<td>105</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Woodstock</td>
<td>Jade (21/4)</td>
<td>24/6– 8/7</td>
<td>ewes and lambs</td>
<td>882</td>
<td>2.4</td>
<td>Crop very compact, easy to harvest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24/6–22/7</td>
<td></td>
<td>1400</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Junee</td>
<td>45Y77 (8/5)</td>
<td>24/7–12/8</td>
<td>n/a</td>
<td>n/a</td>
<td>0.7</td>
<td>Very pleased</td>
</tr>
<tr>
<td>Harden</td>
<td>Bravo (9/4)</td>
<td>1/8–15/8</td>
<td>ewe lambs</td>
<td>420</td>
<td>1.55</td>
<td>Ungrazed yield 1.7 t/ha</td>
</tr>
<tr>
<td>The Rock</td>
<td>45Y77 (1/5)</td>
<td>24/7– 8/8</td>
<td>merino weaners</td>
<td>1200</td>
<td>0.7</td>
<td>Will grow again—sow earlier and graze with more stock</td>
</tr>
<tr>
<td>Wall’been</td>
<td>46Y78 (18/4)</td>
<td>24/6–5/8</td>
<td>XB lambs</td>
<td>1176</td>
<td>2.6</td>
<td>Extremely pleased—if not amazed!</td>
</tr>
<tr>
<td></td>
<td>Garnet (18/4)</td>
<td>24/6–5/8</td>
<td>XB lambs</td>
<td>1176</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>Boorowa</td>
<td>46Y78 (25/4)</td>
<td>30 days</td>
<td>merinos</td>
<td>1500</td>
<td>~2.0</td>
<td>Estimates 0.5 t/ha yield loss</td>
</tr>
<tr>
<td>Mandurima</td>
<td>Bravo, Summit,</td>
<td>30/7–24/8</td>
<td>Pregnant merino</td>
<td>750</td>
<td>2.2</td>
<td>Similar to ungrazed No scouring Rapid recovery</td>
</tr>
<tr>
<td></td>
<td>Rottnest (1–10/5)</td>
<td></td>
<td>ewes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Billimari</td>
<td>Thunder (15/4)</td>
<td>20/6–3/7</td>
<td>ewes and lambs</td>
<td>825</td>
<td>1.8</td>
<td>Same as ungrazed Reduced yield by 0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4/7–25/7</td>
<td>ewes and lambs</td>
<td>690</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Canowindra</td>
<td>45Y77 (25/4)</td>
<td>14/6–7/7</td>
<td>XB lambs</td>
<td>575</td>
<td>1.2</td>
<td>Same yield but oil reduced 43% to 38%</td>
</tr>
</tbody>
</table>

THE MAJOR RISKS AGAIN …

Not thinking ahead—Is the paddock suitable and ready for that early sowing opportunity? What variety provides suitable weed control options in relation to withholding period? Do I have the stock numbers to make money from the feed?

Sowing the wrong variety too late—Only early sown crops provide the grazing opportunity. Is it vigorous, highly blackleg resistant and can I meet herbicide withholding periods?

Grazing too late—Lock up the paddock before the buds are elongating and being eaten by stock (> 10 cm) to avoid yield loss, or weigh up the value of the extra feed vs grain income.

CONTACT DETAILS AND FURTHER INFORMATION

John Kirkegaard
CSIRO Sustainable Agriculture National Research Flagship
CSIRO Plant Industry
GPO 1600
Canberra ACT 2601
Phone: (02) 6246 5080
Fax: (02) 6246 5399
Email: john.kirkegaard@csiro.au

KEY WORDS

grazing crops, canola, mixed farming, feed-gap, sheep

Project No.: CSP00085
Pastures in cropping systems – with and without sheep

Brad Nutt and Angelo Loi, Department of Agriculture and Food, Western Australia

KEY MESSAGES
Forage legumes with on-farm seed production can be used effectively as a remedial brown manure crop to improve soil fertility and manage weeds. They can provide a viable alternative to conventional break crops with or without a livestock enterprise. The hard-seed dormancy of forage legumes can also allow early dry sowing to enrich a pasture based brown manure crop to gain the full use of growing season, maximise organic matter and nitrogen input into the soil and minimise conflict with crop sowing. However, not all cultivars of forage legumes available in the market are suitable for these establishment techniques due to insufficient hard-seed breakdown.

AIMS
To enrich a brown manure crop based on ley pasture with annual legumes by sowing hard-seeded annual legumes in summer-autumn. To determine the timing required to allow adequate hard-seed breakdown for effective plant establishment.

METHOD
The seed used in both experiments for all cultivars, Erica and Margurita French serradella and Santorini and 87GEH72.1a yellow serradella, was sourced from header harvested material (pod) with minimal post-harvest cleaning. For the winter sowing treatment (Experiment 1), seed was extracted from the pods and scarified to greater than 75 per cent germination. Margurita and Erica were applied as a French serradella mixture in equal proportions (experiment 1).

Experiment 1
Summer sowing: Seed (un-scarified) was top dressed at 50 kg of pod/ha in 10 m x 5 m plots, into cereal stubble on the 21 January 2009 and lightly harrowed. Winter sowing: Seed (scarified) was drilled (1 cm) at 10 kg/ha after the application of a knockdown herbicide (1.5 L/ha of Roundup CT®). At both times of sowing 10kg/ha of Alosca® group S granules were applied with the seed. The experiment was arranged as six randomised blocks and was located at the WANTFA research site at Meckering.

All treatments were top dressed with 150 kg/ha of super:potash 3:1 and 120 mL/ha of Talstar® was applied on the 4 June. The regenerating swards remained un-grazed throughout 2009. Dry matter production was determined by direct quadrat harvesting and oven drying on 21 September 2009. Seed yield was determined by hand quadrat harvesting of all pod material.

Experiment 2
Single rows containing 200 seeds (pod) were sown in monthly intervals between February and May 2009 into dry bare soil at approximately 1cm depth. Emerged seedlings from all times of sowing were counted on the 15 June. Four replicate rows were planted per treatment and sowing time. The experiment was sited on the DAFWA Medina Research Station.

RESULTS

Experiment 1
Meckering received considerable rainfall in late February/early March (Table 1) which resulted in some sparse early germination on the summer sown treatments of the French serradellas and 87GEH72.1a yellow serradella. Some of these plants survived (4 to 5 plants/m²) until the winter rains to become very large plants that significantly contributed to the spring dry matter yield on these treatments. The majority of seedlings on the summer sowing treatments emerged from late May which was about three weeks earlier than those on the winter sown treatments. This resulted in large differences in dry matter...
production between the summer and winter sown treatments that continued into spring (Table 2). The pod yields were comparable between the two times of sowing, the winter sowing being assisted by late spring rainfall. All treatments were abundantly nodulated.

Table 1. Monthly rainfall (mm) for the site of Experiment 1 at Meckering in 2009

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Meckering</td>
<td>7</td>
<td>26</td>
<td>11</td>
<td>8</td>
<td>18</td>
<td>47</td>
<td>68</td>
<td>54</td>
<td>24</td>
<td>21</td>
<td>25</td>
<td>309</td>
</tr>
</tbody>
</table>

Table 2. Dry matter and seed yields of serradella cultivars when sown on the 21 January 2009 (summer) as unprocessed pod at 50 kg/ha or sown on the 3 June 2009 (winter) as scarified seed at 10 kg/ha (Meckering).

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Dry matter 21/9/09 (kg/ha)</th>
<th>Pod yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer sown</td>
<td>Winter sown</td>
</tr>
<tr>
<td>Erica/Margurita</td>
<td>2013</td>
<td>208</td>
</tr>
<tr>
<td>87GEH72.1a</td>
<td>3026</td>
<td>290</td>
</tr>
<tr>
<td>Santorini</td>
<td>916</td>
<td>109</td>
</tr>
</tbody>
</table>

Experiment 2.

The first germinating rains did not occur at Medina until the 21 May, three days after the last time of sowing; therefore all dates of sowing emerged at the same time. A high proportion of seed sown in February were accounted for as established seedlings with Margurita and Erica French serradella and 87GEH72.1a yellow serradella (Table 3). This level of establishment was reduced with each successive month of planting, with very low levels occurring with the May sowing. Only a low level of seedling establishment occurred with Santorini yellow serradella at all times of sowing.

Table 3 Initial germination and plant establishment (as % of seed number sown) from machine harvested serradella pod when sown at monthly intervals over the summer/autumn period in 2009 at Medina Research Station.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Initial germination (%)</th>
<th>Plant establishment at 15/6/10 (as % of seed no. sown) from sowing dates;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>13 February</td>
</tr>
<tr>
<td>Erica</td>
<td>18</td>
<td>63</td>
</tr>
<tr>
<td>Margurita</td>
<td>21</td>
<td>77</td>
</tr>
<tr>
<td>87GEH72.1a</td>
<td>9</td>
<td>75</td>
</tr>
<tr>
<td>Santorini</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Rainfall for the 30 days after sowing (mm)</td>
<td>8</td>
<td>6</td>
</tr>
</tbody>
</table>

DISCUSSION

With the right cultivars and on-farm seed production, annual forage legumes can be used to enhance the legume content of a pasture phase by summer/autumn sowing of hard-seed. This technique could be applied to a number of scenarios and be more effective than the traditional winter sowing. In particular, it will offer early winter grazing in a mixed enterprise farm and will lift the legume component in a pasture with a low legume base due to drought and/or intensive cropping. On a crop dominant farm, it could also be used to produce a high legume content ley for brown manuring and thereby maximise the organic matter and nitrogen input to the soil either with or without grazing. Recent bio-economic modelling has shown that the tactical use of single year, un-grazed pasture phases can be more valuable than the use of break crops in crop-only systems when under herbicide resistant weed challenge (Doole and Weetman, 2009). Summer/autumn sowing reduces establishment cost by minimising seed processing particularly in the case of serradella where seed extraction is difficult and expensive, and sowing does not require a pre-sowing application of herbicide.
Normally forage legumes are sown after the main cropping program is completed and require the application of a pre-sowing knockdown herbicide to control established weeds. This treatment seriously reduces early winter pasture production which is then compounded by the slow growth rate of legumes under the cold winter conditions. This effect was clearly demonstrated in Experiment 1 at the Meckering site.

Sowing hard-seed in summer or autumn creates the right environment for hard-seed breakdown over time so an increasing pool of seed is created that can germinate under moist conditions. Although some seed may establish on early autumn rainfall, there will be further breakdown of hard-seed to create a back up if there is insufficient follow up rains for plant survival. However, success of the system is reliant on achieving the greatest amount of hard-seed breakdown during autumn. The French serradella cultivars and the 87GEH72.1a ecotype of yellow serradella appeared to do this in these experiments; however there was insufficient break down of hard-seed in Santorini yellow serradella to be effective.

The time of sowing experiment suggests planting as late as March could provide sufficient breakdown of hard-seed for effective establishment of Erica and Margurita French serradella and 87GEH72.1a yellow serradella. Future work will look at repeatability across seasons and a broader array of commercially available forage legumes that are suitable for on-farm seed production. At present the main forage legume sown as a remedial brown manure crop is Cadiz French serradella and is useful for this purpose because it does not produce hard-seed. This allows for either a dry sowing just prior to crop sowing and is at risk of losing density if there is no follow up rain or sowing after the cropping program which limits pasture productivity. The requirement to sow hard-seeded cultivars in summer or early autumn does lose some of the flexibility to tactically respond to seasonal conditions and this needs to be balanced against the clear productivity advantages demonstrated in Experiment 1.

Note: Seed of Erica and Margurita French serradella and Santorini yellow serradella is protected by PBR. Seed can be produced and used on farm, but cannot be sold unless prior arrangements with registered licensees have been made.

REFERENCE


KEY WORDS

serradella, annual forage legumes, sowing, pasture establishment

ACKNOWLEDGMENTS

The authors thank the Western Australian No-Tillage Farmers Association (WANTFA) and Pasture Australia for supporting this research.

Project No: WP192
Paper reviewed by: Clinton Revell
Can technology substitute for a lupin break?

Wayne Parker, Department of Agriculture and Food, Western Australia, Geraldton

KEY MESSAGES

The area sown to break crops has reduced in recent years and growers are looking to sow longer sequences of wheat on wheat.

While there have been many improvements in wheat agronomy in recent years, it is not known if using these agronomic improvements during a wheat phase can provide the same effects on weeds, disease and nutrition as a break crop.

AIMS

We are using seed dressing, liquid fertiliser and precision sowing in an attempt to improve wheat yield potential in the third wheat year after a break crop. We are testing the hypothesis that wheat yield can be maintained just as well using these technologies as with a lupin break.

BACKGROUND

There has been a move away from break crops, in particular lupin, to growing more wheat in an effort to maintain profitability. However, the number of crops of wheat that can be grown in succession is limited because grass weed populations and cereal diseases increase while nitrogen levels in the soil can easily be depleted. These factors continue to increase to a point when growing wheat becomes unprofitable. In the northern sandplain this usually occurs by the third crop of wheat in succession. This trial is structured to determine if technology, including nitrogen and fungicide application methods, have progressed enough to extend the duration of continuous wheat cropping on these sandplain soils.

Agronomic Improvements

Integrated weed management—It is possible to continue in a wheat rotation if the weed problem is understood and weed populations can be managed. Continued wheat can only happen if utilising integrated weed management techniques at harvest as well as throughout the growing season. This trial is in a paddock with a very low weed burden hence weed management is not anticipated to be a major factor in determining yield potential.

Liquid fertiliser—the widespread adoption of liquid fertiliser technology in the last five years has seen a change in how fertilisers are applied and managed. There is potential for liquid fertilisers to substitute for a leguminous break crop as liquid fertilisers offer the flexibility in nitrogen application that lupin residues cannot. Fertilising to estimated yield potential and reduced leaching are ways in which fertiliser technology is able to circumvent the necessities of a break crop.

Foliar applied fungicides—are another form of technology that reduce the requirement for sowing a break crop. In a low rainfall season the risk of leaf disease is low. In a medium rainfall environment, or moderate rainfall season, foliar fungicide sprays can be used to offset increased leaf disease threat. Foliar fungicides can provide successful management of leaf diseases yellow spot, Pyrenophora tritici-repentis, and septoria nodorum blotch, Phaeosphaeria nodorum which are common within the northern wheatbelt.

Auto-steer guidance—can contribute to increasing the frequency of wheat crops in a rotation by reducing the inoculum load of some root diseases in crop. Precision sowing using guidance at 2 cm accuracy allows movement of the new seasons furrow from the previous furrow. This is movement away from root disease held in old stubble crowns. Precision inter-row sowing has been shown to reduce levels of disease in crop of crown rot, Fusarium pseudograminearum, and common root rot, Bipolaris sorokiniana, in crops in New South Wales (Simpendorfer, Long et al. 2005). There may also be some benefit in reducing or delaying nematodes. Based on the large soil dispersion and daily movement of nematodes Jones and O’Halloran (2006) state that inter-row sowing is only likely to delay infection of plants rather than prevent infection by nematodes.

Predictive disease and nematode testing—Commercial DNA tests are now available to aid in decision making on risk of a third wheat crop. These tests are being taken on this trial.
METHOD

The trial will run over four seasons, 2008 to 2011 comparing four rotations (Table 1). Within each rotation there are two seed fungicide treatments, ± Jockey®, two varieties, Young and Magenta, and two liquid fertiliser treatments, ± Flexi N.

Table 1 Rotation treatments

<table>
<thead>
<tr>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lupin (L)</td>
<td>Wheat (W)</td>
<td>Off Row Wheat (OW)</td>
<td>Off Row wheat (OW)</td>
</tr>
<tr>
<td>Lupin (L)</td>
<td>Wheat (W)</td>
<td>Wheat on Row (RW)</td>
<td>Wheat on Row (RW)</td>
</tr>
<tr>
<td>Lupin (L)</td>
<td>Wheat (W)</td>
<td>Lupin on Row (RL)</td>
<td>Wheat on Row (RW)</td>
</tr>
<tr>
<td>Lupin (L)</td>
<td>Wheat (W)</td>
<td>Off Row Wheat (OW)</td>
<td>Wheat on Row (RW)</td>
</tr>
</tbody>
</table>

Lupin (L) = Bulk lupin sown north south across whole trial site during 2008.
Wheat (W) = Wheat sown east west, across 2008 workings, using knife point press wheel sowing system on 25 cm spacing. Tractor steered using precision guidance to 2 cm accuracy.
Lupin on row (RL) = Lupin sown using knife point press wheel sowing system. Tractor steered using precision guidance to 2 cm accuracy to place lupins into the rows of previous seasons wheat stubble.
Off Row Wheat (OW) = Wheat sown using knife point press wheel sowing system. Tractor steered using precision guidance to 2 cm accuracy to place new wheat rows in the middle of the previous seasons rows. Hence germinating wheat will be separated from previous seasons stubble by 12.5 cm, to the best of our ability, on either side.
Wheat on Row (RW) = Wheat sown using knife point press wheel system. Tractor steered using precision guidance to 2 cm accuracy to place wheat into the previous seasons stubble rows.

Variety, fungicide and nitrogen treatments only apply to the wheat phase of the rotation. When the plots are sown to lupins, there will be only one variety and standard fungicide seed dressing for lupin. Nitrogen treatments will only be applied, in 2010 and 2011 and will not be applied to the lupin plots.

Using each of the aforementioned technologies for growing more wheat in rotation is seen by growers and agronomists as a cheaper substitute to an expensive, ‘risky’ break crop. Recently the lupin wheat rotation has become the lupin wheat, wheat rotation. Given a choice, on sandplain soils, the third wheat after lupin is rarely used as the yield potential is too low (Agri-consultants 2009). There is potential to utilise precision sowing, foliar fungicide, fungicide seed dressing, and foliar fertiliser application to avoid disease and extend the wheat to the third year after lupin.

RESULTS

In this the first season after a lupin crop, only variety, seed dressing and their interaction can be reported on. Varieties were chosen to give the extremes in disease response not for maximum yield. Young, is susceptible to septoria nodorum and tritici blotches, is MS-S for yellow spot and importantly has resistance to CCN while is susceptible to RLN. Magenta has greater resistance to leaf diseases present in the NAR farming system than Young. It is MR-MS to septoria nodorum and tritici blotches, is MR for RLN and MS-S to CCN. The nematode tolerances of Magenta are approximately opposite those of Young.

Table 2. Average tiller number for varieties Magenta and Young, treated and untreated with Jockey®

<table>
<thead>
<tr>
<th>Variety</th>
<th>Jockey®</th>
<th>Nil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magenta</td>
<td>3.4</td>
<td>3.5</td>
</tr>
<tr>
<td>Young</td>
<td>2.7</td>
<td>2.5</td>
</tr>
<tr>
<td>l.s.d.</td>
<td></td>
<td>0.16</td>
</tr>
</tbody>
</table>

Seed Dressing: Non Significant
Var x SD: Significant
Table 3 Yield, t/ha, of Magenta and Young, treated and untreated with Jockey

<table>
<thead>
<tr>
<th>Variety</th>
<th>Seed dressing</th>
<th>Jockey®</th>
<th>Nil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magenta</td>
<td>3.66</td>
<td>3.65</td>
<td></td>
</tr>
<tr>
<td>Young</td>
<td>2.94</td>
<td>3.10</td>
<td></td>
</tr>
<tr>
<td>l.s.d.</td>
<td>Variety</td>
<td>0.136</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seed Dressing</td>
<td>Non Significant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Var x SD</td>
<td>Non Significant</td>
<td></td>
</tr>
</tbody>
</table>

Disease levels on the four leaves, Flag to Flag-3, were rated as a per cent area of leaf. Disease was negligible on all leaves, as anticipated after a lupin break crop in 2008. The impact of seed dressing was seen in the leaves Flag-2 and Flag-3 with a minor reduction in leaf area infected by disease compared to those plots without fungicide seed dressing. Disease levels were still low in these leaves and nothing required fungicide application.

CONCLUSION

In this the first year after a break crop the results for the two wheat varieties were as anticipated. Very low leaf and root disease with yields unlimited by nitrogen.

In 2010 the results of this trial will build on the information generated by Seymour (2009) in his summation of crop sequence work. Seymour found that increased N inputs decreased the yield difference between wheat after wheat and wheat after lupin. With the management included in the trial it is anticipated that this yield difference can be further reduced. The trial continues in 2010 with additional management treatments.

KEY WORDS

continuous wheat, break crops

ACKNOWLEDGMENTS


Seymour, M (2009) Four decades of crop sequence trials in Western Australia. 2009 Crop Updates proceedings, Burswood Entertainment Complex, Western Australian Agriculture Authority.


Project No.: DAW161
Paper reviewed by: Martin Harries
Canola row spacing with and without long term stubble retention on a sandy clay loam at Merredin

Glen Riethmuller, Department of Agriculture and Food, Western Australia, Merredin

KEY MESSAGES
1. The yield at around 0.9 t/ha was good for the dry finish to the season, probably due to being chemical fallowed in the late start 2008 season and there was no effect of previous stubble.
2. On average, the yield dropped 6.3 kg/ha ($3.00/ha at $475/t) for each centimetre increase in row spacing from 9 cm.
3. In-grain ryegrass seed number was generally higher in the wider rows.

AIMS
To test whether increasing canola row spacing has an effect on yield where stubble has been retained or burnt since 1987.

METHOD
This continuing experiment at the Merredin Research Station was initiated in 1987 to investigate stubble and row spacing interactions (87M71). Each year the same treatment is applied to the same plot. Treatments are burnt and retained stubble, with row spacings of 90, 180, 270 and 360 mm with six replications and a plot centre width of five metres.

The soil is a red-brown sandy clay loam (salmon gum, gimlet). The barley in 2007 was low yielding at around 0.4 t/ha. Due to the poor early season rainfall in 2008 (from 19 April to 26 June there was no rain event above 7 mm and the first sowing opportunity was 16 July) the experiment was not sown but was chemical fallowed in 2008 and sown to canola in 2009.

Sowing date: 15 June 2009 (May-October rainfall 195 mm)
Row orientation: 21 degrees west of north
Seed rate: 5.3 kg/ha Tanami canola
Viable seed sown: 129 seeds/m²
Fertiliser: 71.5 kg/ha Agras (12N, 7.2P, 10.2S, 0.072Ca, 0.043Zn) banded 20 mm below the seed (with the seed on 90 mm spacing instead of two passes)
Seeder: All points were 40 mm wide. Janke 110 mm wide chamfered ‘V’ press wheels were set at 2 kg/cm width with 150 mm inside diameter 16 mm ring harrow attached.
Sprays: 15 June 2 L/ha Spray.Seed + 1 L/ha trifluralin
17 June 100 mL/ha Talstar
11 September 200 mL/ha dimethoate for aphids
Harvester: KEW 1.62 m wide (1.8 m or 5 rows for 360 mm spacing) without Rytec ryegrass catcher system but five crop lifters were used for better ryegrass capture.
Harvest date: 9 November 2009

RESULTS
The seed depth was good, averaging 22 mm and the stubble retained treatments were 4 mm deeper than the burnt. This is consistent with other years where perhaps the more friable soil caused the extra depth (Table 1).

The plant density was surprisingly even at around 105 plants/m² (80 per cent field emergence) and no effects of stubble or spacing. Rep 1 was affected by bare patches at the plot entry end where the seed drive shaft had not taken up the slack in the gearbox due to the 1 to 3 reduction gearing.
The experiment was relatively free of weeds early but when late ryegrass had emerged it was too late to apply a selective herbicide, such as clethodim, as flowering had commenced. The final crop height was very similar for all treatments at around 100 cm. Yields were only affected by row spacing which dropped, on average, 0.7 per cent for every centimetre wider than 9 cm row spacing.

The canola oil content is still to be assessed. There was no effect of stubble or row spacing on the canola seed size. The very small seed was probably due to the lack of finishing September rain.

The ryegrass seed, measured from each plots harvested grain sample, showed an interaction of stubble retained and row spacing, which is similar to 2007 where an extra 1 L/ha trifluralin was applied to the 270 and 360 mm rows. The 90, 180 and 270 mm rows with burnt stubble and the 90 and 180 mm rows with retained stubble had less ryegrass than the burnt 360 mm rows or the retained stubble 270 and 360 mm rows.

Table 1. Seed depth, plant density, yield, seed weight and in-grain ryegrass with row spacing and stubble

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Seed depth (mm)*</th>
<th>Plant density (pl/m²)</th>
<th>Harvest yield (t/ha)**</th>
<th>Canola seed weight**</th>
<th>Ryegrass in-grain (log seed/m²)^</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stubble Burnt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. 90 mm rows</td>
<td>17.7</td>
<td>107</td>
<td>0.93</td>
<td>1.98</td>
<td>0.54 (2)</td>
</tr>
<tr>
<td>2. 180 mm rows</td>
<td>21.3</td>
<td>112</td>
<td>0.90</td>
<td>1.96</td>
<td>0.73 (4)</td>
</tr>
<tr>
<td>3. 270 mm rows</td>
<td>18.7</td>
<td>104</td>
<td>0.86</td>
<td>2.01</td>
<td>0.82 (6)</td>
</tr>
<tr>
<td>4. 360 mm rows</td>
<td>23.3</td>
<td>101</td>
<td>0.80</td>
<td>1.93</td>
<td>1.38 (23)</td>
</tr>
<tr>
<td>Burnt mean</td>
<td>20.3</td>
<td>106</td>
<td>0.87</td>
<td>1.97</td>
<td>0.87 (6)</td>
</tr>
<tr>
<td>Stubble Retained</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. 90 mm rows</td>
<td>26.3</td>
<td>98</td>
<td>0.95</td>
<td>1.96</td>
<td>0.82 (6)</td>
</tr>
<tr>
<td>6. 180 mm rows</td>
<td>25.3</td>
<td>111</td>
<td>0.92</td>
<td>1.96</td>
<td>1.09 (11)</td>
</tr>
<tr>
<td>7. 270 mm rows</td>
<td>26.0</td>
<td>103</td>
<td>0.85</td>
<td>2.00</td>
<td>2.10 (126)</td>
</tr>
<tr>
<td>8. 360 mm rows</td>
<td>19.7</td>
<td>107</td>
<td>0.75</td>
<td>1.96</td>
<td>2.29 (195)</td>
</tr>
<tr>
<td>Stubble mean</td>
<td>24.3</td>
<td>105</td>
<td>0.87</td>
<td>1.97</td>
<td>1.58 (37)</td>
</tr>
<tr>
<td>l.s.d. (5%) Stubble</td>
<td>4.06</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.213</td>
</tr>
<tr>
<td>F pr</td>
<td>0.049</td>
<td>0.768</td>
<td>0.801</td>
<td>0.939</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>l.s.d. (5%) Spacing</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.051</td>
<td>n.s.</td>
<td>0.301</td>
</tr>
<tr>
<td>F pr</td>
<td>0.917</td>
<td>0.329</td>
<td>&lt; 0.001</td>
<td>0.288</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>l.s.d. Stub x Spac</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>0.425</td>
</tr>
<tr>
<td>F pr</td>
<td>0.143</td>
<td>0.531</td>
<td>0.382</td>
<td>0.860</td>
<td>0.005</td>
</tr>
<tr>
<td>C. of V. (%)</td>
<td>20.8</td>
<td>12.4</td>
<td>6.4</td>
<td>3.7</td>
<td>26.8</td>
</tr>
</tbody>
</table>

* Reps 1, 2 and 3 only. ** Excluding rep 1. ^ All logs are base 10 of (data + 1). Numbers in brackets are the antilog – 1.

CONCLUSION

1. The field emergence was very good at around 80 per cent with no effect of previous stubble or row spacing.
2. The yield at around 0.9 t/ha was good for the dry season, probably due to being chemical fallowed in 2008, with no effect of previous stubble.
3. The yield dropped, on average, 0.7 per cent for each centimetre increase in row spacing from 9 cm.
4. In-grain ryegrass seed numbers in the stubble retained 270 and 360 mm rows and the burnt stubble 360 mm rows was higher than all other treatments.

KEY WORDS

canola, row spacing, stubble, no-till, ryegrass, yield
ACKNOWLEDGMENTS
The author would like to thank Aaron Middleton and the staff at the Merredin Research Station (Alan Harrod, Matt Harrod and Elmer Kidson) for their patience in looking after this experiment.

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Paper reviewed by: Mohammad Amjad
Impact of stubble retention on water balance and crop yield

Phil Ward1, Ken Flower2,3, Neil Cordingley2 and Shayne Micin1

1CSIRO, Wembley, Western Australia
2Western Australian No-Till Farmers Association
3University of Western Australia

KEY MESSAGES

1. Water use during the growing season is affected by crop type and management, with cover crops generally using less water, due to their early termination.

2. Residue quantities of more than 3–4 t/ha affected evaporation from the soil over summer, resulting in greater soil moisture at sowing for the subsequent crop. Benefits were substantially reduced for residue quantities less than 3 t/ha.

3. Residue quantities of greater than 5 t/ha have been generated with realistic management practices in large plots at both trial sites, indicating the potential for relatively large residue loads under Western Australian conditions.

AIMS

To measure the impact of stubble retention and cover crops on evaporation over summer and soil water storage at the time of sowing the next crop, and to determine the impact on subsequent crop yields.

METHOD

Long-term rotation trials were established by the Western Australian No-Till Farmers Association (WANTFA) near Cunderdin (loam) and Mingenew (deep sand), commencing in 2007. At both trials, four conservation farming ‘philosophies’ are being compared over a full three year rotation in three replicates:

1. Maximum carbon input, limited to cereals only (Saia oat cover crop, barley, barley at Cunderdin; Saia oat cover crop, wheat, barley at Mingenew).
2. Maximum diversity (wheat, vetch/oat cover crop, canola at Cunderdin; wheat, lupin, oilseed cover crop at Mingenew).
3. Maximum flexibility (wheat, wheat, wheat at Cunderdin; serradella, wheat, lupin at Mingenew).
4. ‘District practice’ (wheat, barley, lupin at Cunderdin; slashed barley, wheat, lupin at Mingenew).

The first three philosophies must retain stubble, and 1 and 2 must include a cover crop at least once every six years. Philosophies 1, 2 and 4 are set three year rotations so that each phase of the rotation is presented each year. Each of these rotations is reviewed every three years. Philosophy 4 is not required to retain stubble, and there is no requirement for a cover crop. Measurements at the trials include yield and economic performance, ground cover, weed, insect, nematode and disease monitoring, and aspects of the soil water balance including soil water content and evaporation from the soil surface. Only the residue cover, water balance and crop yield results are discussed in this paper.

Crop yield and residue cover after harvest were assessed by sampling 4 x 0.6 m² quadrats in each plot. Soil water content in all plots was monitored by Neutron Moisture Metre (NMM) to a depth of 2.0 m at Cunderdin and 3.0 m at Mingenew.

RESULTS

Cunderdin

At Cunderdin, yields were lowest in the 2007 season, but greater in subsequent years with kinder seasonal conditions (Table 1). Residue loads have been increasing throughout the trial, and averaged over 7 t/ha after the 2009 harvest (data not shown). During the 2007 season, differences in water use of up to 40 mm were observed, with lupins using the least water, followed by the vetch/oat and Saia...
oat cover crops, and canola. Cereals tended to use more water than other crops. Evaporation during the 2007/08 summer varied between 75 and 123 mm (out of summer rainfall of 125 mm), and was largely unrelated to treatment except that lupins (which used least water during the growing season) lost significantly more water over summer than any other treatment. Residue loads were generally small even after the Saia and vetch-oat cover crops (treatments 1 and 2), with a maximum residue load of 2.3 t/ha, and this was not sufficient to generate consistent effects on summer water loss (Figure 1).

Table 1. Water use (mm), crop yield (t/ha) and residue remaining after harvest (t/ha) at the Cunderdin site

<table>
<thead>
<tr>
<th>Crop sequence e.g. 1 – Saia07/Barley08/Barley09</th>
<th>Water use and (yield) 2007</th>
<th>Water use and ( residue) 2007/08</th>
<th>Soil water May 2008</th>
<th>Water use and (yield) 2008</th>
<th>Water use and ( residue) 2008/09</th>
<th>Soil water May 2009</th>
<th>Water use and ( yield) 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Saia/Barley/Barley</td>
<td>154 ± 6</td>
<td>75 ± 17 (2.1 ± 0.2)</td>
<td>285 ± 11</td>
<td>275 ± 16</td>
<td>78 ± 10 (3.9 ± 0.3)</td>
<td>257 ± 12</td>
<td>259 ± 13 (2.5 ± 0.1)</td>
</tr>
<tr>
<td>1 – Barley/Barley/Saia</td>
<td>156 ± 7 (1.4 ± 0.1)</td>
<td>78 ± 4 (1.5 ± 0.1)</td>
<td>280 ± 3</td>
<td>271 ± 9</td>
<td>83 ± 6 (3.8 ± 0.3)</td>
<td>252 ± 13</td>
<td>221 ± 3 (na)</td>
</tr>
<tr>
<td>1 – Barley/Saia/Barley</td>
<td>174 ± 10 (1.3 ± 0.1)</td>
<td>99 ± 10 (1.7 ± 0.1)</td>
<td>242 ± 20</td>
<td>252 ± 12 (na)</td>
<td>61 ± 10 (6.4 ± 0.2)</td>
<td>254 ± 18</td>
<td>278 ± 18 (2.9 ± 0.1)</td>
</tr>
<tr>
<td>2 – Wheat/Vetch-Oat/Canola</td>
<td>152 ± 1 (1.4 ± 0.1)</td>
<td>84 ± 4 (1.9 ± 0.2)</td>
<td>279 ± 5</td>
<td>247 ± 15 (na)</td>
<td>70 ± 7 (4.6 ± 0.2)</td>
<td>287 ± 4</td>
<td>253 ± 5 (0.8 ± 0.1)</td>
</tr>
<tr>
<td>2 – Vetch-Oat/Canola/Wheat</td>
<td>145 ± 12 (na)</td>
<td>96 ± 15 (2.3 ± 0.2)</td>
<td>274 ± 3</td>
<td>235 ± 29 (1.1 ± 0.1)</td>
<td>78 ± 13 (4.0 ± 0.3)</td>
<td>286 ± 35</td>
<td>252 ± 21 (2.1 ± 0.1)</td>
</tr>
<tr>
<td>2 – Canola/Wheat/Vetch-Oat</td>
<td>148 ± 2 (0.1 ± 0.1)</td>
<td>97 ± 1 (1.8 ± 0.4)</td>
<td>269 ± 2</td>
<td>248 ± 13 (2.9 ± 0.1)</td>
<td>58 ± 2 (4.6 ± 0.4)</td>
<td>289 ± 10</td>
<td>236 ± 7 (na)</td>
</tr>
<tr>
<td>3 – Wheat/Wheat/Pasture/Pasture</td>
<td>160 ± 10 (1.4 ± 0.1)</td>
<td>92 ± 3 (1.6 ± 0.1)</td>
<td>262 ± 7</td>
<td>242 ± 14 (2.9 ± 0.1)</td>
<td>77 ± 4 (4.2 ± 0.3)</td>
<td>268 ± 3</td>
<td>261 ± 5 (2.2 ± 0.1)</td>
</tr>
<tr>
<td>4 – Wheat/Barley/Lupin</td>
<td>148 ± 7 (1.3 ± 0.1)</td>
<td>78 ± 17 (1.6 ± 0.1)</td>
<td>289 ± 11</td>
<td>279 ± 17 (2.9 ± 0.1)</td>
<td>92 ± 10 (3.6 ± 0.3)</td>
<td>242 ± 5</td>
<td>197 ± 6 (1.8 ± 0.1)</td>
</tr>
<tr>
<td>4 – Barley/Lupin/Wheat</td>
<td>164 ± 1 (1.3 ± 0.1)</td>
<td>85 ± 22 (1.4 ± 0.1)</td>
<td>266 ± 22</td>
<td>245 ± 30 (0.9 ± 0.1)</td>
<td>78 ± 2 (2.7 ± 0.3)</td>
<td>268 ± 7</td>
<td>251 ± 10 (2.1 ± 0.1)</td>
</tr>
<tr>
<td>4 – Lupin/Wheat/Barley</td>
<td>133 ± 5 (0.6 ± 0.1)</td>
<td>123 ± 8 (1.3 ± 0.1)</td>
<td>258 ± 12</td>
<td>234 ± 5 (3.0 ± 0.1)</td>
<td>73 ± 13 (4.8 ± 0.4)</td>
<td>277 ± 9</td>
<td>268 ± 12 (2.5 ± 0.1)</td>
</tr>
</tbody>
</table>

During 2008, grain yields were much higher, with correspondingly higher residue levels. Grain yield within the cereals was not related to soil moisture at sowing. Once again, differences in water use during the growing season were observed, with the sub-clover pasture using 45 mm less water than any other treatment, and the cereal crops using marginally more water than lupins, canola and the cover crops.

Residue loads during the 2008/09 summer varied from more than 6 t/ha for the Saia oat cover crop to less than 3 t/ha for the pasture and lupin plots. Average water loss from the 6 plots with 4.0 t/ha or less of residue was 81 mm (out of 99 mm of summer rainfall), compared with 68 mm for plots with more than 4.0 t/ha of residue (Figure 1). Despite the observed differences in summer evaporation, there were no significant differences in soil water storage at the start of the 2009 growing season for the plots going into cereal, and so effects on grain yield could not be determined at this site in 2009.

Mingenew

Yields were lowest at the Mingenew trial in 2007, but were greater in 2008 and 2009 with better seasonal conditions. Residue levels have increased throughout the trial, and averaged nearly 5 t/ha after the 2009 harvest (data not shown).
In the 2007 growing season, water use varied between 101 mm for the pasture and 146 mm for a wheat crop (Table 2). Cereal crops and lupins used more water than the pasture, slashed barley (to simulate grazing), or the two cover crops (Saia oats in treatment 1 and oilseed in treatment 2). In contrast to the Cunderdin site, there was a strong negative correlation ($r^2 = 0.97$) between water use during 2007, and water use during the 2007/08 summer. Plots with more water at the time of harvest lost more water by evaporation over summer, and differences in stored soil water were minimal (< 10 mm) at the time of sowing in 2008. The small residue loads generated during 2007 were not sufficient to protect soil water over summer (Figure 1).

### Table 2. Water use (mm), crop yield (t/ha) and residue remaining after harvest (t/ha) at the Mingenew site

<table>
<thead>
<tr>
<th>Crop sequence e.g.</th>
<th>Water use and (yield) 2007</th>
<th>Water use and (residue) 2007/08</th>
<th>Soil water May 2008</th>
<th>Water use and (yield) 2008</th>
<th>Water use and (residue) 2008/09</th>
<th>Soil water May 2009</th>
<th>Water use and (yield) 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Saia/Wheat/Barley</td>
<td>$127 \pm 7$ (na)</td>
<td>$88 \pm 13$ (2.0 ± 0.2)</td>
<td>$247 \pm 5$ (3.2 ± 0.5)</td>
<td>$15 \pm 2$ (4.0 ± 0.5)</td>
<td>$181 \pm 5$ (1.8 ± 0.1)</td>
<td>$290 \pm 2$ (1.8 ± 0.1)</td>
<td>$290 \pm 2$ (1.8 ± 0.1)</td>
</tr>
<tr>
<td>1 – Wheat/Barley/Saia</td>
<td>$146 \pm 6$ (1.5 ± 0.1)</td>
<td>$78 \pm 7$ (1.4 ± 0.2)</td>
<td>$239 \pm 2$ (1.7 ± 0.1)</td>
<td>$206 \pm 2$ (3.9 ± 0.5)</td>
<td>$17 \pm 2$ (3.9 ± 0.5)</td>
<td>$186 \pm 3$ (na)</td>
<td>$301 \pm 11$ (na)</td>
</tr>
<tr>
<td>1 – Barley/Saia/Wheat</td>
<td>$129 \pm 11$ (2.0 ± na)</td>
<td>$87 \pm 7$ (1.8 ± 0.3)</td>
<td>$246 \pm 1$ (na)</td>
<td>$204 \pm 14$ (6.6 ± 0.7)</td>
<td>$20 \pm 5$ (6.6 ± 0.7)</td>
<td>$191 \pm 8$ (2.4 ± 0.2)</td>
<td>$302 \pm 5$ (2.4 ± 0.2)</td>
</tr>
<tr>
<td>2 – Wheat/Lupin/Oilseed</td>
<td>$138 \pm 5$ (1.6 ± 0.2)</td>
<td>$82 \pm 6$ (1.4 ± 0.1)</td>
<td>$242 \pm 3$ (4.1 ± 0.4)</td>
<td>$227 \pm 8$ (3.4 ± 0.1)</td>
<td>$14 \pm 3$ (3.6 ± 0.4)</td>
<td>$170 \pm 3$ (3.4 ± 0.1)</td>
<td>$285 \pm 4$ (3.4 ± 0.1)</td>
</tr>
<tr>
<td>2 – Lupin/Oilseed/Wheat</td>
<td>$144 \pm 11$ (1.1 ± 0.1)</td>
<td>$77 \pm 7$ (1.9 ± 0.1)</td>
<td>$240 \pm 1$ (na)</td>
<td>$182 \pm 3$ (2.9 ± 0.3)</td>
<td>$32 \pm 1$ (2.9 ± 0.3)</td>
<td>$195 \pm 3$ (3.4 ± 0.1)</td>
<td>$330 \pm 5$ (3.4 ± 0.1)</td>
</tr>
<tr>
<td>2 – Oilseed/Wheat/Lupin</td>
<td>$104 \pm 9$ (na)</td>
<td>$115 \pm 5$ (1.3 ± 0.2)</td>
<td>$241 \pm 2$ (2.6 ± 0.3)</td>
<td>$225 \pm 2$ (3.6 ± 0.6)</td>
<td>$15 \pm 1$ (3.6 ± 0.6)</td>
<td>$171 \pm 3$ (3.4 ± 0.1)</td>
<td>$310 \pm 2$ (3.4 ± 0.1)</td>
</tr>
<tr>
<td>3 – Pasture/Wheat/Lupin</td>
<td>$101 \pm 7$ (na)</td>
<td>$115 \pm 2$ (1.4 ± 0.1)</td>
<td>$248 \pm 2$ (2.5 ± 0.3)</td>
<td>$234 \pm 6$ (3.3 ± 0.5)</td>
<td>$4 \pm 12$ (3.3 ± 0.5)</td>
<td>$188 \pm 8$ (3.3 ± 0.5)</td>
<td>$323 \pm 11$ (3.3 ± 0.5)</td>
</tr>
<tr>
<td>3 – Pasture/Pasture/Pasture</td>
<td>$101 \pm 7$ (na)</td>
<td>$112 \pm 2$ (1.4 ± 0.1)</td>
<td>$251 \pm 3$ (2.6 ± 0.3)</td>
<td>$206 \pm 3$ (1.8 ± 0.4)</td>
<td>$30 \pm 6$ (1.8 ± 0.4)</td>
<td>$184 \pm 10$ (na)</td>
<td>$279 \pm 4$ (na)</td>
</tr>
<tr>
<td>4 – Barley(S)/Wheat/Lupin</td>
<td>$115 \pm 6$ (na)</td>
<td>$101 \pm 4$ (2.2 ± 0.2)</td>
<td>$243 \pm 4$ (2.9 ± 0.3)</td>
<td>$223 \pm 3$ (5.1 ± 1.0)</td>
<td>$14 \pm 1$ (5.1 ± 1.0)</td>
<td>$175 \pm 5$ (3.2 ± 0.1)</td>
<td>$315 \pm 3$ (3.2 ± 0.1)</td>
</tr>
<tr>
<td>4 – Wheat/Lupin/Barley(S)</td>
<td>$137 \pm 3$ (1.7 ± 0.2)</td>
<td>$88 \pm 5$ (1.1 ± 0.1)</td>
<td>$237 \pm 3$ (2.6 ± 0.2)</td>
<td>$233 \pm 3$ (5.0 ± 0.9)</td>
<td>$14 \pm 2$ (5.0 ± 0.9)</td>
<td>$160 \pm 2$ (3.7 ± 0.1)</td>
<td>$264 \pm 3$ (3.7 ± 0.1)</td>
</tr>
<tr>
<td>4 – Lupin/Barley(S)/Wheat</td>
<td>$137 \pm 6$ (1.1 ± 0.2)</td>
<td>$82 \pm 3$ (2.3 ± 0.3)</td>
<td>$241 \pm 8$ (2.2 ± 0.1)</td>
<td>$165 \pm 11$ (na)</td>
<td>$34 \pm 1$ (2.2 ± 0.1)</td>
<td>$212 \pm 17$ (na)</td>
<td>$342 \pm 10$ (na)</td>
</tr>
</tbody>
</table>

During 2008, better seasonal conditions resulted in residue levels varying between 1.8 t/ha for the pasture and 6.6 t/ha for the Saia oat cover crop. Despite the very dry summer conditions, differences in evaporation were observed, with plots with 4.0 t/ha or more of residue losing an average of 15 mm, and plots with less than 4.0 t/ha (excluding the pasture plots) losing an average of 25 mm (Figure 1).

Good grain yields were also observed in 2009, ranging between 2.4 and 3.7 t/ha for wheat (treatments 1, 2 and 4), and 2.7 and 3.2 t/ha for lupins (treatments 2, 3 and 4). In the wheat plots, crop yield was closely related to water use and to soil moisture at sowing, but these relationships were not evident in the lupin plots. Other factors must be influencing yield in these treatments.
Further data analysis, including weed populations, will be undertaken for both sites to shed further light on the interactions between crop rotation, stubble management, and crop yield and water use.

CONCLUSION

Preliminary analysis of data from long-term rotation trials indicates that residues greater than about 3–4 t/ha are capable of affecting the quantity of evaporation from the soil surface during the summer months, even in the absence of substantial rainfall. Benefits for crop production associated with greater soil moisture at sowing were demonstrated for the deep sandy soil at Mingenew, but have not yet been demonstrated for the heavier soil at Cunderdin. The trials are funded for a further three years, and so data collection and analysis will continue.

KEY WORDS

stubble management, rotation, evapotranspiration

ACKNOWLEDGMENTS

Thanks to Cameron Weeks and Steve Cosh for assistance with managing the Mingenew site. Bec Parsons and Chris Herrmann provided valuable technical support.

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Paper reviewed by: Steve Milroy and Yvette Oliver
Using POAMA rainfall forecasts for crop management in South-West WA

Senthold Asseng1, Peter McIntosh2,3, Mike Pook2,3, James Risbey2,3, Guomin Wang3, Oscar Alves3, Ian Foster4, Imma Farre4 and Nirav Khimashia1
1CSIRO Plant Industry, Perth
2CSIRO Marine and Atmospheric Research, Hobart
3Centre for Australian Weather and Climate Research (CAWCR), A partnership between the Australian Bureau of Meteorology and CSIRO, Melbourne
4Department of Agriculture and Food, Western Australia

KEY MESSAGES
Using new seasonal rainfall forecast systems could substantially increase profitability of wheat cropping in Western Australia by up to A$50/ha.

AIMS
To explore the benefits from seasonal rainfall forecasts in N management using the POAMA model.

METHOD
Seasonal rainfall forecasts from POAMA (Predictive Ocean Atmosphere Model for Australia) were benchmarked against other forecasting systems available for Western Australia. The POAMA forecast was then applied to N management decisions in wheat cropping and the financial benefits from using such a forecast were determined.

POAMA
Australia's seasonal climate forecast model system is called POAMA (Predictive Ocean Atmosphere Model for Australia). It is run by the Bureau of Meteorology in both operational and experimental modes. Operational output are available at http://www.bom.gov.au/climate/coupled_model/poama.shtml. Experimental output from POAMA is available at http://poama.bom.gov.au/experimental/poama15/r_gen.htm, and contains a range of information, including rainfall forecasts. Currently, the operational and experimental versions of POAMA are the same, being POAMA 1.5.

The operational version of the model runs once a day, forecasting up to 9 months ahead. Ensemble forecasts are obtained by averaging as many of these daily runs as required. These forecasts have been running with POAMA 1.5 for about two years. However, a hindcast data set is available spanning the years 1980 to 2006, from which the skill and value of this version of the model can be assessed. The ensemble structure of this data set is different from the operational setup. The hindcast data set comprises ten forecasts initialised at the start of every month from January 1980 to December 2006. These forecasts also extend to 9 months. The model output used here is a simple average of the ten ensemble members.

The spatial resolution of POAMA is relatively coarse, being exactly 2.5 degrees in longitude, and approximately 2.5 degrees in latitude. The temporal resolution of the model is about 15 minutes during the model run, but the output is only stored at a daily timescale. The data used here is averaged to monthly values.

Skill
The skill of POAMA for seasonal rainfall forecasts of May-October rainfall starting from 1 May were benchmarked against other forecasting systems in WA, including other GCMs and statistical forecasts available from a previous project. The skill is a measure of the quality of a forecast in predicting the future season-type.
**N-management**

The APSIM-Nwheat model was used to run a series of crop simulation experiments for Katanning, Nyabing (both in the southern wheatbelt), Merredin (central wheatbelt) and Mullewa (northern wheatbelt). The experiments explored the optimum N-application for different soil types, initial soil water conditions, wheat prices and N application costs based on POAMA forecasts of above or below median rainfall.

**RESULTS**

More than half of the variation in gross margins in wheat cropping in south-west Western Australia (SWWA) can be explained by growing season rainfall variability (May to October). Forecasts of seasonal rainfall should therefore enable the adjustment of management practices to maximise returns from ‘good’ seasons and minimise losses from ‘bad’ seasons. Growing season rainfall forecasts from Australia’s seasonal climate forecast model POAMA 1.5 indicated some skill, with a linear correlation of 0.3 to 0.4 with observed rainfall data in some parts of the south of SWWA, but less in the north of SWWA. The percentage of correct forecasts in a 2-category forecast (above and below average rainfall) reached up to 70 per cent in the south of SWWA, which was close to the highest values from eastern Australia. When benchmarking the POAMA forecast with other global circulation model forecasts and statistical forecasts for SWWA, POAMA showed significantly higher skill for the south of SWWA, but similar low or less skill for the north of SWWA.

The POAMA forecast was then applied to management decisions of N fertiliser applications in wheat cropping in the south of SWWA. The forecast produced up to A$50/ha/year higher returns by varying N applications according to POAMA forecasts of above and below average seasons compared to a constant fertiliser application. The current lack of forecast skill for the north of SWWA resulted in no value in using a forecast for N management decisions in this region. The benefits from using the POAMA forecast in the south of SWWA will vary with increasing wheat prices and cost of fertiliser (Figure 1) and also differs for different soil types and initial soil water conditions (not shown). The highest benefits from using the seasonal POAMA rainfall forecast at this location is with 2A$/kgN and 200A$/t wheat price.

Some caution is required as the available hindcast data set for evaluating the POAMA forecast is limited to only 27 years where a few very responsive years can have a large impact on the outcomes of such an analysis.

![Figure 1](image-url) **Figure 1** Absolute (A$) and relative (%) benefits from using POAMA seasonal rainfall forecasts for N management decisions at Katanning with variable wheat price (100–500A$/t) and N application costs (1 and 2 A$/kg N applied).
CONCLUSION

The seasonal rainfall forecast from POAMA for the central and southwest wheatbelt of Western Australia could be used for nitrogen management decisions in wheat cropping with financial benefits of up to 50 A$/ha through increased N applications in above median rainfall seasons and reduced N applications in below median rainfall seasons.

KEY WORDS

POAMA, seasonal rainfall forecast, wheat, N-management, rainfall season-types

ACKNOWLEDGMENTS

We thank the Managing Climate Variability program of former Land and Water Australia, GRDC, CSIRO Climate Adaptation Flagship, Bureau of Meteorology and Department of Agriculture and Food, Western Australia for financial support.

Project No.: R-550-28
Paper reviewed by: Dr Steve Milroy
Adaptation to changing climates and variability – results of the Agribusiness Changing Climates regional workshop

1 Roderick Grieve Farm Management Consultants
2 Coffey International P/L
3 Department of Agriculture and Food, Western Australia

KEY MESSAGES
1. Action on adaptation to climate change is required regardless of the eventual conclusions of the climate change debate. For action on adaptation to climate change there are clear directions. By contrast the issue of required actions for mitigation of climate change still requires direction for farm businesses.
2. Managing with seasonal variability will continue to be the main business driver for change.
3. The agricultural industry is adapting but further R,D&E is needed to sustain adaptation. Five key needs areas and four R&D areas have been identified for adaptation to be achieved.
4. Different extension methodology is needed and suggested to achieve real change.
5. Management strategies to adapt to changes in seasonal variability are viable.

AIM

The 'Changing Climates Agribusiness Workshop' was held in April 2009 in the Southern Agricultural region. The focus of the workshop was on impacts of changing climates and options for adaptation of farming systems in the Southern region of WA. Underpinned by the best available climate science, the workshop aim was to identify knowledge gaps and future R&D priorities and test the assumption that industry has adapted to changing climates and will be able to continue to adapt.

The forum had 40 participants with company agronomists (22 per cent), independent consultants (23 per cent), agribusiness bankers from the finance sector (20 per cent), DAFWA specialists (25 per cent) and other mainly Grains industry representatives (10 per cent). Presenters included two consultants and five DAFWA specialists. This paper describes the methodology followed at the workshop, its results and conclusions.

METHOD FOR THE CHANGING CLIMATES AGRIBUSINESS WORKSHOP

The method involved a six step process

1. Negotiate the assumptions. 2. Review climate projections. 3. Present regional scenarios and actual trends. 4. Introduce options and implications. 5. Workshop the information needs and R&D priorities and 6. Develop workshop conclusions: The workshop question for the agribusiness groups was ‘What are the key information gaps that need addressing to support agribusiness decision making on changing climates?’

1. The assumptions

The assumption negotiated in preparation for the workshop was that contingency planning and action on adaptation to climate change needs consideration now regardless of the eventual conclusions of the climate change debate. This assumption was based on updated 2009 scientific information (but workshop was prior to the release of the Copenhagen Diagnosis).

However the specific global debate on mitigation actions needs some resolution before businesses can get clear direction for climate mitigation actions. The precautionary principle could apply.

2. **Climate projections and updated regional scenarios** using the best available information were presented (Stephens et al.)². These are based on the global projections below undertaken by climatologists using modeling with decreasing rainfall, etc. for mid latitudes projected (refer the Climate Wizard Tool by Girvetz, E, Zganjur, C et al.³ and also OzClim by CSIRO).

![Figure 1 Global rainfall change projections (Hennessey⁴)](image)

![Figure 2 Projected rainfall change by 2030. The example analysis is based on the medium emissions scenario (refer Climate wizard). Significant decreases in winter and spring are ‘likely’, with less confidence about decreases in summer and autumn (Stephens 2009).](image)

There remain divergent positions in various industries on climate projections but agribusiness in the Grains industry has pointed out that the actual trends are occurring and require assessment.

SH Schneider, SC Shenwood, RCJ Somerville et al., The University of New South Wales, Climate Change Research Centre (CCCR), Sydney, Australia.


3 The Climate Wizard Tool is available on open release <http://ClimateWizard.org/custom>.

3. **Actual trends to date:** Trends were consistent with the scenario projections

![Image: Western Australian Wheatbelt May - October Rainfall Zones 1976-2008 compared to 1910-1975](image)

**Figure 3** Changes in the 225 and 450 mm isohyets contrasting the years 1976 to 2008 with 1901 to 1975.

![Image: Growing season (May to October) rainfall variation from 1908 to 2009 for Katanning](image)

**Figure 4** The Katanning decline in Growing Season Rainfall of 53 mm (with P < 0.01).

This is representative of those trends that have already occurred across the Western part of the Southern region. Conclusion: Actual trends are consistent with projections (see above).

4. **Implications and Options**

The implications of these changes for crop yields were examined by Farre, Foster & Asseng (2009)\(^5\) using APSIM models. This indicated for the Southern region a 5–15 per cent decline in yield when comparing 1975–2004 with projections for 2035–2064. 

**NOTE:** Projections use current agronomy and do not estimate future technology advances. To maintain yields an increase in crop water use efficiency of 3 kg/mm of GSR is required. So what are the options to improve the agricultural systems? See over.

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4. **OPTIONS – Extracted pointers for region from Lemon J and Grieve R presentations**

Based on the scenarios presented the technical and business management options included:

**Increasing broad-acre WUE**: Can we increase Plant Available Water and WUE (Anderson W⁶)?
- Addressing soil constraints—require robust BCA’s⁷ on soil amelioration investment.
- VRT to match crop inputs to soil and PAWC potential (Robertson M, 2009 Crop Updates).
- Sow earlier with ‘plastic’ maturity to avoid spring drought but still avoid frost and maintain IWM?
- Canopy management with tactical N application to manage leaf area for particular season.

**Improved selectivity of land use**

Determine land potential—yield maps are very useful. Use of Yield probability forecasting:
- Need robust alternatives for land with low Plant Available Water capacity (PAWC).
- Perennial based systems to include pasture, but need resilient animal systems.
- Dual purpose annual crops, shrubs and trees for carbon, bio-fuels, protection, fodder, etc.
- Water supply and fodder conservation investment; Experience with confinement feeding.
- Weed control and summer fallow; better use of anchored stubbles. Stubble cover claims need a review; disc seeders to retain soil moisture; sowing into existing furrows; companion planting.

**Farm Business management options**—Examples of businesses growing their equity five fold even under extreme seasonal variability were presented to the workshop.
- Coping with uncertainty requires risk management: Profit = Area x yield x price – costs (fixed and variable). The best form of risk management is cost control as poor cost control is a major reason for business failure (Grieve et al.). This limits downside loss but the 10 per cent rule applies. NOTE: Costs per tonne (unit output) are a more effective measure than costs per hectare.
- Improved seasonal predictions—While advances are possible, uncertainties will remain and there will be a continued need to apply seasonal climate probabilities to decision making.
- Decision support tools (fertiliser, herbicide, lot feeding calculators, rainfall analysis); deferring inputs (limited to N and fungicides, possibly K). Hedging and spreading costs and prices.
- Industry based Risk Analysis. There is a critical need for assessment of climate risks for businesses in the Southern Agricultural region (cf ‘Viability of farming in the North East Agricultural Region’ Planfarm 2008). There is a need to interpret the benchmarking of farm businesses and implications for farm businesses in upper or lower quartiles.
- Maybe re-structure farm business or locate farm business in diverse locations (note other risks).
- GM options and dreams (which of the ‘possibilities’ will give real options?)

**Assumptions**: 1. That R&D investment and the current rates of advancement in efficiencies of production and resource use efficiency (water, nutrients, energy, etc.) will continue. 2. That the economic factors, such as the terms of trade, will not decline at the rates of previous decades. 3. The modelling of the impacts of changes in temperature, PAW and CO₂ are in the right ball park.

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⁷ BCA = Benefit Cost Analysis  VRT = variable rate technology  IWM = Integrated Weed Management
5. **Workshop Results – Key information gaps for adaptation to climate change**

Table 1: **KEY Information gaps and needs for future action from the six Agribusiness groups**

<table>
<thead>
<tr>
<th>Key Information gap and need for future action on adaptation to climate changes</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Building capacity of decision makers with targeted information and tools for managing climate variability and use of innovative extension methodology.</td>
<td>42</td>
</tr>
<tr>
<td>2. Business management studies on the potential impacts of climate change and adaptation to climate change (benchmarking, modelling and case studies).</td>
<td>42</td>
</tr>
<tr>
<td>3. Amelioration of soil limitations, water holding capacity and land capability for achieving higher Water Use Efficiency (and higher efficiency in nutrients, energy, etc.).</td>
<td>38</td>
</tr>
<tr>
<td>4. Improved Seasonal forecasting and medium term climate analysis/ predictions.</td>
<td>37</td>
</tr>
<tr>
<td>5. Policy and whole of landscape implications—policy from analysis of social, environmental and economic interactions which could result in larger implications.</td>
<td>26</td>
</tr>
</tbody>
</table>

There were four key action areas in general agreement (see table) and the first three needs were for within-region action. There were other needs identified by the groups however many required more external action outside of the region.

R&D priorities and investment needs identified in the workshop were as follows:

- **New strategies required for managing climate variability** in the Southern Agricultural region. To date there has been largely reactive adjustment by the individual farm businesses to climate variability. Current case studies indicate this has been sufficiently successful to date however experience in the Northern wheatbelt indicates a need for more proactive business strategies.

- **Increased water use efficiency (WUE) is required.** To sustain global competitiveness requires higher WUE as much of Australia’s Southern regions are projected to receive less rainfall while many other countries will have their agricultural regions gaining rainfall (and in some cases such as Canada, improved growing temperatures). While average GSR may fall, current R&D in the region is indicating how plant available water and water use efficiency can be increased (Anderson, Herbert and Stephens: pers. comm.). Other resource efficiencies (energy efficiency, nutrient efficiency, carbon efficiency, etc.) are linked and are further targets to be achieved.

- **Timely investment in water storage and forage and fodder.** This is a business management strategy and a whole of industry and whole of landscape issue. If decisions and investment are deferred will investment be more costly?

- **Industry based risk analyses.** Sets of risk analyses developed with agribusiness will enable the public and private service sectors to provide some clear guidance. There is a need to interpret the benchmarking of farm businesses and implications for farm businesses in upper or lower quartiles.

6. **Workshop Conclusions**

**The driver for change: Climate change or seasonal variability?**

The scenarios presented confirmed that the Southern Agricultural Region can expect a drying climate with declining growing season rainfall and rising temperatures. The magnitudes of these underlying changes are small to date, however in the future they may impact more on interannual variability. Current trends are consistent with the actual changes experienced (across 30 years) in the Western part of the region. Over future decades, seasonal variability will remain a dominant driver of adjustment at the farm level, with the underlying longer-term trends less important within the farm business cycle. There is valuable experience in areas North and East of the Southern region.

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The industry is adapting with available options

On current evidence, professionals within industry, agribusiness and R&D organisations conclude that producers within agricultural industries are adapting to climate change and will continue to adapt. The current industry assumptions about the feasibility of adaptation were validated. The analyses presented support this industry position. Case studies for farm businesses performing in the upper quartiles also confirm this adaptation is occurring in parts of the industry.

For businesses performing in the lower quartile, further studies are required. What is evident is that the industry has the capacity to adapt but for many individual farm businesses, capacity may need to be developed. There are issues concerning water resources, the natural biological resources and biodiversity for landscapes. It is suggested that building resilience in the landscape through sound natural resource management (reducing stressors) will be the key to reducing impacts such as species extinction. This is highlighted in the whole of landscape analyses undertaken for the region in 2009 (Price M. pers. comm.). Social and environmental implications for rural communities will increase the total economic implications and investment in research and participative development is needed. Current analyses are identifying ‘hotspots’ which have a need for proactive change, as well as ongoing incremental adjustment by individual businesses.

Different extension methodology

The Workshop identified that both better interpretation of climate change information and better targeted extension are needed. Farming communities are typically uncertain about the reality of climate change, which contrasts with their acknowledgement of seasonal variability. They have tended to receive conflicting messages. This represents a challenge for traditional extension, because the relevant information is complex and the benefits and costs are based on probabilities rather than certainties. A ‘best fit’ approach was preferred to a ‘best practice’ approach in indicating options.

There is a strong need for both the public and private arms of the service sector to engage in joint activities to build producers’ skills in decision-making under climate change. Agribusiness linked to research alliances such as ARWA (DAFWA, the universities and CSIRO) have the potential to provide clear messages on climate variability and change and ultimately achieve shared objectives.

Adaptation to Climate Change is potentially a viable strategy for inclusion in individual farm business strategies

The technical options and future potential options presented confirm that many farm businesses will be able to adapt. This assumes that the current rates of advancement in efficiencies of production and in resource use efficiency (water, nutrients, energy, etc.) will continue and that the decline in other economic factors, such as the terms of trade, will not decline at the rates of previous decades. The development of pro-active strategies for managing seasonal variability (and adaptation to climate change) was identified as a priority. This requires joint action linking the technical research and farm business management research and development.

Evaluation

An evaluation questionnaire was completed with participants seeking further briefings, about climate trends and analysis, options for adaptation and implications for business.

KEY WORDS
climate change, adaptation, seasonal variability, farm business management options

ACKNOWLEDGMENTS
Agribusiness participants plus the workshop facilitators: Carmody, P, Jones, H, Ohlsen, K.

Paper reviewed by: Dr Ian Foster
Farmers’ management of seasonal variability and climate change in WA

DA Beard, DM Gray, P Carmody, Department of Agriculture and Food, Western Australia

KEY MESSAGES

Farmers’ ability to manage seasonal variability is critical to their profitability and sustainability and is integral to all aspects of on-farm management. Our exploratory analysis of this aspect of their management approach was viewed through the eyes of advisors and influencers, with whom they typically have close contact.

We have found that farmers’ responses to seasonal variability in WA are highly uneven and depend on a range of factors such as level of exposure to and the consequences of seasonal risk, the risk profile of the farmer, age, use of appropriate technology and practices, and levels of management experience and expertise. Many farmers are uncertain about whether climate change is occurring, some denying that it is. There is a low level of acceptance that it is the result of human activity, reflecting a high level of uncertainty rather than widespread open scepticism. Advisors mirror these attitudes to a degree but are more likely to agree that climate change is man made. Where climate change is accepted, many believe that current risk management is appropriate and adequate to managing climate change.

An examination of perceived constraints to improved management of seasonal variability and climate change provide evidence that there are three key factors which are fundamental to understanding the reasons for the variable acceptance. These are:

(i) the extent to which practices are perceived to be adoptable
(ii) the need for effective systems, networks and intermediaries linking researchers with farmers
(iii) extension activities delivered as part of these systems appropriate to farmers’ needs.

These three factors will be the subject of further exploration.

AIMS

The exploratory analysis reported here is the first part of a needs analysis designed to scope and document factors influencing farmers’ decisions relating to seasonal and climate change risk management. Its focus is on exploring perceptions of people in the supply and advisory network, rather than farmers.

We emphasise that this paper reports a piece of exploratory social research. By its nature, it is manifestly less appropriate, at least in the early stages, to state a priori hypotheses about behaviour. The findings are, appropriately, descriptive in nature. They address issues which are of considerable social and practical importance.

METHOD

Interviews were conducted in late November and December 2009. The primary target area was the WA wheatbelt. Respondents were interviewed by telephone or on a face to face basis using either an interview guide or informal conversational interview approach. Respondents were asked questions relating to industry needs and issues associated with the management of seasonal and climate change risk by farmers. Respondents included independent consultants (n=11), supplier representatives/agronomists (n=4), DAFWA advisory staff (n=12), farmer group representatives (n=7), banking representatives (n=3) and other industry players (n=2). It should be noted that this is not a random sample, and the views expressed by respondents are not necessarily representative of the industry as a whole.

Respondents’ views about farmer attitudes towards climate change were also assessed by means of a short attitudinal questionnaire, which in form and detailed questions followed the work of Evans et al. (2009).
RESULTS

Respondents raised a wide range of issues in relation to climate risk management. These are broadly categorised in this paper in terms of issues relating to management of seasonal variability, management of climate change, and possible intervention strategies for the farming community and its supply and advisory network. A number of common themes became apparent throughout the interviews, but not unexpectedly there were also some conflicting views.

Management of seasonal variability

Many respondents saw the management of seasonal variability as being critical to farmers' bottom line and business goals. Rainfall variability, drought, frost, water logging and wind and water erosion were all cited as being important climatic risks. Many had an understanding of how farmers were achieving the management of seasonal variability and to a lesser extent had views on the constraints to better management being faced by farmers.

Some farmers are currently using a range of ‘best practice’ techniques to reflect their judgement about the probabilities of different seasonal outcomes, hence providing inherent flexibility and resilience in their farming systems. They include use of no-till to enhance soil moisture retention, summer weed control, tramlines to reduce compaction, increasing row spacing, diversity in the crop mix, dry seeding, fodder conservation and introducing perennials to exploit unseasonable summer rainfall. Use of these practices is driven by seasonal variability rather than climate change.

In response to the expectation of the season ahead, respondents cited several key managerial tactical decisions which farmers made including farmers planning their seeding programme and timetable in relation to historical rainfall and temperature expectations for their location, the use of varied approaches depending on the timing of the break, and management of the amounts and types of inputs after the break dependant on rainfall received, intuitively ‘playing the season’ as it unfolds.

Respondents' views were very mixed on the extent to which farmers adequately respond to seasonal risk. Several cited key criteria to describe ‘good managers’ such as being in the upper quartile, tendency to be younger, innovative, have some off-farm investment, have flexible systems, make appropriate use of the technology available to them and prepared to take a moderate level of risk. Those who appeared to make timely decisions ‘when it matters’ were praised for their abilities as good managers of seasonal risk.

Many respondents cited certain constraints to improved farmer management of seasonal variability. These included relevance, accuracy and timeliness of seasonal forecasts, lack of understanding of weather and climate drivers, lack of understanding and inadequate communication of the relative importance of critical factors impacting on decision making, lack of skill of farmers and some advisors to predict yield and respond with appropriate changes in inputs, a focus by advisors on the use of tools rather than on the principles underpinning them and extension methods not in keeping with the ways in which farmers think and make decisions. A major exception was the DAFWA AgTactics newsletter which was praised by many in the north and central regions. Several believed that the publication and the way in which it produced (i.e. in collaboration with the private sector) should be reflected in DAFWA's delivery in other regions.

Management of climate change risk

Responses to the attitudinal questionnaire showed farmers generally believed that climate change is occurring but not necessarily due to greenhouse gases. While farmers largely believed there was a need to respond to climate change, many were uncertain about what to do. Adaptation to seasonal variability is far more important than responding to climate change and from their viewpoint strategies for adapting to the one are the same as to the other.

These views were reinforced by our interviews with doubts being expressed by respondents about the need for a management response to climate change by farmers, citing issues such as a perceived high level of scepticism about climate change in the farming community and confusion or doubt about the validity of predictions and their impact. Most believed that current risk management is appropriate and adequate in managing climate change and reflected in current industry trends e.g. larger farm sizes, adoption of new technologies, off-farm investments and purchase of land in other climatic zones. A minority view was that some farmers were responding to climate change but its influence was quite subtle, for instance in affecting land purchase decisions.
Possible interventions

Most respondents had views on the types of activities which could be undertaken to assist in building the capacity of the farming community and their advisors to better manage seasonal variability. Fewer were able to identify activities for managing climate change risk. There was a minority view that learning or communication activities with farmers directly addressing climate change would be useful.

There was substantial support for activities that had a focus on soils and soil moisture, e.g. water use efficiency (WUE), understanding plant available water, soil constraints to effective water use and interpreting soil types in terms of the way they affect crop production in different seasons. How time of sowing is managed according to the season and soil type and the integration of this with decisions about frost, variety choice and rotations. In the NAR most respondents mentioned and were complimentary about the work already being undertaken as part of the DAFWA NEAR strategy, and the ARWA Climate Adaptation Program. In contrast there were no respondents with ideas on specific topics relating to climate change adaptation.

A variety of ideas on ways in which information could be delivered were mentioned. Some respondents liked the idea of workshop activity, particularly if it was driven through and in conjunction with grower groups. The case study concept had significant support with a strong preference for on-farm delivery involving discussion of issues, rather than by other means. On-farm demonstrations and trials were mentioned by several people as providing value. The AgTactics approach attracted a lot of support. The internet was seen by many as less than ideal with information often hard to find and also time consuming.

There was widespread support for the concept of building the knowledge and skills of advisors and others in the industry concerning climate science. A senior banking respondent indicated that if climate risk management was being discussed at the board room level it was yet to filter down to their agribusiness client managers. Time and resources was a constraint for a smaller agribusiness supply company to even consider the consequences of climate change on their business in the future.

Several respondents mentioned further R&D as being important, both in its own right to assist farmer better manage climatic risks but also through appropriate consultative processes as a means of helping farmers recognise the need and having ownership of the outcomes.

CONCLUSION

Farm earnings are two to three more times sensitive to production than they are to price and climate variability is the biggest factor impacting on production (Carroll 2005). It follows that farmers' effectiveness in managing seasonal variability is critical to their profitability and sustainability as farm businesses. Many of those interviewed confirmed this view. It could be expected then that management of seasonal variability should be integral to all aspects of on-farm management.

However our interviews indicate that farmers' response to seasonal variability in WA is highly uneven and depends on a range of factors such as level of exposure to and the consequences of seasonal risk, the risk profile of the farmer, age, use of appropriate technology and practices, and levels of management experience and expertise.

For many farmers climate change is simply not on their radar, but even when it is, farmers believe that management of seasonable variability is an adequate response. There is some support for this view in the literature (e.g. Howden, Soussana et al. 2007) although the authors also caution that there are limits to the effectiveness of such responses under more severe climate changes and that more systemic or transformational changes needs to be considered.

Several authors (Evans et al. 2009, Gray DM 2009) have found that there is a low acceptance in rural WA communities that climate change is occurring and an even lower acceptance that it is the result of human activity. However the low acceptance reflects a high level of uncertainty among rural people rather than widespread open scepticism. Evans et al. also found that farmers did not prioritise climate change as an economic imperative and that generally did not recognise or underestimated the short to medium term risk climate change represented to their businesses or lifestyles. Responses to our short attitudinal survey and discussions with industry reinforce this view. Unless farmers are convinced that climate change is a real risk that will significantly impact on their business they are unlikely to give any serious consideration to either the response itself or even any information associated with it.
There is overwhelming evidence in the 'enabling change' literature that if a practice or technology is not adopted in the long term, it is because landholders are not convinced that it advances their goals sufficiently to outweigh its costs. The technology must be 'adoptable' (Pannell and Marshall 2006), supported by effective systems, networks and intermediaries linking researchers with farmers, and extension activities delivered as part of these systems appropriate to farmers’ needs. These three elements are fundamental in understanding the reasons for a variable uptake of practices aimed at improving adaptation to seasonal variability and climate change.

There is considerable support in the literature for the important role that can be played by intermediaries in linking scientists to the users of that science. Clearly both private and public sector advisors in WA have an important role to play in the communication of climate risk information to farmers. There is also a wide range of opinion in the consulting community relating to climate change and the need for adaptive responses by farmers. Advisors need to have the relevant information to enable them to make informed judgements about climatic risk so that they can provide the best possible advice to their farmer clients.

The financial sector has significant influence over long term farm planning and offers potential to assist in improving farmers’ response to climate change risk. In addition, agribusiness company boards or managers need to be embracing that risk and actively informing their employees on how to engage in conversations with their clients.

There is a need to consider new and innovative approaches to communicating the risks to farmers and industry implied by climate change. While there might be merit in considering the extension strategy suggested by several respondents that the focus of activities should be on seasonal variability, rather than climate change; this alone is unlikely to be sufficient to engage farmers in an appropriate long term strategies to prepare them to adapt to climate change.

This and other issues constraining the ability of the farming community to respond effectively to climatic risk will be explored in the second phase of the needs analysis.

**KEY WORDS**
seasonal variability, climate change, risk management, adoption, communication

**ACKNOWLEDGMENTS**
The authors would like to thank the industry consultants, staff of the various agribusiness suppliers DAFWA staff and all those who gave up their time to talk to us and provide their views, perceptions and ideas on current and future industry directions and needs.

**Paper reviewed by:** Dr Ian Foster, Department of Agriculture and Food, Western Australia

**REFERENCES**
Is there a value in having a frost forecast for wheat in South-West WA?

Imma Farre\(^1\), Senthold Asseng\(^2\), Ian Foster\(^1\) and Doug Abrecht\(^3\)
\(^1\)Department of Agriculture and Food, Western Australia, CSIRO, Floreat
\(^2\)CSIRO Plant Industry, Perth
\(^3\)Department of Agriculture and Food, Western Australia, Centre for Cropping Systems, Northam

**KEY MESSAGES**

Using new seasonal frost forecast systems could substantially increase profitability of wheat cropping in the areas of the South-West of WA where there is a high frost risk around flowering. The frost forecast would not increase profitability in those areas where frost risk around flowering is low. The simulations showed the trade-offs between managing for frost risk and managing for yield potential. It is possible to minimise frost risk by appropriate choice of cultivar phenology for a given showing date.

**AIMS**

Risk of yield loss in wheat due to spring frosts around the flowering stage is a constraint to wheat yield in some parts of the wheatbelt of WA. Even though frost damage can occur at different stages of wheat development, in this paper we only study frost damage to the head around flowering.

Recent developments in dynamical methods of seasonal climate prediction offer the possibility of predicting the risk of frost events at the start of the growing season. Before we use the proposed frost forecast, we need to understand the trade-offs between management for frost risk and managing for yield potential. We used a simulation approach to assess whether sowing time or cultivar could change the timing and coincidence of flowering and frost events. This information will provide the basis for assessing the value of having a perfect frost forecast for wheat yields in WA.

**METHOD**

The APSIM-Wheat (v. 6) model was used to run a series of crop simulation experiments for two locations in the central wheatbelt. The experiments explored the effect of time of sowing and cultivar length on grain yields and frost risk around flowering.

We coupled the APSIM-Wheat model with historical weather data for the period 1957–2008 to define potential yields and frost risks for two locations in the wheatbelt that have high quality weather data, Wandering and Cunderdin. APSIM-Wheat was run for six times of sowing (sowing at 15 days intervals from end of April to mid July), three wheat cultivars (long, medium and short season) and two soil types (clay duplex and deep sand).

**RESULTS**

The simulation experiments provided information on yield penalty and frost risk with sowing date and the interactions with season, soil type and cultivar. The results of the long-term simulations showed a steep response of wheat yields and frost risk to delay in sowing.

Yields were higher in Wandering (high rainfall zone) than in Cunderdin (medium rainfall zone), but the yield penalty with delayed sowing was steeper in Cunderdin than in Wandering (Figure 1). Within soil types the yield response to sowing date was steeper for the clay soil than for the sandy soil (Figure 1). Within cultivars, the effect of a long season cultivar was associated with lower frost risk and higher yields for early sowings (Figure 1 and 2). After mid to end-May sowings the differences between cultivars diminished in terms of yield and frost risks. On the clay soil, in both locations, long season cultivars gave the highest yields for early sowings, but yielded less than short season cultivars for late sowings. On the sand soil, the short and medium season cultivars yielded better than the long season cultivar.
The risk of a damaging frost around flowering, quantified by the occurrence of at least one day with temperature below 2°C, was higher in Wandering than in Cunderdin (Figure 2). Within cultivars, long season cultivars, had a reduced risk of frost at flowering by flowering later and therefore avoiding the frost event. The differences between cultivars in terms of frost risk diminished for later sowings.

The results of the long term simulations for the short, medium and long season cultivars, demonstrated the steep response of frost risk to delay in sowing at the two locations, Wandering and Cunderdin (Figure 2). For instance, delaying sowing date between end-April and end-May reduced the risk of frost at flowering for the long season cultivar from 0.9 to 0.6 in Wandering, and from 0.3 to 0.1 in Cunderdin.

There is a lack of published knowledge quantifying the relationship between frost and yield loss in wheat. The yield loss associated with frost damage depends on a number of factors such as screen temperature, duration of the low temperatures and location in the landscape. Frost at flowering has been reported to cause a wide range of yield losses in wheat, ranging from 5 per cent to 90 per cent, depending on frost severity.
A limited dataset on frost impact on yield from selected sites in the 1998 WA frost event (Craig White, unpublished data) allowed us to develop a preliminary relationship between frost risk and yield losses (data not shown). Using this relationship we obtained average yield losses due to risk frost for every sowing date and location. Subtracting the yield losses due to frost from the potential yield for each sowing date, gave us an attainable grain yield for each sowing date, cultivar, soil type and location. This analysis showed that, with the combined effect of sowing date and frost risk, long season cultivars would be preferred for early sowings in both locations and soil types. For sowings after May, there were no marked differences between cultivars.

CONCLUSION

The trade-offs between managing for frost and for yield potential showed that in Wandering, where the frost risk is quite high for early sowings, the knowledge of a highly skilled frost forecast would justify delay sowing until end-May or mid-June to minimize the yield losses due to frost. In Cunderdin, where the yield penalty with delayed sowing is quite steep and the frost risk quite low, a frost forecast would not justify delaying sowing to minimise frost risk.

KEY WORDS

simulation model, time of sowing, flowering, yield

ACKNOWLEDGMENTS

We thank the Managing Climate Variability program of former Land and Water Australia, GRDC, CSIRO Climate Adaptation Flagship, Bureau of Meteorology and Department of Agriculture and Food, Western Australia for financial support.

Paper reviewed by: Phillip George
Does buying rainfall pay?
Greg Kirk, Planfarm Agricultural Consultants

KEY MESSAGES
For the six year period 2003–08, farm profitability per hectare was highest in high rainfall zones, and generally declined with rainfall. However when land values were taken into account, returns on investment in land were greatest in the low rainfall zones, followed by the medium rainfall and the high rainfall zones.

AIMS
With the drier than average seasons experienced since 2000, increased importance has been placed on growing season rainfall in farm expansion and farm purchase decisions. This raises the question of this paper—Does buying rainfall pay?

The aim was to determine the relative profitability of investment in land in the various rainfall zones of the Western Australian Wheatbelt.

METHOD
Data from the Planfarm Bankwest Benchmarks was analysed over the period 2003 to 2008 for each of the Department of Agriculture and Food, Western Australia crop variety testing Agzones 1 to 4. Agzone 5 was excluded from the analysis due to insufficient data. A total of 282 farm businesses were included in this analysis.

Operating surplus per hectare was the measure used to express profitability. By expressing this as a percentage of land value ($ per cleared and arable hectare) for each farm business a measure was obtained of the return on land investment. Land values are those determined by the agricultural consultant annually at review time. For the purpose of analysis the average operating surplus for the six year period was divided by the average land value for the same period.

RESULTS
The results show that profits per hectare over this six year period are greatest in the high rainfall Agzones and generally decline with growing season rainfall (Figure 1). The exceptions being Agzone 1 which experienced two abnormally dry years in 2007 and 2008, and L4 which performed better than expected.

When we recalculate these results to take into account land values we find that operating surplus for each dollar invested in farm land is greatest in the low rainfall zone and declines as you move into the wetter areas as shown in Figure 2. Clearly those who are prepared to pay the price for high value, high rainfall land are also prepared to forego the additional return on investment that is achieved by those farming in lower rainfall regions.
CONCLUSION

It is not surprising that low rainfall, low land value farms produce the best operating returns on investment. They do after all involve more risk and volatility and there are factors other than income such as proximity to services, lifestyle, etc. which impact on land values particularly in higher rainfall zones. In addition, the question of capital growth in the high rainfall v low rainfall regions must be taken into account.

In conclusion, if farm income is high on your priority list then it is clear from this analysis that buying rainfall is not the best way to find it. Indeed for those high rainfall farmers looking to expand, a well chosen low rainfall property is likely to be a much more profitable option than the farm next door.

KEY WORDS

farm performance, benchmarking, farm profitability

ACKNOWLEDGMENTS

Graeme McConnell, Planfarm Peter Rowe Bankwest
Which region in the WA wheatbelt makes best use of rainfall?

Peter Rowe, Bankwest Agribusiness

KEY MESSAGES
The key limiting factor in broad acre farming in Western Australia is growing season rainfall. Using operating profit per mm of growing season rainfall over multiple years allows you to determine the most efficient place to farm by converting rainfall into profit.

Based on operating profit per mm of growing season rainfall the most efficient places to farm are located in the medium rainfall zones 2, 3 and 4 followed by low rainfall zone 4 and high rainfall zone 2.

AIMS
Identify the agricultural regions in Western Australia that are the most efficient at converting growing season rainfall, the largest limiting factor in broad acre farms, into operating farm profit per ha.

METHOD
Data from the Planfarm Bankwest Benchmarks was analysed over the period 2003 to 2008 to determine long term operating profitability. The farms were analysed based on their location within the Department of Agriculture and Food agzones (Agzones 1–4). Agzone 5 was excluded due to insufficient numbers.

Historically within the Planfarm Bankwest Benchmarks operating profit per Ha was used to determine the most efficient farm which removed the impact of ownership structure (debt to equity, size of the farm), but operating profit tends to increase from lower to higher rainfall regions and so it is not perfect way to determine efficiency. With growing season rainfall being the greatest limiting factor in WA broad acre farming long term analysis has to look at how efficient a farm business is at converting the key limiting factor into profit. Hence the adoption of operating profit per mm of growing season rainfall per ha.

RESULTS
The average farm in the data series over the six years from 2003 to 2008 generated operating returns per ha from a low of $34 in 2006 to a high of $180 in 2007 and an average of $112 operating profit per ha. Growing season rainfall also varied across the six year period from 145 mm in 2006 to 290 mm in 2005 and an average of 230 mm. Growing season rainfall was defined as 30 per cent of January-April rain plus all of May-October rain less 50 mm evaporation.

Table 1 demonstrates the average or state wide operating efficiency across each of the six years analysed. The average operating profit per mm of growing season rainfall per ha was 50¢/mm with a range from 16¢ in 2006 to $1.12 in 2003. Operating profit per mm of growing season rainfall reflects a combination of rainfall and the impact of commodity prices.

Table 1  Average operating profit per mm of growing season rainfall 2003–2008

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</thead>
<tbody>
<tr>
<td>Operating profit $ per ha</td>
<td>$156</td>
<td>$180</td>
<td>$34</td>
<td>$83</td>
<td>$61</td>
<td>$158</td>
<td>$112</td>
</tr>
<tr>
<td>Growing season rainfall (mm)</td>
<td>254</td>
<td>203</td>
<td>145</td>
<td>289</td>
<td>241</td>
<td>279</td>
<td>231</td>
</tr>
<tr>
<td>Operating profit/mm growing season rainfall/ha</td>
<td>$0.68</td>
<td>$0.81</td>
<td>$0.16</td>
<td>$0.38</td>
<td>$0.22</td>
<td>$1.12</td>
<td>$0.50</td>
</tr>
</tbody>
</table>

The most efficient regions to farm in WA with average operating profits of 55–60¢/mm growing season rain/ha were in the medium rainfall zones as can be seen in Figure 1 followed by low rainfall 4 and high rainfall 2.
Given the variability in rainfall associated with the low rainfall zones, it was expected that volatility of return would be higher in the low rainfall zones. Ag zone L1 experienced two drought years as well as one of the best seasons in memory over the last 6 years and the volatility reflects that. In the other low rainfall Ag zones volatility of operating profit per mm of growing season rainfall is relatively consistent with the medium rainfall zones and reflects the ability to limit expenses in poor seasons. Profitability and performance per mm of growing season rainfall assumes that all land is valued based on mm of growing season rainfall. However, land in high rainfall regions is considerably more expensive than low rainfall regions. In a linked paper Greg Kirk from Planfarm looks at this issue in more detail.

CONCLUSION
Growing season rainfall is the limiting factor in dryland agriculture in Western Australia.

Analysis of the Planfarm Bankwest benchmarks over the period 2003–08 clearly show that the medium rainfall zones of the WA wheatbelt were the most efficient at converting growing season rainfall into operating profits per hectare.

KEY WORDS
farm performance, farm operating efficiency, farm profitability

ACKNOWLEDGMENTS
Graeme McConnell and Greg Kirk, Planfarm
POAMA – the Predictive Ocean-Atmosphere Model for Australia

Guomin Wang and Oscar Alves, Centre for Australian Weather and Climate Research (CAWCR), A partnership between the Australian Bureau of Meteorology and CSIRO, Melbourne

KEY MESSAGES
Dynamical seasonal climate prediction has potentially useful skill in South-West Western Australia (SWWA). Further improvements to reduce coupled model biases are likely to lead to further increases in forecast skill.

AIMS
(i) To introduce the Bureau of Meteorology dynamical seasonal prediction system POAMA—the Predictive Ocean-Atmosphere Model for Australia and some recent research and development related to improving climate predictions for Western Australia.

(ii) To explore impact of variations of tropical Indian Ocean surface temperatures for driving rainfall variations in SWWA and to assess their predictions with the POAMA model, especially focusing on the impact of reducing SST bias in the forecasts.

METHOD

POAMA
POAMA (Predictive Ocean Atmosphere Model for Australia) is an intra-seasonal to inter-annual climate prediction system based on coupled ocean and atmosphere general circulation models. The first version (POAMA-1) was developed jointly between the Bureau of Meteorology Research Centre (BMRC), CSIRO Marine Research (CMR) and the Managing Climate Variability (MCV) program. POAMA-1 became operational at the Bureau of Meteorology (BoM) in October 2002. The main focus for POAMA-1 was on the prediction of tropical Sea Surface Temperature (SST) anomalies associated with El Niño/Southern Oscillation, which is primarily achieved through initializing the model with observed conditions in the tropical Pacific Ocean. The POAMA system is continually being developed and improved and in 2007 a new version, POAMA-1.5, became operational. In this version an Atmosphere-Land Initialization scheme was implemented to provide observed atmospheric initial conditions. This upgrade made it possible to go beyond forecasts of tropical Pacific SST and to explore forecasts of regional climate variations in Australia. Recently, a more advanced POAMA Ensemble Ocean Data Assimilation System (PEODAS) has been developed that provides a superior depiction of observed ocean conditions than the previous system. This enhancement forms part of a new POAMA-2 system that will be transferred to BoM operations in 2010.

The main modules in POAMA-2 include the ocean model ACOM2 (Australian Community Ocean Model version 2), the atmospheric model BAM3 (the BMRC Atmospheric Model version 3) and the OASIS (Ocean Atmosphere Sea Ice Soil) coupler. The spatial resolution is approximately 2.5º longitude by 2.5º latitude for the atmosphere and 2º longitude by varying 0.5º~1.5º latitude for the ocean models.

Unlike short range forecasts, making seasonal forecasts requires a procedure called hind-casts to provide a model benchmark against which forecast anomalies can be derived. A comprehensive hind-cast set has been produced for 27 years (1980–2006) using the new POAMA-2 model and initialisation system. Initialized on 1st day of each month, a 10 member, 9-month forecast has been generated. Multi-member ensemble prediction is needed in order to reduce noise in the forecasts associated with weather events.

More details about POAMA can be found on a dedicated web site at http://poama.bom.gov.au.
Experimental Climate Forecasts

Climate prediction with a coupled ocean-atmosphere-land model built on physical and dynamical principles has progressed significantly in the past two decades. However there are still major challenges. One such challenge is model drift, whereby the simulated climate with POAMA gradually deviates from the observed climate with increasing forecast lead-time. To alleviate the drift a method of bias correction has been developed to artificially reduce the model bias. The bias correction is applied by adding mean corrections to the heat, momentum and fresh water quantities that get exchanged between the ocean and atmosphere. The role of these correction terms is to counteract the model drift; therefore the forecasts with bias correction have less model drift than otherwise. We hypothesize that a better simulation of mean climate, especially tropical SST and rainfall, will result in a better depiction of the teleconnection between the major drivers of climate variability (e.g. El Niño) to regional climate anomalies across Australia, using the argument that atmospheric circulation anomalies develop under the influence of the background state.

In this contribution we assess forecast skill using hind-cast sets from POAMA-1.5 (P1), POAMA-2 standard (P2) and POAMA-2 with bias correction (P2C). As only a 5-member ensemble is available for P2C, results shown here are all based on 5-member ensemble hind-cast set for consistency, although normally hind-cast skill would be assessed using at least a 10-member ensemble.

Interannual variations of Australian rainfall are influenced by a variety of climate drivers, but the major predictable climate drivers are El Niño/La Niña events (ENSO) in the Pacific and Indian Ocean Dipole events (IOD) in the Indian Ocean. Often El Niño (warm Pacific) and a positive IOD (cold eastern Indian Ocean) occur concurrently and their effects across southern and eastern Australia compound (both cause dry conditions). Sometimes El Niño and a positive IOD can develop independently to each other. A neutral year is when both ENSO and IOD are absent. Observational analyses of the past half century data reveal that dry years in SWWA often correspond to the occurrence of a positive independent IOD in the SON season. For this reason we focus on the three month SON forecasts initialized from 1 September in this preliminary study. Forecasts for other seasons and at longer lead times will be investigated in future work.

Skill assessment method

We assess the model bias in simulating the mean SST by calculating the difference between the simulated climatology from POAMA and the observed climatology. We assess forecast skill of the IOD by scoring the forecasts of the Dipole Mode Index (DMI). We assess regional forecast skill by calculating anomaly correlation coefficient (ACC) between forecast anomalies and observation anomalies. We concentrate on Indian Ocean SST and Australian rainfall. A more detailed study using more sophisticated skill measures is underway.

RESULTS

Figure 1 shows the SST bias in tropical Indian Ocean from the three hind-cast sets P1, P2 and P2C. Mean SST is generally half to one degree Celsius cooler in most areas, and can be 1.5°C cooler near the Sumatra coast in P1 and P2, although the bias in P2 is slightly less. Note that the area near the Sumatra coast is where strong IOD activity develops. The SST bias is much reduced in P2C, as expected by the introduction of the bias correction.

The ACC skill for IOD SST prediction using the DMI is 0.88, 0.91 and 0.91 for P1, P2 and P2C, respectively. It indicates that there is a slight improvement from P1 to P2, but no improvement from P2 to P2C. This implies that the new PEODAS ocean initialization scheme implemented in POAMA-2 has a positive impact on forecasts of Indian Ocean SST; but improvement in simulating the mean SST through the use of bias correction in P2C appears to have little impact on forecast skill of Indian Ocean SST.

Based on our proposed hypothesis for the importance of simulating a realistic mean SST for simulating realistic regional teleconnections of El Niño and the IOD to Australia, we might expect to see a positive impact on Australian rainfall prediction brought about as a result of improved mean SST simulation. Figure 2 displays ACC skill for Australian rainfall from the three experiments for the SON season. Overall the skill level is comparable among the three cases. However, when focusing on the SWWA region there is a steady increase in skill from P1 to P2 to P2C. In fact ACC skill calculated with
using area average rainfall over 115º-125ºE, 30º-35ºS (see box in Figure 2) is 0.44, 0.51, and 0.62 for P1, P2, and P2C, respectively. The rainfall skill improvement in SWWA is likely the result of improved mean SST, because the change in SST anomaly skill is negligible for the IOD.

Figure 1 Mean Sea Surface Temperature difference between POAMA forecasts and observation for September-October-November season. POAMA forecasts are from P1, P2, and P2C initialized on 1 September. Contour interval is 0.5ºC, and zero contour is not shown.

Figure 2 Australian rainfall ACC skill from POAMA forecasts for September-October-November season. POAMA forecasts are from P1, P2, and P2C initialized on 1st September. ACC is expressed by percentage, and contour interval is 10. The box indicates an area in SWWA bounded by 115º–125ºE, 30º–35ºS.
In light of the argument we put forward before, rainfall forecasts during pure positive IOD years should stand out well. There are two pure positive IOD years 1994 and 2004, in the hind-cast period. The SON seasonal rainfall anomaly over the same SWWA region averaged for the two years is -24.3 mm from observation, and the corresponding forecasts averaged for the two years are -11.7, -20.7, and -23.4 mm from P1, P2, and P2C, respectively. These results support our hypothesis that better mean SST forecasts are beneficial for Australian rainfall forecasts. However, these results are based on a small number of cases and a more detailed analysis using a larger ensemble that covers more years is required.

CONCLUSION

The Bureau of Meteorology seasonal to inter-annual climate prediction system POAMA (Predictive Ocean Atmosphere Model for Australia) is introduced. Forecast skill from hind-casts using the new version, POAMA-2, with and without bias correction are discussed. For SWWA better initialization and more realistic depiction of the mean SST in the forecasts have a positive impact on skill of the rainfall forecasts during September-October-November season. This is a preliminary study using a 5-member ensemble set. A more complete study will be conducted when 10-members are available. We will also assess the forecast skill by combining the standard and bias corrected forecasts into a multi-model ensemble consisting effectively of 20 members.

KEY WORDS

POAMA, seasonal rainfall forecast, Indian Ocean SST forecasts, bias correction

ACKNOWLEDGMENTS

We thank the Managing Climate Variability program of Land and Water Australia, for partially funding this research.

Project No.: R–550–28

Paper reviewed by: Dr Harry H Hendon
Exploring the link between water use efficiency and farm profitability

Cameron Weeks, Planfarm and Peter Tozer, PRT Consulting

KEY MESSAGES

Statistical analysis of Planfarm client data collected from 2003–2007 shows that operating surplus or farm profitability was driven by wheat yield more than any other farm management factor.

Winter rainfall was the driver of wheat yield followed by summer rain received, WUE and nitrogen rate.

On average we have found that the efficiency of use of all inputs was 77 per cent. This means that the majority of producers could, on average, improve their output with the same level of inputs by 23 per cent when compared to the most efficient producers.

AIMS

To explore the link between water use efficiency (WUE) and farm profitability by analysing farm business data collected from WA clients of farm business consulting firm Planfarm.

METHOD

Statistical analysis was carried out on farm business data collected from some 400 clients of Planfarm for the period 2003–2007. As part of its annual business review effort for clients across the Western Australian grainbelt, Planfarm carries out detailed production, cashflow and profitability analysis for each business. A part of the production analysis is a measure of WUE achieved by the wheat crop over all hectares sown to wheat in each year.

The WUE of the wheat crop was calculated as follows:

Wheat yield (kg/ha) / (Summer rain x 0.3 + (growing season rain – 50 mm)) = ‘x’ kg/mm/ha

Note: 50 mm is deducted from the growing season rainfall total in all rainfall zones. This figure is somewhat flawed as it is too low for wetter rainfall years / zones—resulting in a reduction in the WUE calculation in wetter years / zones. However it has been used constantly over time by Planfarm and is therefore still a useful benchmarking tool.

Farm profitability has been simply taken as operating surplus per effective area (ha). The calculation of operating surplus was as follows:

Farm income including grain, livestock, contracting income

Minus

Farm operating expenses including (seed, fertiliser, chemical, administrative, repairs, freight, fuel, livestock costs)

Expenses excluded from operating included interest paid, drawings / cost of management, plant depreciation / HP payments, capital payments and tax.

Note: The calculation of operating surplus has been ‘normalised’ to remove income that has been generated in a previous year (i.e. past crop pool payments) as well as allocating expenditure that has been incurred but in fact belongs to another year (i.e. fertiliser purchased in advance).

The statistical analysis

Linear Regression—was used to estimate the effects that independent variables, such as wheat yield, operating costs, plant value and crop area, have on a dependent variable, such as operating surplus or wheat yield. The base model for this analysis used 21 variables initially, but some variables did not affect the dependent variables and were subsequently deleted. The adjusted R2 is a statistic that measures how well the linear model fits the data. A value close to one indicates a good fit and low number indicates that the dependent variable was not explained by the model of independent variables.
Data envelopment analysis (DEA)—uses a non-parametric method to estimate the efficiency of production systems. This method essentially measures the difference between a production frontier, estimated within the analysis, and a production unit. The distance between the frontier and the production unit determines the level of efficiency. The important part about the measure of efficiency determined by DEA and some other techniques is that the efficiency is not independent of the data used, therefore when using DEA, efficiency is determined by productive units within the data set used. Hence in the analysis reports efficient producers relative to inefficient producers.

**RESULTS**

Table 1: Average operating surplus in each region over the period 2003–2007 (from Planfarm farm business survey)

<table>
<thead>
<tr>
<th>Region</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low rainfall north</td>
<td>$149.49</td>
<td>$24.80</td>
<td>$82.12</td>
<td>$(14.56)</td>
<td>$27.43</td>
</tr>
<tr>
<td>Low rainfall south</td>
<td>$124.58</td>
<td>$8.60</td>
<td>$55.98</td>
<td>$61.69</td>
<td>$112.73</td>
</tr>
<tr>
<td>Medium rainfall north</td>
<td>$189.07</td>
<td>$82.41</td>
<td>$89.26</td>
<td>$2.68</td>
<td>$162.49</td>
</tr>
<tr>
<td>Medium rainfall south</td>
<td>$140.65</td>
<td>$60.45</td>
<td>$62.37</td>
<td>$57.11</td>
<td>$272.58</td>
</tr>
<tr>
<td>High rainfall north</td>
<td>$129.96</td>
<td>$89.94</td>
<td>$78.20</td>
<td>$9.82</td>
<td>$159.49</td>
</tr>
<tr>
<td>High rainfall south</td>
<td>$128.67</td>
<td>$90.48</td>
<td>$105.57</td>
<td>$72.76</td>
<td>$264.62</td>
</tr>
</tbody>
</table>

Note: The average operating surpluses calculated here were for all clients included in the annual survey (inc. those provided by fellow consulting firms Bedbrook, Johnson and Williams plus Geoff Byers). The various analyses presented below are for the Planfarm clients only and some of these were removed due to missing data.

Table 2: The drivers of operating surplus

<table>
<thead>
<tr>
<th>Year</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat yield (t/ha)</td>
<td>77.1</td>
<td>77.6</td>
<td>52.3</td>
<td>78.7</td>
<td>141.2</td>
</tr>
<tr>
<td>Operating costs ($/ha)</td>
<td>−0.32</td>
<td>−0.35</td>
<td>−0.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per cent crop</td>
<td>221.6</td>
<td>60.0</td>
<td></td>
<td>228.4</td>
<td></td>
</tr>
<tr>
<td>Av plant/eff ha ($/ha)</td>
<td>0.06</td>
<td>0.04</td>
<td></td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.62</td>
<td>0.36</td>
<td>0.35</td>
<td>0.41</td>
<td>0.81</td>
</tr>
</tbody>
</table>

The above analysis has been carried out by running Planfarm client data from 2003–2007 through a linear regression model. The analysis was of operating surplus per ha using wheat yield as an independent variable and shows that wheat yield was the major factor affecting operating surplus. However factors such as operating costs, per cent crop and plant investment per effective area also have an impact in three out of the five years.

The negative impact from operating costs was simply that operating surplus was eroded as operating costs increased.

Table 3: The drivers of wheat yield

<table>
<thead>
<tr>
<th>Year</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter rainfall (mm)</td>
<td>0.007</td>
<td>0.008</td>
<td>0.008</td>
<td>0.009</td>
<td>0.009</td>
</tr>
<tr>
<td>Summer rainfall (mm)</td>
<td>0.002</td>
<td>0.001</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>WUE (kg/mm/ha)</td>
<td>0.22</td>
<td>0.20</td>
<td>0.20</td>
<td>0.12</td>
<td>0.16</td>
</tr>
<tr>
<td>Nitrogen (kg/ha)</td>
<td>0.0017</td>
<td>0.0028</td>
<td>0.0039</td>
<td>0.039</td>
<td>0.039</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.83</td>
<td>0.92</td>
<td>0.88</td>
<td>0.93</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Given that wheat yield came out as the dominant driver of operating surplus (Table 2) it was of interest to explore what the major factors were that had been driving wheat yield. Again the data was run through the same linear model (GLM) with water use efficiency and winter rainfall coming out as the dominant drivers. Summer rainfall and nitrogen applied also came out as factors but not in every year.

![Graph of Water Use Efficiency](image1)

**Figure 1** Average annual water use efficiency for each agricultural zone

Water use efficiency was variable but was consistently around an average of 9.5 kg/mm/ha. The range, however, in any one region in any one year was wide with WUE as high as 15–18 kg/mm/ha and as low as 2–3 kg/mm/ha.

![Graph of DEA Efficiency Score](image2)

**Figure 2** Efficiency of input use

Efficiency of use for all inputs has been measured using ‘data envelopment analysis (DEA)’. On average we have found that the efficiency of use of all inputs was 77 per cent. This means that producers could have, on average, improved their output with the same level of inputs by 23 per cent when compared to the most efficient producers.

Interestingly average efficiency has declined over the study period. Graph 2 also highlights that there was significant seasonal variation in efficiency in some regions.

From a water use efficiency point, the producers who were most efficient had a higher WUE than the inefficient producers.
Table 4: Water use efficiency of efficient and inefficient producers 2003–2007

<table>
<thead>
<tr>
<th>Year</th>
<th>LRN Eff</th>
<th>LRN In eff</th>
<th>LRS Eff</th>
<th>LRS In eff</th>
<th>MRN Eff</th>
<th>MRN In eff</th>
<th>MRS Eff</th>
<th>MRS In eff</th>
<th>HRN Eff</th>
<th>HRN In eff</th>
<th>HRS Eff</th>
<th>HRS In eff</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>10.93</td>
<td>9.60</td>
<td>10.61</td>
<td>9.01</td>
<td>11.63</td>
<td>9.50</td>
<td>9.84</td>
<td>7.79</td>
<td>9.27</td>
<td>7.78</td>
<td>8.91</td>
<td>6.89</td>
</tr>
<tr>
<td>2007</td>
<td>10.60</td>
<td>7.09</td>
<td>13.05*</td>
<td>9.82</td>
<td>12.78</td>
<td>9.84</td>
<td>15.09</td>
<td>11.96</td>
<td>10.92+</td>
<td>8.44</td>
<td>11.82</td>
<td>9.59</td>
</tr>
</tbody>
</table>

* Indicates significantly different from inefficient producer at a 1% level.
+ Indicates significantly different from inefficient producer at a 10% level.

CONCLUSION

Farm profit

Farm profitability was impacted upon by many factors but from analysing Planfarm client data it is clear that some factors are more significant than others. Most notably wheat yield comes out as the key driver of farm profitability.

Other factors that proved to have a significant impact on operating surplus in at least three out of the five years included:

Operating costs—The negative relationship reported was simply a function of the higher the operating costs for a set level of operating income the less the operating surplus or profit. This analysis; however, does not prove that less is always more as only $0.23-$0.35 of every dollar spent reduces operating surplus, implying that the remainder contributes to the operating surplus! Certainly there is an optimal level of operating expenditure for any particular business with inputs such as fertiliser depending on soil type, yield potential, past fertiliser history, etc. Thus reducing some inputs or operating costs can actually result in a detrimental impact on operating surplus.

Per cent crop—Mostly a medium term farming system choice made by the manager and one which the Planfarm data suggests is critical in maximising profitability. Attitude to risk, preference for livestock versus crop, plant capacity, soil type, long term sustainability, weed issues, etc. all come into the decision on per cent crop but the Planfarm data suggests that the optimal level of crop was greater than 80 per cent in all rainfall zones.

Average plant value per effective ha—This essentially represents plant capacity and the analysis shows that it had a significant impact on operating surplus in 3 out of the 5 years analysed. The obvious benefit of greater capacity was that critical crop management operations were carried out on time (i.e. seeding). It is important to recognise, however, that excess capacity can end up representing nothing more than just an added cost so large farms in particular need to ensure they are getting one of the major potential benefits of scale and that is efficiency of plant/machine usage.

Further analysis showed that rainfall was the factor that most determines wheat yield followed by water use efficiency and nitrogen rate.

Wheat yield and water use efficiency

If we consider the practical implications of what drives wheat yield we can keep in mind that, apart from changing locations, there is nothing that can be done to improve the most significant factor—rainfall. But there is much that can be done to improve the use of rainfall both from a crop choice and efficiency point of view.

This is where water use efficiency becomes critical to maximising farm profits. If available rainfall is a fixed figure in any given season then it is essential that efficient use of rainfall is achieved to maximise profitability. Traditionally improvements in water use efficiency have focused on agronomic and soil management opportunities but Planfarm Consultant experience suggests that other farm management decisions also impact on a business’s ability to maximise the use of available rainfall.
In 2008 Planfarm clients in the northern wheatbelt were surveyed to gain a better understanding of some ‘non agronomic’ factors that may impact on WUE. These factors included soil type, scale, livestock stocking rate, available labour, plant capacity (in detail), approach to seeding (i.e. dry seeding, hours worked, etc.), use of GPS technology and the use of advisers.

The results of this survey have already provided some interesting insights into the impact of these factors on WUE; however, we will be collating the same responses over the 2009 and 2010 seasons before drawing any conclusions.

**Efficiency of use of inputs**

On average we have found that the efficiency of use of all inputs was 77 per cent. This means that producers could, on average, improve their output with the same level of inputs by 23 per cent when compared to the most efficient producers. This assessment can be impacted on by soil type (some soils are inherently inefficient) but largely it was determined by the operators management approach.

Efficiency of input use is critical to operating surplus and ultimately business success. Efficiency of input use tells us much about an operator’s skill but also much about the level of risk involved in the farming approach. High inputs raise crop break even yield and when drought is an inherent risk in all rainfall zones (obviously to differing degrees) then this is not always a desirable outcome.

Of course, as mentioned earlier in this paper, less is not always more when it comes to the use of inputs but there is an optimal level in all zones which is what farmers should be striving to achieve.

**KEY WORDS**

water use efficiency (WUE), operating surplus, farm profitability

**ACKNOWLEDGMENTS**

This work is funded by the GRDC through a CSIRO hosted project entitled ‘Increasing Water Use Efficiency in the Northern Sandplain Region of WA’.

**Paper reviewed by:** Terence Farrell
A plethora of paddock information is available – how does it stack up?

Derk Bakker, Department of Agriculture and Food, Western Australia, Albany

KEY MESSAGES

- Measuring soil conductivity (SC) was found to be of limited value in the prediction of grain yield variability across paddocks as a first step to delineate production zones for Precision Agriculture (PA) on farms in the Southern Agricultural Region (SAR).
- Plant Cell Density (PCD) images were found to be more robust for this purpose.

AIMS

During a three-year period (2006–2008) information on soil properties and productivity was collected as part of a research project on ‘Key Limiting Factors for Sustainable Production’ in the (SAR), funded by South Coast NRM. The aim of that project was to detect production limiting soil physical, chemical and biological factors of typical soils in the SAR. That allowed for an assessment of the usefulness of the various ‘layers’ of paddock information in predicting soil properties and grain yield variability. This in turn assists in the delineation of production zones for PA. This paper reports on those findings.

METHOD

Five farms in the SAR were selected and were located near Tambelup, Woogenellup, Gairdner, Jerramungup and Jerdacuttup. At each farm three paddocks were selected. The soil types ranged from deep sand to heavy clay at the surface, and from shallow iron stone conglomerate to highly saline shallow clay in the sub-soil.

In each paddock 12 to 13 soil samples were taken, down to 60 cm at 10 cm increments and analysed for nutrients (0–10 cm only), soil texture, depth to clay, moisture and gravel content, pH and EC. At each sampling point, the soil conductivity (SC) was measured with an EM38. From that information, and for the purpose of this paper only relationships between the SC and the depth to clay were derived.

The SC surveys were conducted during the summer of 2007. Towards the end of September of each year, PCD images were captured from every paddock. The timing was such that crops and pastures were still green and actively growing. The image pixel size represented an area of 1 m² on the ground and each image was geo-referenced. In 2006, grain yield maps were available from only two farms. In 2007, all five growers were able to provide grain yield maps, while in 2008, due to some technical difficulties only three were able to provide a map.

All three layers of information (SC, PCD and grain yield) were imported into ArcView GIS and the data points of the SC related to the PCD and the grain yield surfaces. In this way as many as 4000 SC values per paddock were related to PCD and grain yield values. The squared coefficient of correlation ($R^2$) was calculated for the relationships between the SC and PCD, SC and grain yield and PCD and grain yield values, as well as the level significance of each relationship.

RESULTS

The relationships between the EM38 readings and the depth to clay of the three paddocks at the five farms have been presented in the Figure 1 below.
Figure 1 The depth to clay as a function of EM38 readings in the three paddocks at Tambelup (A), Woogenellup (B), Gairdner (C), Jerramungup (D) and Jerdacuttup (E).

In general the EM38 readings correlated reasonably well with the depth to clay across the three paddocks for each farm except at Jerramungup (Figure 1D), but less so for the individual paddocks as the conductivity range tended to be smaller.

Only two summaries of the various relationships are presented in this paper. The $R^2$ of the relationships and the direction of the slope between SC vs. grain yield and SC vs. PCD of the three paddocks on the five farms are presented in Table 1.

Table 1 Summary of the $R^2$ of the relationships between SC and yield and SC and PCD in the different years. All the slopes of the fitted regression lines are negative unless indicated by a ‘+’ sign which means a positive slope.

<table>
<thead>
<tr>
<th>Location</th>
<th>Paddock</th>
<th>2005 R$^2$ of SC vs. yield</th>
<th>2006 R$^2$ of SC vs. yield</th>
<th>2007 R$^2$ of SC vs. yield</th>
<th>2008 R$^2$ of SC vs. yield</th>
<th>2006 R$^2$ of SC vs. PCD</th>
<th>2007 R$^2$ of SC vs. PCD</th>
<th>2008 R$^2$ of SC vs. PCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tambelup</td>
<td>B</td>
<td>0.03</td>
<td>0.32+</td>
<td>0.00+</td>
<td>0.32</td>
<td>0.07+</td>
<td>0.32</td>
<td>0.07+</td>
</tr>
<tr>
<td></td>
<td>L&amp;G</td>
<td>0.64+</td>
<td>0.32</td>
<td>0.05+</td>
<td>0.45+</td>
<td>0.21+</td>
<td>0.10</td>
<td>0.32+</td>
</tr>
<tr>
<td>Woogenellup</td>
<td>100</td>
<td>0.16</td>
<td>0.36</td>
<td>0.28+</td>
<td>0.05+</td>
<td>0.45+</td>
<td>0.21+</td>
<td>0.00+</td>
</tr>
<tr>
<td></td>
<td>St</td>
<td>0.1 +</td>
<td>0.05</td>
<td>0.02</td>
<td>0.04+</td>
<td>0.18</td>
<td>0.04</td>
<td>0.00+</td>
</tr>
<tr>
<td></td>
<td>WG</td>
<td>0.68+</td>
<td>0.23+</td>
<td>0.40+</td>
<td>0.68+</td>
<td>0.42+</td>
<td>0.40+</td>
<td>0.00+</td>
</tr>
<tr>
<td>Gairdner</td>
<td>14</td>
<td>0.05</td>
<td>0.63</td>
<td>0.53</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>0.18</td>
<td>0.09</td>
<td>0.23</td>
<td>0.07+</td>
<td>0.07+</td>
<td>0.07+</td>
<td>0.07+</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>0.07+</td>
<td>0.15</td>
<td>0.36</td>
<td>0.54+</td>
<td>0.00+</td>
<td>0.00+</td>
<td>0.00+</td>
</tr>
<tr>
<td>Jerramungup</td>
<td>DW</td>
<td>0.47+</td>
<td>0.14+</td>
<td>0.01</td>
<td>0.44+</td>
<td>0.06</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>Fl</td>
<td>0.86+</td>
<td>0.38</td>
<td>0.06</td>
<td>0.11</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>0.40</td>
<td>0.37+</td>
<td>0.40+</td>
<td>0.61+</td>
<td>0.79</td>
<td>0.79</td>
<td>0.79</td>
</tr>
<tr>
<td>Jerdacuttup</td>
<td>FB</td>
<td>0.07</td>
<td>0.09+</td>
<td>0.06+</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>FR</td>
<td>0.22+</td>
<td>0.59+</td>
<td>0.06+</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>UR</td>
<td>0.40</td>
<td>0.10</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
</tr>
</tbody>
</table>
Based on the magnitude of the $R^2$, several paddocks (WG, L&G, L, 14) were reasonably consistent from year to year in the prediction of yield and PCD using the SC as the predictor, others were consistently poor in the prediction (St, B, Fl, FB, 24). However of the consistent paddocks only WG was consistent in the slope of the relationships. Paddocks such as L and L&G were found to have a high $R^2$ but the relationship changed from negative to positive from year to year.

The use of grain yield maps or PCD images to predict the yield variability in subsequent years was investigated by comparing the high and low yielding/PCD areas with one another over several years. The comparisons were made irrespective of crop type. The correlation coefficients of the various combinations are presented in Table 2.

**Table 2 Correlation coefficients between the yield and the PCD between the years as indicated for different locations and paddocks.**

```
<table>
<thead>
<tr>
<th>Location</th>
<th>Paddock</th>
<th>Yield 2006–’07</th>
<th>Yield 2006–’08</th>
<th>Yield 2007–’08</th>
<th>PCD 2006–’07</th>
<th>PCD 2006–’08</th>
<th>PCD 2007–’08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tambelup</td>
<td>B</td>
<td>0.11</td>
<td>0.85</td>
<td>0.88</td>
<td>0.83</td>
<td>0.20</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>L&amp;G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woogenellup</td>
<td>WG</td>
<td>0.12</td>
<td>0.69</td>
<td>0.46</td>
<td>0.82</td>
<td>0.86</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.61</td>
<td></td>
<td>0.94</td>
<td>0.91</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ST</td>
<td>0.35</td>
<td>0.14</td>
<td>0.22</td>
<td>0.72</td>
<td>0.19</td>
<td>0.54</td>
</tr>
<tr>
<td>Gairdner</td>
<td>46</td>
<td>0.17</td>
<td>0.67</td>
<td>0.49</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td></td>
<td>0.89</td>
<td>0.07</td>
<td>0.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jerramungup</td>
<td>DW</td>
<td>0.01</td>
<td>–0.14</td>
<td>0.26</td>
<td>0.37</td>
<td>0.66</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Fl</td>
<td></td>
<td>0.73</td>
<td>0.94</td>
<td>0.92</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L</td>
<td></td>
<td></td>
<td>0.90</td>
<td>0.17</td>
<td>–0.01</td>
<td></td>
</tr>
<tr>
<td>Jerdacuttup</td>
<td>UR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>FB</td>
<td></td>
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<td></td>
<td></td>
<td>0.34</td>
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<tr>
<td></td>
<td>FR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.62</td>
</tr>
</tbody>
</table>
```

Of the 13 grain yield correlations, five combinations correlated well with one another. The availability of PCD information at each of the paddocks in each of the three years allowed for three combinations in most paddocks. Only four of the 36 combinations provided a poor correlation between the PCD images of the various years.

**DISCUSSION**

From relationships presented in Figure 1 it is clear that the EM38 can be used to provide information on the depth to clay across multiple paddocks and soil types which tends to correlate well with plant available water capacity. However, on an individual paddock level, that relationship was sometimes poor, i.e. the paddocks at Gairdner and Jerramungup. From a PA point of view the within-paddock variability is more important than the across farm variability because it is at a paddock level that the management can be refined. This limits the usefulness of SC with the EM38 in defining soil types on some farms of the SAR.

The SC did not provide a good and consistent prediction of either the PCD or the grain yield whereas yield maps and particularly the PCD images provided more reliable and robust predictions of the yield variability in subsequent years. PCD images were captured in the middle of the growing season, before the effects of a dry finish, frost, or a wet harvest become visible and as such they provide a good idea of the status of the crop up to that time. While the impact of the various soil types on crop productivity is not yet fully developed in the middle of the growing season, there is already enough differentiation in the crops to provide information on the spatial variability. Capturing the PCD information was done by an aircraft using high-resolution digital cameras. Satellite captured PCD...
imagery is also available for a lower cost per ha but with a lower resolution (25 m x 25 m pixel size) compared to a resolution of 1 m² per pixel. The timeliness of capturing images is less certain than collecting SC information but the usefulness of SC can only be assessed after extensive and expensive soil sampling.

**CONCLUSION**

After surveying fifteen paddocks across 5 farm properties in the SAR it was concluded that measuring the SC on its own provided less certainty delineating production zones for PA than the actual yield maps or PCD images. The latter were the most robust from year-to-year.

**ACKNOWLEDGEMENT**

This work was funded in part by South Coast Natural Resource Management Inc. The contribution of the various farmers, contractors and Grey Poulish (DAFWA, Albany) has been appreciated.

_Paper reviewed by:_ Jeremy Lemon (DAFWA) Albany
Variable rate prescription mapping for lime inputs based on electromagnetic surveying and deep soil testing

Frank D’Emden, Quenten Knight and Luke Marquis, Precision Agronomics Australia

KEY MESSAGES
Soil acidity is recognised as a major limiting constraint to crop productivity in Western Australia (DAFWA, 2006). Electromagnetic induction (EM) surveying is starting to be recognised as a reliable tool for mapping soil changes within paddocks across the WA wheatbelt. Electromagnetic induction surveys measure apparent electroconductivity (ECa), which is primarily influenced by soil salinity, moisture and clay content (Lesch et al. 2005). A strong relationship between soil pH and ECa was observed and used to develop variable rate prescription maps for lime application.

AIMS
This study sought to identify whether electromagnetic data with ground-truthing at a density of 0.025 samples/ha could be used to determine changes in soil pH across the landscape with the aim of developing variable rate prescription maps for lime application.

METHOD
The study area (324 ha) is located approximately 23 km southeast of Tambellup (480 mm annual rainfall) and is situated within a landscape predominantly consisting of middle and upper slopes and broad hillcrests. Soils consisting of grey shallow sandy and loamy duplexes, including soils with alkaline subsoils and grey deep sandy duplex soils. The lower parts of the survey area (i.e. 1~260 m ASL) are situated within a landscape consisting of minor drainage depressions dominated by generally shallow grey sandy duplex soils with outcrops of granite and dolerite and minor areas of red duplex soils (Stuart-Street and Marold, in press).

Geophysical data
Apparent electroconductivity was measured with a Geonics DUALEM38 instrument that integrated ECa measurements over 0–50 cm (shallow) and 0–150 cm (deep) depth intervals. These data were gathered at a sampling density of approximately 60 readings/ha. Interpolated surfaces were created by Precision Cropping Technologies using the Kriging method. Processed data were analysed using Viewpoint II, a Geographical Information Systems (GIS) software package designed for Precision Agriculture applications.

Soil data
Soil samples were collected from seven sites across the study area, representing the range of shallow ECa values (Figures 2). Soil samples were collected by a hydraulic soil corer of 50 mm diameter, with subsamples for the 10–30 cm depth interval prepared from three cores. Seven 0–10 cm samples were collected from evenly arranged points around the perimeter of a circle of 35 cm diameter. Samples were analysed for field texture, pH (CaCl₂) and gravel percentage by CSBP’s soil laboratory.
RESULTS

Table 1 shows the results of the soil analyses, recommended lime rates, exchangeable sodium percentage and the corresponding ECa values and elevation data for each site. Exponential regressions revealed a strong, negative relationship between ECa and elevation ($R^2 = 0.75$) and a strong, positive correlation between ECa and 10–30 cm chloride levels ($R^2 = 0.89$). The relationships between ECa, pH and soil texture are explored in further detail in the following sections.

Table 1: Soil analyses results by sampling depth and site elevation and shallow ECa values.

<table>
<thead>
<tr>
<th>Site</th>
<th>Field texture</th>
<th>Gravel (%)</th>
<th>pH (CaCl2)</th>
<th>Lime rate (t/ha)</th>
<th>Chloride (mg/kg)</th>
<th>Al (CaCl2) mg/kg</th>
<th>Elevation (m ASL)</th>
<th>ECa (Shallow mS/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–30 cm</td>
<td>0–10 cm</td>
<td>10–30 cm</td>
<td></td>
<td>0–30 cm</td>
<td>0–10 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SH1</td>
<td>1.5</td>
<td>25–30</td>
<td>5.1</td>
<td>5.5</td>
<td>1</td>
<td>19</td>
<td>0.7</td>
<td>267</td>
</tr>
<tr>
<td>SH2</td>
<td>1.5</td>
<td>5–10</td>
<td>4.8</td>
<td>5</td>
<td>1.5</td>
<td>34</td>
<td>0.6</td>
<td>265</td>
</tr>
<tr>
<td>SH3</td>
<td>2–2.5</td>
<td></td>
<td>4.9</td>
<td>6.1</td>
<td>1</td>
<td>34</td>
<td>1.4</td>
<td>267</td>
</tr>
<tr>
<td>SH4</td>
<td>2–3</td>
<td></td>
<td>5.9</td>
<td>7.1</td>
<td>0</td>
<td>57</td>
<td>3.3</td>
<td>263</td>
</tr>
<tr>
<td>SH5</td>
<td>2.5–3</td>
<td></td>
<td>6.7</td>
<td>8</td>
<td>0</td>
<td>92</td>
<td>3.5</td>
<td>259</td>
</tr>
<tr>
<td>SH6</td>
<td>2.5</td>
<td></td>
<td>6.5</td>
<td>8</td>
<td>0</td>
<td>597</td>
<td>4.5</td>
<td>258</td>
</tr>
<tr>
<td>SH7</td>
<td>2.5–3</td>
<td></td>
<td>7.7</td>
<td>8.2</td>
<td>0</td>
<td>7067</td>
<td>12.5</td>
<td>256</td>
</tr>
</tbody>
</table>

10 1.5 = Sandy Loam; 2 = Loam; 2.5 = Clay loam; 3 = Clay
11 Weighted average of 0-10cm and 10-30cm depth intervals
**Apparent electroconductivity and soil pH**

There was a significant correlation (R-sq = 0.79, p < 0.05) between the 0–30 cm weighted average of soil pH and shallow ECa at or below 114 mS/m (Figure 1), representing 89 per cent of the survey area. Areas with an ECa over 114 mS/m were deemed to be limited more by salinity constraints than pH and thus excluded from the analysis (see Table 1). A 3rd order polynomial regression (R-sq = 0.96) was used to determine lime rates at the lower end of the ECa spectrum (i.e. < 80 mS/m).

![Graph showing relationship between shallow (0–50 cm) apparent electroconductivity (ECa) and weighted average pH of 0–10 cm and 10–30 cm sampling depths.]

**pH Buffering Capacity and Productivity**

Apparent electroconductivity is influenced by soil moisture, clay and salt content; therefore several factors are likely to be influencing the indirect relationship between soil pH and ECa. The upper landscape is characterised by sandy loam topsoils (0–10 cm) and midsoils (10–30 cm) with a low ECa. Soil pH buffering capacity (pHBC) increases with clay content, therefore the relatively low clay content of the soils characterised by a low ECa indicates a lower pH buffering capacity compared to the heavier textured soils with a higher ECa. Organic carbon levels varied from 0.9 per cent to 2.3 per cent, with no clear relationship with ECa.

Visual analysis of a 2 m contour map indicates that the most elevated areas in the survey area shed water and are less productive due to this localised topographical variation and the effect of higher gravel content in reducing plant-available water content. The midslope soils accumulate water, contain less gravel and are generally well drained, resulting in higher potential productivity. The low pH of the soils represented by sample site SH2 is most likely to be influenced by both product removal and relatively low clay content and consequent pHBC.

Soils lower in the landscape (represented by sites SH4–SH6) have higher clay contents and therefore higher pHBC. The soil-landscape descriptions of Stuart-Street and Marold (in press) also suggest that these sections of the landscape have inherently alkaline soils, further increasing their pHBC.

**Economic implications of pH variability**

Normal farmer practice for this property would be to spread 1 t/ha of lime across the entire property every five years. As a result of this work, it was found that lime was not required, at this point in time, across 58 per cent of the survey area. The savings from this are summarised in Table 2.
Table 2  Soil analysis results by sampling depth and site elevation and shallow ECa values

<table>
<thead>
<tr>
<th>Variable rate (t/ha)</th>
<th>Area (ha)</th>
<th>Tonnes</th>
<th>Traditional spreading @ 1 t/ha</th>
<th>Savings = 164 tonne @ $50/ha spread</th>
<th>EM Survey and groundtruthing cost</th>
<th>Net saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>187</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>90</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>47</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>324</strong></td>
<td><strong>160</strong></td>
<td><strong>324 t</strong></td>
<td><strong>$8200 (25/ha)</strong></td>
<td><strong>$6062 (19/ha)</strong></td>
<td><strong>$2138 (6/ha)</strong></td>
</tr>
</tbody>
</table>

Commercial rates for EM surveys with ground-truthing range from $17 to $20/ha, therefore the financial benefits of conducting a geophysical survey with ground-truthing are evident in the example provided. The surveying cost is a once-off; therefore future net benefits would be greater than those shown here. Ongoing monitoring of topsoil and midsoil pH is recommended to determine variable-rate effectiveness and appropriate rates of future lime applications.

CONCLUSION

An electromagnetic induction survey of the study area revealed a wide variation in apparent electroconductivity (ECa) and was used to guide soil sampling for a range of characteristics, including topsoil and subsoil pH. A significant relationship between ECa and average top-mid soil pH was observed across the study area. Clay content, as determined by field texture, also appeared to be correlated with ECa. Variable rate application of lime can be used to ameliorate production-limiting pH levels in soils with lower ECas. Assigning higher rates of lime to soils assessed as being at greatest risk of acidification through low buffering capacity and product removal, leads to considerable savings in lime application costs.

This work is on going and further testing is required to confirm the application of electromagnetic induction surveys and site assessment as a means of determining acidification risk and lime requirements.

KEY WORDS

electromagnetic induction, variable rate, lime, precision agriculture

REFERENCES


Stuart-Street, A & Marold, R (in press) Tambellup-Borden Area Land Resources Survey, Department of Agriculture and Food WA.

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The authors wish to acknowledge the support of Richard House in allowing the data from his property to be used for this paper and thank the reviewers for their useful comments and suggestions.

Paper reviewed by:  David Hall and Derk Bakker
Trial design and analysis using precision agriculture and farmer’s equipment

Roger Lawes, CSIRO Sustainable Ecosystems, Centre for Environment and Life Sciences, Floreat

BACKGROUND

Farmers are often interested in trialling a new technology before adopting it across the farm. If farmers have precision agriculture technology including yield monitors and variable rate controllers they can use it to conduct an on farm trial. They can use one new technology to test another.

To date, quite complex designs have been developed to provide farmers with the information necessary to run on farm trials (Bramley et al. 1999). Some of these approaches evolved from techniques developed to analyse large agronomic or variety trials and unfortunately they can be complex to implement, and analyse and interpret. In 2008 CSIRO and the Liebe Group attempted to run some trials using these complex techniques with farmer’s machinery. Every trial failed; they are simply not farmer friendly. Replicated and randomised block designs were not designed to be planted with a 15 m seeder bar, managed with a 30 m spray boom and harvested with a 10 m front!

Paddock level experimentation differs from plot level experimentation in so far as the experiment is conducted in a commercial field that must return a profit with commercial equipment. The farmer is unlikely to allocate large areas to a treatment ‘control’ as this will generate sub optimal and uneconomic yields. The entire cropping operations must take place in a continuous manner (i.e. split plots are not allowed!) and be conducted in a manner that does not hinder conventional paddock operations, such as seeding, spraying and post emergent applications of fertiliser. Trial management should be integrated into normal paddock operations as farmers are too busy to deal with a complex trial that requires their attention at critical periods during the crops life.

To overcome some of these practical problems faced by farmers we outline a methodology that was successfully implemented by four farmers in the 2009 growing season using commercial seeding and harvesting equipment.

PRINCIPLES OF ON FARM TRIALS

1. Few rather than more treatments

The most important process in experimentation is to ask an appropriate question and test it. Conventional experiments can be complex, where scientists may evaluate multiple rates of fertiliser on multiple crop species. In on farm experiments, where treatments must fit in with a commercial operation we recommend restricting the number of treatments to just one or two at most. The remainder of the paddock should be thought of as a control. A simple trial that generates a definitive outcome is better than a very complex and time consuming trial that confounds the issue.

When deciding on a treatment it is important to decide on a question that you want to ask and these are usually prefaced with words such as ‘what, how, when or where’. For example:

What effect does increased nitrogen have on grain yield?
• How will the crop respond to increased nitrogen?
• When will the crop yield more if nitrogen is increased (season)?
• Where will the crop yield more if nitrogen is increased (region)?

2. Go for large treatment differences

Once the question has been asked, it is important to make sure the treatment counts and is likely to change the yield of the crop. It is important to remember that the objective of a trial is to learn something about how the crop responds to inputs. To ensure this happens, the treatments must be large enough to bring about a change in crop yield. Even though the treatment might be uneconomic, it will provide insights into how the crop grows or how management should be changed in different
regions in the paddock. Examples of treatments that will have an impact on crop yield if there is a deficiency or constraint might include:

- increasing N by at least 20 kg/N/ha (i.e. ~ 50 kg/ha of urea)
- increasing P by at least 4 kg/P/ha
- applying Gypsum at a rate of at least 2 t/ha
- applying Lime at a rate of at least 2 t/ha.

3. **Orientate the trial and treatments ‘up and back’**

If farmers have a yield monitor they will be able to identify zones in the paddock that are high yielding and zones that are low yielding. These areas may require different management strategies and may respond differently to the same treatment.

To explore this, the trial should be orientated to traverse the high zone and the lower or average yielding zone in the paddock, as indicated in Figure 1. It is also essential the sowing harvesting and treatments are all orientated in the same up and back manner. This is vital, as it facilitates an analysis known as a ‘pair wise comparison or t-test’ on the different zones within the paddock. This challenges the conventional wisdom of trial design, where researchers’ would normally set the trial up in blocks on the good zone and the poor zone. However this approach keeps the trial design simple and ensures famers will be able to implement it with ordinary farm machinery.

The treatment should occupy at least two seeder bar widths (Figure 1). The location of the treatment must be recorded using a GPS so they can be overlayed on a yield map. The treatment should be located next to the control, which would often be the standard paddock management. This minimises the amount of the paddock that is ‘experimental’ and ensures the costs associated with running a trial are kept to a minimum. When the trial is harvested, it is important to keep the comb within the confines of the treatment and keep the comb full through the centre of the treatment, otherwise the yield information generated will be incorrect.

![Figure 1. Orientation of strip trials across a paddock with high yielding and averaging yielding zones.](image)

4. **Analyse the trial data with a paired t-test or by eye**

It is important that data from each strip (control and treatment) are not averaged and simply compared. From the farmers perspective trial data can be analysed informally or by eye.

A paired t-test should be employed to formally analyse the trial. There is a lot of spatial information collected by the harvester and by pairing pixels adjacent to each other, it is possible to conduct a paired t-test across the whole strip, and separately on the low performing zone and the high performing zone. This is a powerful form of an analysis and is as statistically as robust as an analysis of variance.
The approach is demonstrated in Figure 2 where each pair of pixels from the yield maps is treated as an experimental unit. One of the pixels is a control, the other is the treatment. Each pair of pixel provides a form of replication. Assuming a paddock is 500 m wide, and a yield is recorded every 10 m, there will be 50 pixels with control and treatment information. If this is split across high and low performing zones there should still be approximately 20 pixels for each zone with trial data.

From Figure 2, the average difference between the treatment and the control is just 0.18 t/ha and using a paired t-test comparison, the difference is not significant (p = 0.09). When the low zone is analysed separately, the difference between the treatment and the control was just 0.06 t/ha and not significant (p = 0.06). In contrast, in the high zone the difference between the treatment and the control was 0.375 t/ha and highly significant (p = 0.004). In this instance, it is worth applying the treatment on the high zone.

![Figure 2](image_url)

**Figure 2** An example of a paired t-test comparison of treatment means with the yields (t/ha) derived from multiple pixels in each zone.

Providing the trial has been conducted in an ‘up and back’ manner and the treatments were chosen to generate a yield response, it may be sufficient to analyse the trial by eye and avoid formal statistical testing. To do this, simply zoom into the trial and carefully examine the yield in the treatment and the control. If the treatment is significant, a yield difference should be observed. It will be easier to identify treatment differences if the treatment is two seeder bar widths wide.

**SUMMARY**

The approach presented here has been trialled with data farmers in the Eastern Wheatbelt, in the Northern Agricultural Region and in the South Coast. In one instance the trial was frosted and the trial was not harvested, but in other cases the trial was successfully completed. In 2009, we successfully implemented and obtained results from four farm trials. This compares favourable with the four trial failures in 2008.

In conclusion, when running a trial it is important to:
1. Ask a question.
2. Apply treatments that are likely to make a difference.
3. Make sure the trial covers the range of soil types or zones of interest.
4. Sow and harvest the trial in the same direction.
5. Ensure the trial is harvested where the comb does not enter the neighbouring treatment. This prevents the data becoming confounded by the experimental approach.
6. Analyse the data as individual pixels using a paired t-test or by eye. Strong treatment effects may even stand out by eye on some parts of the paddock.
7. Avoid combining data and simply comparing the means or averages of the two strips.
ACKNOWLEDGEMENTS

We thank Nigel Metz from SEPWA, Steve Davies from DAFWA and Chris O’Callaghan from the Liebe group for supervising on farm trials in 2009.

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Paper reviewed by: Dr Yvette Oliver

REFERENCES

Farmer perspectives of precision agriculture in Western Australia: Issues and the way forward

Dr Roger Mandel, Curtin University

KEY MESSAGES

The adoption of precision agriculture (PA) techniques in the West Australian wheatbelt has moved rapidly from the introduction of guidance and yield mapping in the late ‘90s, but has somewhat stalled at making the next major step to variable rate technology (VRT). Agronomists and farmers are skilled at determining what is limiting production, whether it is soil fertility, pH, plant available water capacity (PAWC) or others, but most have less confidence in managing spatial variability.

Until recently the paddock has been thought of as the working unit of a farm. Regions of the paddock are averaged out for ameliorant and fertilizer application resulting in the some regions being under resourced and the others over resourced. With VRT, zones within a paddock can be defined and targeted with the appropriate resources. Although WA farmers understand the need to adopt these techniques they have encountered major problems with a lack of compatibility between hardware and software, complexity of software packages, and poor technical support. The way forward for the industry includes new hardware compatibility standards (ISOBUS 11783) and a continuing commitment to education of both farmers and industry support providers. GRDC has funded two precision agriculture extension projects in WA but farmers require more support from the machinery dealers and consultants who can troubleshoot the complex software and hardware problems.

AIMS

This paper reports on WA farmers’ perception of precision agriculture, variable rate technology and the causes of slow or stalled adoption. We also propose of a way forward for farmers and the grains industry as a whole.

METHOD

A paper based questionnaire was circulated to growers in the WA northern agricultural region through the LIEBE group, in the central wheatbelt and in the Esperance region with SEPWA. Responses were voluntary, but were drawn from active participants in these grower groups. Case studies of two farmers from each of the three regions were developed to document their progression in PA.

RESULTS

The results of the responses to the questionnaire are summarized in the following tables. Values are weighted averages of respondents answering ‘YES’ to the questions.

Does variability exist on your farm and what does it mean to you?

<table>
<thead>
<tr>
<th>102 growers in total</th>
<th>Esperance (45)</th>
<th>North (28)</th>
<th>Central (29)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the yield vary in ANY paddock by more than 1 t/ha?</td>
<td>84%</td>
<td>89%</td>
<td>88%</td>
<td>87%</td>
</tr>
<tr>
<td>Are low yielding parts of your farm reducing profitability?</td>
<td>84%</td>
<td>96%</td>
<td>100%</td>
<td>92%</td>
</tr>
<tr>
<td>Do you vary inputs between paddocks for the same crop?</td>
<td>78%</td>
<td>100%</td>
<td>88%</td>
<td>87%</td>
</tr>
<tr>
<td>Do you vary inputs to different parts of a paddock?</td>
<td>44%</td>
<td>75%</td>
<td>63%</td>
<td>58%</td>
</tr>
<tr>
<td>Could varying inputs (within the paddock) make your cropping program more profitable?</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

How?

<table>
<thead>
<tr>
<th></th>
<th>Esperance (45)</th>
<th>North (28)</th>
<th>Central (29)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>By variation on general farm areas</td>
<td>20%</td>
<td>36%</td>
<td>25%</td>
<td>26%</td>
</tr>
<tr>
<td>By variation on individual paddocks</td>
<td>38%</td>
<td>29%</td>
<td>25%</td>
<td>32%</td>
</tr>
<tr>
<td>By variation of inputs within a paddock</td>
<td>64%</td>
<td>75%</td>
<td>100%</td>
<td>77%</td>
</tr>
</tbody>
</table>

Crop Updates is a partnership between the Department of Agriculture and Food, Western Australia and the Grains Research & Development Corporation
Variability is wide spread and widely acknowledged by farmers and most farmers manage individual paddocks differently. Thus variability is already managed at the paddock level. However the vast majority of farmers are interested in varying inputs within a paddock under the belief that this will increase their profitability.

**How did you know you had a yield limiting problem?**

<table>
<thead>
<tr>
<th>102 growers in total</th>
<th>Esperance (45)</th>
<th>North (28)</th>
<th>Central (29)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers observation</td>
<td>64%</td>
<td>57%</td>
<td>88%</td>
<td>69%</td>
</tr>
<tr>
<td>Soil test</td>
<td>31%</td>
<td>93%</td>
<td>62%</td>
<td>57%</td>
</tr>
<tr>
<td>Yield maps</td>
<td>29%</td>
<td>36%</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>Agronomists</td>
<td>11%</td>
<td>14%</td>
<td>13%</td>
<td>12%</td>
</tr>
<tr>
<td>NDVI images</td>
<td>11%</td>
<td>11%</td>
<td>0%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Most farmers believe they know if and where they have a yield limiting problem simply by observation. One grower indicated that he could see this variability most when spraying and that he felt confident in drawing ‘mud maps’ of yield variation in his paddocks. Soil testing within a paddock normally averages a series of cores within a paddock. The ‘average’ requirements are then used produce a uniform application rate. Yield mapping is being carried out by most farmers, but the maps are often stored for years without being used. Farmer observations and yield maps should be used together to develop a soil sampling protocol to test the zones within paddocks. The combination of years of observation, yield maps and strategic soil sampling with or without agronomist input are all part of developing a targeted VRT program.

**How did you work out where to put the different rates? (Between paddocks or within a paddock)**

<table>
<thead>
<tr>
<th>102 growers in total</th>
<th>Esperance (45)</th>
<th>North (28)</th>
<th>Central (29)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers knowledge</td>
<td>33%</td>
<td>33%</td>
<td>58%</td>
<td>40%</td>
</tr>
<tr>
<td>Yield maps</td>
<td>27%</td>
<td>27%</td>
<td>20%</td>
<td>25%</td>
</tr>
<tr>
<td>Soil surveys</td>
<td>13%</td>
<td>13%</td>
<td>33%</td>
<td>19%</td>
</tr>
<tr>
<td>EM surveys</td>
<td>18%</td>
<td>18%</td>
<td>–</td>
<td>13%</td>
</tr>
<tr>
<td>Agronomists</td>
<td>4%</td>
<td>4%</td>
<td>20%</td>
<td>9%</td>
</tr>
<tr>
<td>NDVI imagery</td>
<td>4%</td>
<td>4%</td>
<td>–</td>
<td>3%</td>
</tr>
</tbody>
</table>

Developing VRT zones within a paddock depends on the level and cause of the variability. Differences in the ability of soils to hold water (Plant Available Water Capacity—PAWC) account for much of the yield variability in WA agriculture. Changes in soil types within a paddock can be observed by farmers, backed up by yield maps, soil testing and surveys. All of these data layers are used to develop zones within a paddock and can be used to produce prescription maps. There is no one ‘right data layer’.
Problems for Growers (What is holding them back in adopting PA?)

<table>
<thead>
<tr>
<th>Problem</th>
<th>Esperance (45)</th>
<th>North (28)</th>
<th>Central (29)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software and machine interaction</td>
<td>38%</td>
<td>27%</td>
<td>50%</td>
<td>38%</td>
</tr>
<tr>
<td>Data interpretation and complexity</td>
<td>33%</td>
<td>39%</td>
<td>26%</td>
<td>33%</td>
</tr>
<tr>
<td>Cost</td>
<td>13%</td>
<td>7%</td>
<td>13%</td>
<td>11%</td>
</tr>
<tr>
<td>Time</td>
<td>4%</td>
<td>9%</td>
<td>13%</td>
<td>8%</td>
</tr>
<tr>
<td>Not yet convinced</td>
<td>4%</td>
<td>9%</td>
<td>–</td>
<td>4%</td>
</tr>
<tr>
<td>Inexperienced seasonal workers</td>
<td>–</td>
<td>4%</td>
<td>–</td>
<td>1%</td>
</tr>
<tr>
<td>Reliability</td>
<td>–</td>
<td>4%</td>
<td>–</td>
<td>1%</td>
</tr>
</tbody>
</table>

The major impediments to the adoption of precision agriculture are the problems of hardware interactions and complexity of software (combined average of 72 per cent). In our case studies we have numerous stories of lack of support for new equipment, lack of understanding from machine dealerships on the capabilities of systems and a general attitude of ‘we sell the machines, it is up to you to make them work’. There are always exceptions to this. Cost and lack of time to process and develop VRT maps were minor impediments to uptake of VRT systems. Only 4 per cent of those surveyed were not convinced that the system would not be beneficial and make their farm more profitable.

CONCLUSION

The farming community strongly endorse the adoption of precision agriculture technology to manage variability within paddocks. Nevertheless they have become frustrated with the technology and this has impeded uptake more than any other factor. This implies they are comfortable making the appropriate agronomic decisions given the data and will move forward when they get the systems up and running.

KEY WORDS

precision agriculture, variability, VRT

ACKNOWLEDGMENTS

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