Crop Updates 2009 - Farming Systems

Derk Bakker
Department of Agriculture and Food

Grey Poulish
Department of Agriculture and Food

Steve Lacy
Nufarm Australia Ltd

Svetlana Micic
Department of Agriculture and Food

Peter Mangano
Department of Agriculture and Food

Follow this and additional works at: https://researchlibrary.agric.wa.gov.au/crop_up


This conference proceeding is brought to you for free and open access by the Grain and other field crop research at Research Library. It has been accepted for inclusion in Crop Updates by an authorized administrator of Research Library. For more information, please contact jennifer.heathcote@agric.wa.gov.au, sandra.papenfus@agric.wa.gov.au, paul.orange@dpird.wa.gov.au.
Authors

This conference proceeding is available at Research Library: https://researchlibrary.agric.wa.gov.au/crop_up/42
The use of high resolution imagery in broad acre cropping

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

KEY MESSAGES

The use of high resolution digital multispectral images (DMSI) allows for the detection and quantification of ‘detailed’ agronomy issues resulting in lower yielding patches/strips. Rhizoctonia damage was identified and quantified as was wheel track damage caused by urea spreading under wet conditions. Whilst no in-season management decisions were made based on these images, quantification of the damage using the DMSI allows for better decision making to rectify the issues.

AIMS

Over the last few years there has been a rapid adoption of precision agriculture (PA), particularly guidance systems and yield maps are now fairly common. The next step in PA is now to start making use of the yield maps and other layers of information. Yield maps will provide information of the actual yield, hence will assist in making management decisions in the following season. There are also other ways of gathering information about the crop that might be helpful to assist with possible management decisions. One such method is the high resolution digital multispectral imagery (DMSI) which consists of taking aerial photos with a high quality digital camera and geo-referencing them (i.e. attach spatial information such as latitude and longitude to the image).

DMSI come both in true colour (i.e. a combination of red, blue and green light reflectance) and in false colour (i.e. near infra-red, red and green light reflectance) and in a processed format as the ratio of near-infra red and red light reflectance. All three images are geo-referenced. The images can come in different resolutions but the standard is 1 m resolution, so that one pixel (the grain of the image) reflects an area of 1 m² on the ground, which is a much higher resolution than a yield map. A yield map is made up of readings from the yield monitor and the GPS at a rate of, usually, 1 per second across the swath width of the header which is for example 10 m wide. At a harvesting speed of 7.2 km/hr (= 2.0 m/sec) and a comb width of 10 m the resolution of the yield map equals to 20 m² (2 x 10 m).

The yield map might give information on the effects of soil type, position in the landscape, and fertiliser applications on crop yield but because of the low resolution doesn’t provide information about the ‘smaller/detailed’ issues in the crop such as nematode or Rhizoctonia damage, non-wetting problems, header rows (fertiliser effect or poor germination), or wheel track effects. Due to the higher resolution DMSI can highlight the effect of these issues. This paper reports on the capturing, interpretation and use of such images and includes an economic assessment.

METHODOLOGY

As part of a NHT funded Soil Health Program through South Coast NRM Inc. several farms along the South Coast were surveyed for soil health in terms of chemical, physical and biological ‘well-being’. On three farms several paddocks were found to be affected by issues resulting in low yielding patches or strips which were clearly visible in the DMSI. In one paddock (Paddock 1) which was severely affected by low yielding patches, the cause of these patches was not conclusively identified. In another paddock (Paddock 2) Rhizoctonia was positively identified with the Predicta-B® test through detailed soil sampling of the affected and non-affected areas. In a third paddock (Paddock 3) wheel tracks were identified as the primary cause of low yielding strips by visually locating these wheel tracks in the field even though specific measurements to identify the impact of the traffic on the soil were not carried out. Two paddocks were photographed in early August and one in the middle of September. The images, which cost between $3–$5/ha depending on the area captured, were processed and the details highlighted by converting the red light reflectance to a contrasting image of only black and white. In that way the affected area could be easily calculated. The results are presented below.
RESULTS

Paddock 1

The image of Paddock 1 with many low yielding patches of which the cause is not clear is presented in Figure 1.

![Figure 1 Patchiness of a barley crop in Paddock 1 in early August.](image)

The paddock had been divided into strips by the farmer to assess varietal productivity differences of barley. The size of affected areas is presented in Table 1.

<table>
<thead>
<tr>
<th>Barley variety</th>
<th>Total area (m²)</th>
<th>Affected area (m²)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baudin</td>
<td>258 230</td>
<td>7 993</td>
<td>3.1</td>
</tr>
<tr>
<td>Hindmarsh</td>
<td>180 690</td>
<td>6 608</td>
<td>3.7</td>
</tr>
<tr>
<td>Fleet</td>
<td>215 146</td>
<td>6 000</td>
<td>2.8</td>
</tr>
<tr>
<td>Vlamingh</td>
<td>197 013</td>
<td>10 738</td>
<td>5.5</td>
</tr>
</tbody>
</table>

From biomass cuts at the end of September the average dry matter weight in the paddock (excluding affected areas) was 9.5 t/ha. Biomass cuts taken in the affected areas yielded 5.8 t/ha. Assuming a harvest index of 35%, the affected areas would yield 2.03 t/ha while the unaffected areas would yield 3.3 t/ha. The affected areas were about 3–5% @ 2.03 t/ha which equates to about 65 kg/ha of grain due to the nematodes which in the context of the overall yield is a small effect. This is the equivalent of about $19.5 per ha. Note that the crop was affected but not eliminated. A total elimination of the crop in the affected patches would constitute a loss of about 165 kg/ha @ $300 per tonne which equates to $49 per ha. These figures can be used to look into the cost effectiveness of possible treatments with reference to the cause of patches.

Paddock 2

The detail of a paddock photographed in the middle of September affected by Rhizoctonia is presented in Figure 2.
Figure 2 This image reflects the maximum area affected by Rhizoctonia and some other edge effects.

Depending how the black and white image is generated the black area can vary in size; hence a minimum and maximum area was calculated and presented in Table 2.

Table 2 Details of the size of the area in Figure 2, highlighting the areas affected by Rhizoctonia

<table>
<thead>
<tr>
<th></th>
<th>Total area (m²)</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affected area (m²)</td>
<td>94 386</td>
<td>165 908</td>
<td></td>
</tr>
<tr>
<td>% Affected</td>
<td>0.15</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>DM not affected area (t/ha)</td>
<td>8.9</td>
<td>8.9</td>
<td></td>
</tr>
<tr>
<td>DM affected area (t/ha)</td>
<td>4.5</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Yield not affected area (t/ha)</td>
<td>3.56</td>
<td>3.56</td>
<td></td>
</tr>
<tr>
<td>Yield affected area (t/ha)</td>
<td>1.8</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Average yield (t/ha)</td>
<td>3.3</td>
<td>3.11</td>
<td></td>
</tr>
<tr>
<td>Yield penalty (t/ha)</td>
<td>0.26</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>@ $300/tonne</td>
<td>77</td>
<td>135</td>
<td></td>
</tr>
</tbody>
</table>

From the table it can be seen that the losses per ha can be considerable. The very dry start to the season, which hampered early root development, exacerbated the problem. The treatment for Rhizoctonia is cultivation, adequate nutrition and fungicide application at the time of crop establishment (DAFWA Bulletin 4732). A regular disc ploughing operation (once every 10 years) is included in the farming practices of this grower and was last carried out on this paddock in 2007. However, the impact of Rhizoctonia still appears to be significant.

Paddock 3

On one farm a very strong stripy pattern in the DMSI was noted. The stripes appeared at regular intervals 20 m apart. The stripy pattern in the image reflected indeed the biomass levels in the field. At the end of September biomass cuts were taken from the crop in the dark and the light grey strips. The results are presented in Table 3.
Table 3 Biomass cuts in dark and light grey strips of the image at Figure 3a

<table>
<thead>
<tr>
<th>Replicate</th>
<th>Dark grey (t/ha)</th>
<th>Light grey (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.4</td>
<td>5.3</td>
</tr>
<tr>
<td>2</td>
<td>6.8</td>
<td>4.4</td>
</tr>
<tr>
<td>3</td>
<td>7.1</td>
<td>6.8</td>
</tr>
<tr>
<td>4</td>
<td>8.8</td>
<td>5.8</td>
</tr>
<tr>
<td>5</td>
<td>8.9</td>
<td>7.0</td>
</tr>
</tbody>
</table>

A sample of the area taken up by the low yielding strips can be seen in the Figure 3b.

The square represents 10.4 ha of which 39% is affected. Those affected strips yielded 5.9 t/ha compared to 8 t/ha in the better areas. At a harvest index of 35% at the time of the year (10 October) the low yielding areas would cause a yield reduction of 0.29 t/ha which @ $300 would equate to $87/ha.

From observations in the paddock the strips of affected crop were clearly associated with wheel tracks (2 m apart), every 20 m and were from the urea spreader mixed with wheel tracks from sprayer. The urea was applied at the end of July after a very wet period and caused damage to the crop and the soil. Applying a liquid fertiliser through the spray rig, instead of the urea spreader, could have been an option to reduce the damage but the farmer was not set-up for that option. An aerial application of the urea (at $15–20/ha) would have been another option. Given the soil conditions at the time with the associated crop loss from the damage caused by the urea spreader, this could have been a more profitable option.

CONCLUSION

Quantifying the ‘smaller’ and more ‘detailed’ issues in the agronomy of broad-acre crops allows the farmer to make better informed decisions on the whether to address the issues or not. The use of DMSI is a very useful tool to help in that decision making process.

Some comments

DMSI’s were captured with a conventional aircraft utilising specialised equipment sourced from Perth via a local supplier. The timing of image capturing can be critical. However, the service is dependent on the weather which at times limits the usefulness of the service. Other services are available that provide high resolution images from satellites, coverage of specific areas and the timing would need to be checked. Another development in the area of image capturing is the use of remote control aircraft, particularly helicopters such as the DraganFly®, equipped with high resolution cameras. The employment of such craft is very flexible but perhaps less economical and practical when large areas and distances between properties are involved. Regardless of the capturing technique, image processing and timely delivery to the client is of utmost importance if and when these images are to be used for management decisions.
KEY WORDS
precision agriculture, digital images

ACKNOWLEDGMENTS
This work has been partly funded by the National Landcare Program’s Soil Health Extension project, an initiative of the Western Australian NRM regions of South Coast NRM and Avon Catchment Council, in partnership with the Australian Government.

Paper reviewed by: Dr Wal Anderson (DAFWA, Albany) and Geoff Thomas (DAFWA, South Perth)
Spraywise decisions—Online spray applicators planning tool

Steve Lacy, Nufarm Australia Ltd

KEY MESSAGES

- Off target deposition from pesticides can be minimised with correct application techniques and applying product in the right climatic conditions.
- Spraywise Decisions has been designed for the pesticide applicator to plan for the best possible conditions for the spraying process.
- Spraywise Decisions uses unique geo-spatial interpolation techniques to generate weather parameter estimates for the nearest 1 km² grid cell anywhere across Australia.

Off target deposition (drift) is a major concern in most agricultural areas today.

The presence of sensitive crops growing adjacent to the spray target area invariably increases the possibility of off-target damage. The APVMA has already introduced restrictions for the application and use of 2,4-D products with the level of label constraints for the use of agricultural pesticides only set to increase. It is more important than ever that the agricultural industry demonstrates responsible chemical use practices to reduce the need for more severe restrictions.

The incidence of spray drift can be minimised through correct nozzle selection and proper application technique under the right environmental conditions.

Spraywise Decisions has been developed for Nufarm from the ‘ground up’ with the pesticide applicator in mind. It is a subscription based internet service that helps rural landholders and contractors to better plan and match the timing of pesticide application to prevailing local weather conditions.

Spraywise Decisions uniquely:

- Uses advanced geo-spatial technology to generate weather parameter estimates for the nearest 1 km² grid cell anywhere across Australia.
- Incorporates definitive accuracy estimates by comparing predicted versus recorded values on an ongoing basis for the nearest of 270 Bureau of Meteorology automated weather stations.
- Generates forecast meteograms (Figure 1) from two to fourteen days ahead with predicted wind speeds, wind direction, Delta T, rainfall, temperature and humidity.
- Provides a Spray Planner (Figure 2) incorporating frost, wind and inversion risk predictions to plan the best application windows.
- Updates every three hours to provide the latest weather data.

Currently subscriber numbers for the Spraywise Decisions web-site exceeds 750. Applicators are finding that Spraywise Decisions is providing valuable localised planning information which allows greater efficiency and reduced off-target deposition.
KEY WORDS
weather, application, drift, Delta T, inversion
Testing for redlegged earth mite resistance in Western Australia

Svetlana Micic\textsuperscript{A}, Peter Mangano\textsuperscript{B}, Tony Dore\textsuperscript{A} and Alan Lord\textsuperscript{B}
\textsuperscript{A} Department of Agriculture and Food, Western Australia, 444 Albany Hwy, Albany WA 6330
\textsuperscript{B} Department of Agriculture and Food, Western Australia, 3 Baron-Hay Court, South Perth WA 6151

KEY MESSAGES

- To date there have been four sites identified with resistant RLEM to frequently used synthetic pyrethroids such as bifenthrin.
- Resistance to synthetic pyrethroids is hereditary.
- Managing resistant RLEM is a long term problem and requires integrated management.

AIMS

- To survey canola paddocks in the great southern region with RLEM to determine the incidence of RLEM resistance to synthetic pyrethroids.
- To survey known locations of RLEM resistance to determine persistency.

METHOD

\textit{Mite collection}

RLEM were collected either by using a suction sampler or by collecting weeds with mites on them from along fencelines. At least 100 mites were collected and placed into air tight containers with moistened paper towel and plant material.

At each collection site the following was recorded:
1. GPS reading.
2. Location of paddock and farmer’s name.
3. Property name.

Mites were stored below 15°C until testing for resistance could commence.

\textit{Testing for resistance}

The inside of 5 mL vials were coated with either:

- 0.3 g/L (LD 99) of alpha-cypermethrin (Umina pers. comm.).
- 0.3 g/L (LD 99) of bifenthrin (Umina pers. comm.).
- Distilled water only.

Vials were then left upside down at room temperature until all inner surfaces were completely dry. Once dry, a single canola cotyledon was placed at the bottom of each vial.

Then for each collection site, a single RLEM in good condition was placed on top of the canola cotyledon in the vial. For each treatment there were 30 replicates.

\textit{Scoring for resistance}

After 24 hours mites were assessed. Mites that were alive receive a score of 1, mites that were incapacitated or dead received a score of 0. An average of these scores gives an indication of the number of live mites and a resistance level for that area.
RESULTS AND DISCUSSION

Location of resistant RLEM

Locations of resistance within the southern WA are geographically quite distinct, suggesting that the resistance is developing in isolated RLEM populations within each property. Resistant RLEM were found at 4 locations out of a total of 23 locations that were tested from 2006–2008. RLEM with resistance to bifenthrin and alpha-cypermethrin were found in 2006 at Esperance (Umina 2007), in 2007 at Cranbrook and Piesseville and in 2008 at South Stirlings. These areas are geographically quite separate. It is unlikely that resistant RLEM between locations.

Level of resistance

Alpha-cypermethrin and bifenthrin belong to the synthetic pyrethroids (SP) group of insecticides (Group 3A). All SP’s have the same molecular mode of action at the cellular level, i.e. they prolong the opening of sodium channels in the nerve membrane causing spasms in the target organism (Vijverberg et al. 1982). If insects develop resistance to one insecticide then they are usually resistant to all insecticides in the same chemical group.

The level of resistance identified to SP’s varied from site to site suggesting that resistance has not spread from a single population of RLEM. The site at Esperance and Cranbrook had similar resistance levels with an average of 63% of tested mites surviving at both sites; whereas at Piesseville and South Stirlings on average had a lower survival rate of 3%.

Heritability of resistant traits

Resistance in RLEM to synthetic pyrethroids is heritable and persists. Initially in 2006, resistant RLEM from Esperance were collected and sent to the Centre for Environmental Stress Adaptation (CESAR) in Victoria for further testing. It was found that the resistance to synthetic pyrethroids in this population was heritable under laboratory conditions (Umina 2007). In 2007 and 2008, mites from this site were again tested and the level of resistance was unchanged. Similarly resistant mites in Cranbrook were also retested in 2008 and the level of resistance was also found to be unchanged. However, the site at Piesseville was not re-tested.

Spread of resistance?

Resistant RLEM populations may spread into neighbouring paddocks. Paddocks adjacent to the initial site of resistant RLEM at Esperance were sampled in 2006, 2007 and 2008 and in Cranbrook in 2007 and 2008. Initially resistant RLEM were restricted to the paddock of origin. However, further testing in the following year at both sites found, resistant RLEM, in adjacent paddocks. This suggests that resistant RLEM are spreading into neighbouring paddocks.

Managing resistance

The most common management option for invertebrate pest control including RLEM in the Southern areas of Western Australia is the applications of synthetic pyrethroid insecticides. This was also the case at the Cranbrook, Esperance and South Stirlings RLEM SP insecticide resistant sites. As was, the common practice of applying a synthetic pyrethroid insecticide (prophylactic spray) with the pre-seeding herbicide application. Repeated use of SP insecticides within seasons and between seasons suggests there is strong selection pressure for RLEM resistance to develop to synthetic pyrethroids.

Growers with resistant RLEM have been able to control these mites using insecticides from the organophosphate (OP) group (Group 1B), e.g. dimethoate, omethoate. As yet there has not been any evidence for cross resistance in RLEM as has been the case in other insect species, e.g. silverleaf whitefly, *Bemisia tabaci*.

However, residual populations of SP resistant RLEM have been discovered in small areas within paddocks, after the use of OP insecticides. These mites have been found mainly on weeds along fencelines. Controlling these weeds along fencelines with herbicide or spraying fencelines with an organophosphate will be a beneficial management option to decrease populations of SP resistant RLEM individuals. This should also decrease the likely spread of resistant RLEM from source paddocks.
It is unknown for how many RLEM generations the genes for resistance to SP’s will persist. It is therefore more prudent to prevent the occurrence of resistance initially developing by decreasing overall on-farm SP application use. Further information on the management options of resistant RLEM is available in the 2008 crop update proceedings (Mangano 2008).

At sites with known resistant RLEM populations, regardless of the level of resistance in RLEM at those sites, it is essential that the RLEM on the site are not exposed to further SP applications. This can be achieved by following integrated practices such as:

- Spraying alternative chemical groups to the SP’s.
- Growing crops that do not support large RLEM populations, e.g. cereals.
- Decreasing weeds in the crop and around fencelines.
- Applying alternative more selective chemical options to SP’s for the control of pests other than RLEM, e.g. pirimor for the control of aphids.

CONCLUSION
Four confirmed cases of resistance by RLEM to frequently used synthetic pyrethroids have now been recorded in WA. This highlights the need for the use of alternative integrated practices to manage RLEM. Fortunately the majority of RLEM populations are currently easily controlled with use of SP or OP insecticides, however, this maybe in jeopardy if an over reliance and repeated applications of the same chemical groups continues.

Resistance testing
Resistance is likely to occur in other areas. Farmers and agronomists who discover RLEM that survive registered rates of insecticide treatments are encouraged to contact the Department of Agriculture and Food Entomologists where arrangements can be made to have samples of mites tested for their level of resistance.

KEY WORDS
redlegged earth mite, resistance

REFERENCES


ACKNOWLEDGMENTS
Grains Research and Development Corporation is gratefully acknowledged for providing funding for this research to occur.

Paul Umina at CESAR of the University of Melbourne for providing protocols.

Project No.: DAW00177
Paper reviewed by: John Moore
Screening cereal, canola and pasture cultivars for Root Lesion Nematode (Pratylenchus neglectus)

Vivien Vanstone, Helen Hunter and Sean Kelly, Department of Agriculture and Food, Western Australia, South Perth

KEY MESSAGES

• Consecutive crops of susceptible wheat or canola will significantly increase the risk of developing yield limiting nematode populations where the root lesion nematode (RLN) Pratylenchus neglectus is present.

• Following a resistant or moderately resistant crop such as barley, oat, field pea or narrow-leafed lupin, fewer P. neglectus will remain in the soil to infect subsequent crops—however, if the initial nematode population is high, levels may not decrease sufficiently over only one season.

• RLN populations can increase on some pastures, however lotus, serradella and sula are resistant or moderately resistant to P. neglectus.

• Monitor crops and use soil and/or plant tests to diagnose RLN, then implement rotations appropriate for the RLN species identified to maintain low nematode levels.

BACKGROUND AND AIMS

Pratylenchus neglectus is the predominant RLN species in WA, infesting at least 40% of cropping paddocks. Other Pratylenchus species also occur and are referred to as RLN. These require a different range of resistant crops for their management. For example, field pea, lupin and faba bean are resistant to P. neglectus, but susceptible to P. penetrans. Chickpea, canola and cereals are susceptible to both P. neglectus and P. penetrans.

P. teres is identified in 10% of the crops infested with RLN, and this species can reach high levels on cereals (particularly barley) and canola. Future cultivar testing will focus on this RLN species.

Crop rotation is the key to reducing RLN and the damage they cause. However, it is crucial to have the RLN identified so rotations can be tailored to the nematode species present.

During 2008, current and newly released cereal and oilseed cultivars, as well as breeding lines, were tested in the glasshouse against P. neglectus. A range of pastures was also assessed. Cultivar specific information on resistance and susceptibility to P. neglectus allows growers to make rotational choices for paddocks where P. neglectus has been identified.

METHODS

Eight replicates each of 36 wheats, 36 barleys, 16 oats and 26 oilseeds (canola, mustard, camelina and crambe), and ten replicates each of 28 pastures (lotus, serradella, sula, lucerne, biserrula, clovers and medics), were grown in 750 mL pots of sandy soil in the glasshouse. Each pot contained a single plant. At emergence, cereal and oilseed plants were inoculated with 4000 P. neglectus (adults + juveniles) and pastures with 2000 P. neglectus (adults + juveniles) that had been reared on carrots in laboratory culture. Ten to twelve weeks after inoculation, soil was washed from the roots under running tapwater, and the nematodes extracted from each root system. Nematodes were counted microscopically, and the total nematode population in each root system quantified.

Cereals, oilseeds and pastures were assessed in separate experiments, each containing replicated check cultivars: P. neglectus susceptible Machete and Brookton wheats, and P. neglectus resistant Tanjil lupin and Kaspa field pea. Test plants were statistically compared to the check cultivars. Susceptible checks allowed nematode multiplication so that numbers increased during the test period, at least doubling and in some cases tripling the initial population of 4000 RLN. Nematodes were not able to feed and multiply on the roots of resistant checks, so numbers were reduced below the initial population of 4000 RLN during the test period.
RESULTS AND CONCLUSIONS

Resistance or susceptibility to RLN can be classified as follows:

- **Resistant cultivars (R)** do not support multiplication of the nematodes, so their numbers in the soil will decrease over the growing season. Resistant cultivars are useful in rotations where high RLN levels are known to occur.

- **Moderately resistant cultivars (MR)** will reduce nematode density, but to a lesser degree than resistant cultivars. If nematode levels are already high, more than one season of an MR cultivar may be required to sufficiently reduce the population.

- **Moderately susceptible cultivars (MS)** will lead to some increase in the nematode level during the growing season. If nematode levels are low, MS cultivars can result in development of moderate levels. If nematode levels are already moderate, MS cultivars can result in production of high levels.

- **Susceptible cultivars (S)** support high nematode multiplication, leading to significant increase in the soil population during the season. Levels should be monitored where nematodes are known to occur, and rotations implemented to reduce the population by using R or MR cultivars.

- **For production purposes, the place of tolerant and intolerant cultivars in the rotation also needs to be considered for paddocks where RLN is present.**

The following conclusions can be made from the data presented:

- All wheat cultivars are S, so will support multiplication of *P. neglectus*. However, Wyalkatchem, Sapphire, Magenta, Annuello and Yitpi are MR or MS, so that in most seasons these will lead to less nematode multiplication in infected paddocks (Figure 1a).

- Most canola cultivars are S to *P. neglectus*, although Tranby, Rocket CL and Bravo TT are R, while Tribune, Tornado, Thunder TT and Barra are MR (Figure 1b). The canola quality mustard (*Brassica juncea*) cultivar Dune is MS.

- The potential biodiesel crops crambe (*Crambe abyssinica*) and camelina (*Camelina sativa*) are, respectively, S and MR to *P. neglectus* (Figure 1b). *B. carinata* and *B. juncea* mustards range from MR to S (Figure 1b).

- All the barley cultivars assessed were R to *P. neglectus*, although Vlamingh was MR (Figure 1c).

- All the oat cultivars tested were R to *P. neglectus* (Figure 1d).

- The lotus, serradella and sulla assessed against *P. neglectus* were R or MR (Figure 2). Clovers, medics and biserrula were S.
**Figure 1** Pratylenchus neglectus (RLN/plant) populations extracted from the whole root systems of plants 10–12 weeks after inoculation with 4000 RLN/plant. Each test plant was replicated 8 times. Black bars indicate the resistant (Tanjil lupin, Kaspa field pea) and susceptible (Machete and Brookton wheats) check cultivars. The horizontal dotted line indicates the initial nematode population, above which represents nematode multiplication (i.e. susceptibility) and below which indicates that the nematodes have not multiplied (i.e. resistance).
Lotus ITA 8.1 A1  
Lotus ITA 3A  
Margurita French serradella  
Flamenco Sulla  
Yelbini Yellow serradella  
Dalkeith Sub clover  
Nitro Plus Persian clover  
Dalkeith Sub clover  
Cefalu Arrowleaf clover  
Electra Purple clover  
Bladder clover CFD27  
4715 Serradella  
Charano Yellow serradella  
Santorini Yellow serradella  
Sceptre Lucerne  
Caprera Crimson clover  
Santiago Burr medic  
Sothis Eastern Star clover  
Machete Wheat  
Mauro Biserrula  
Cefalu Arrowleaf clover  
Biserrula 2002ESP4  
Caldaro clover  
Coolamon Sub clover  
Dorko  
Santiago Burr medic  
Caldaro clover  
Biserrula 2002ESP4  
Caldaro clover  
Frontier Balansa clover  
Caliph Barrel medic  
Machete Wheat

**Figure 2** *Pratylenchus neglectus* (RLN/plant) populations extracted from the whole root systems of pasture plants 10–12 weeks after inoculation with 2000 RLN/plant. Each test plant was replicated 10 times. Black bars indicate the resistant (Tanij lupin) and susceptible (Machete wheat) check cultivars. Pasture data were transformed and analysed on a natural log (Ln) scale.

R = resistant, MR = moderately resistant, S = susceptible.

To substantiate that cultivar reactions to *P. neglectus* recorded in the glasshouse are comparable to those in the field, a sub-set of these plants (including pastures) will be assessed in trials during 2009.

Plants will be tested against *P. teres* in the glasshouse during 2009, and at an infested field site.

**KEY WORDS**

*Pratylenchus*, root lesion nematode, RLN, rotation, resistant, susceptible

**ACKNOWLEDGMENTS**

Lucy DeBrincat, Xiao Hui Zhang and Ali Bhatti provided technical assistance in the sowing, maintenance and assessment of glasshouse trials.

Cereal and canola seed were supplied by various DAFWA colleagues in crop breeding and evaluation, plant pathology and agronomy.

DAFWA Pasture Management staff provided seed for testing, and advice on growing pastures.

GRDC fund this research.

**Project No.:** DAW00157  
**Paper reviewed by:** Bill MacLeod
Lessons from five years of cropping systems research

WK Anderson, Department of Agriculture and Food, Western Australia, Albany

KEY MESSAGES
- The major factors limiting production on under-performing paddocks can be identified using a combination of objective diagnostic tests and experiments to assess the suggested treatments. 'Problem' paddocks mostly have more than one factor limiting production.
- Responses to remedial treatments are not necessarily the same each year, but depend on seasonal conditions. Their impacts on grain yield are likely to be additive, allowing for sequential adoption as resources permit.
- The soil properties identified as limiting were improved by the respective treatments after one season.
- The best treatments each year gave yields that were close to the calculated yields expected from well-managed crops according to the seasonal rainfall.

AIMS
The aim of the work described here, and cropping systems research in general, is to diagnose the factors limiting production, especially in under-performing paddocks, and to apply treatments likely to lift production to the limits set by the seasonal rainfall.

METHOD
Two paddocks representing common soil types in the South Stirling area (average annual rainfall approx. 500 mm) were selected in collaboration with cooperating farmers. Initially the whole paddocks were sampled in the pasture phase in 2003 and then representative areas were selected for trial sites. Soils were analysed for all chemical (including all nutrients, pH, EC) and physical characters (non-wetting, slaking and dispersion, penetrometer resistance), soil biology (Predicta B test) and weed species were identified. A checklist of management practices was assessed to determine if management was likely to be limiting production.

In the 'Camp' paddock of M and R Easton the factors diagnosed as limiting production were soil acidity in the 10−20 cm soil layer (pH 4.6 in CaCl₂), potassium deficiency in the 10−20 cm layer (29 ppm) and marginal non-wetting (MED test 1.6). The paddock was also subject to wind erosion. The soil in 'Camp' paddock (E 598700/N 6171700) was loamy sand (bleached at 10–20 cm) over gravel at ~35 cm and clay at ~75 cm. The topography was gently sloping. The Western Australian Soil Group was grey deep sandy duplex, gravelly and the Australian Soil Classification was a Chromosol.

In the 'One Tree' paddock of N and V Shearer the problems were severe compaction above the clay layer (penetrometer resistance > 2 500 kPa at the 10−20 cm layer), waterlogging was observed in the wetter years and there was sodicity in the subsoil (Na 1.54 me%). In the 'One Tree' paddock (E 622700/N 6169900) the soil was loamy sand to ~8 cm, over bleached sand to gravel at ~20 cm over domed, columnar clay at ~50 cm. The topography was flat. The Western Australian Soil Group was grey shallow sandy duplex gravelly, and the Australian Soil Classification was a Sodosol.

Factors not treated at each site were not considered to be limiting according to the diagnostic tests.

Factorial trials, with four replicates, were established in 2004 on both sites. In the Camp paddock treatments included all combinations of deep placement of lime (2 t/ha), deep placement of potassium (50 kg/ha) and claying (100 t/ha); in the One Tree paddock treatments consisted of deep ripping (to 25 cm), raised beds and gypsum (2.5 t/ha). The crop species or pastures used in the experiments were the same each year as used by the farmer in each case. In 2005 the plots were split and the annual dose of N fertiliser was applied at sowing on one half of each plot or split into two or three doses applied at sowing and after rain events exceeding 20 mm (Tactical N) on the other half.
Crop measurements

Grain yield or pasture dry matter was measured each year using a plot harvester (grain) or hand cuts (pasture). Biomass was measured at anthesis of crops and crop development was observed. The soils were re-sampled and analysed for nutrients in each treated plot in 2005 and again in 2009 after the experiments were terminated. Only the grain yields and some soil data are presented in this paper.

RESULTS

Seasonal rainfall

Rainfall in the growing season (GSRF, sowing to maturity) was 232 mm in 2004, 471 mm in 2005 (335 mm for re-sown crop), 177 mm in 2006, 261 mm in 2006 and 247 mm (Easton) or 367 (Shearer) in 2008. Heavy rain after sowing in 2005 lead to re-sowing all plots at Camp paddock and those not sown on raised beds at One Tree paddock.

Yields

Only the significant (P < 0.05) responses are considered. Yield of well-managed crops (Yman) has been calculated using seasonal losses of water at 33% of seasonal rainfall and the water use efficiency values (kg/ha.mm) have been varied according to the crop—20 for barley, 12 for canola, 25 for oat grain and 50 for oat biomass.

Camp paddock

The yield of canola in 2004 was significantly increased by 0.37 t/ha in the lime treatments, by 0.22 t/ha in the potassium treatments and by 0.18 t/ha in the clayed plots. There were no additional increases in combined treatments but the highest yields were 98–108% of the calculated yield of well-managed crops (Yman = [GSRF – (GSRF x 0.33)] x 12).

In 2005 the yield of the re-sown barley crop exceeded 4 t/ha despite the July (re-)sowing. Only the tactical N treatment (90 kg/ha in 3 doses) resulted in a significant yield increase of 0.95 t/ha. The maximum yield was 96% of Yman, calculated as: Yman = [GSRF – (GSRF x 0.33)] x 20 for barley.

In the dry year of 2006 an oat crop was grown. Half the plots were cut for hay and the rest left for grain. There were no significant increases in grain yield due to the treatments, and the control yield was 98% of Yman = [GSRF – (GSRF x 0.33)] x 25. The establishment on the clayed plots was significantly less than the control due to soil crusting in the dry conditions after sowing. This was possibly responsible for a lower hay yield for this treatment. The tactical N treatment (90 kg/ha in three doses) yielded 0.94 t/ha more than the control for the hay cut and the yield was well above (123%) the calculated Yman = [GSRF – (GSRF x 0.33)] x 50.

Pasture was re-sown in 2007 (mixed grass and clover sward), another dry year. Winter production was increased in the clayed treatment but spring production was reduced. Early spring production was increased by the potassium treatment. In an adjacent trial in 2007 on pasture there was no response to deep ripping alone.

The yield of canola in 2008 was increased by 0.13 t/ha in the lime treatment and by 0.23 t/ha using tactical N (70 kg/ha in 2 doses); the combined treatment lifted yield by 0.33 t/ha (to 1.68 t/ha or 85% of Yman) compared to the control. Re-application of potassium in 2008 did not result in a further yield increase.

One tree paddock

In 2004 deep ripping alone raised the yield of canola by 0.2 t/ha. Raised beds also raised yield by 0.19 t/ha even though no surface drainage was observed. The best yields were 122% of the calculated Yman.

In 2005 the raised beds were associated with a yield increase of barley of 0.96 t/ha compared to the untreated controls. The best yield was 72% of the calculated Yman. On the re-sown flat plots the tactical N treatments yielded 0.34 t/ha more than the controls, or 88% of the calculated Yman for these later sown plots.
In the dry year of 2006 there was insufficient pasture re-growth to measure effectively.

The canola crop in 2007 yielded 133% of the calculated Yman and the gypsum treatment increased the yield of canola by 0.36 t/ha.

The yield of barley was increased in 2008 by the gypsum treatment by 0.67 t/ha. There was a response to deep ripping on the flat-sown plots of 0.44 t/ha and an increase of 0.52 t/ha due to tactical N, but only on the plots treated with deep ripping, gypsum and raised beds. The top yield was 110% of Yman.

Soil changes

One year after the treatments were applied the soils were re-sampled to assess any initial changes. In the Camp paddock the pH in CaCl2 was raised in the limed plots from 4.6 to 5.6 in the 10−20 cm layer, the cation exchange capacity (CEC) in the clayed plots was raised from 1.1 to 2.5 me% in the 10−20 cm layer and the K test was raised from 29 to 58 ppm by the addition of K into the 20 cm layer. The CEC values are still very low in this site and in the One Tree paddock.

In the experiment in the One Tree paddock the CEC was raised in the 10−20 cm layer from 0.8 me% to 1.63 after deep ripping and to 2.62 after ripping plus raised beds. This was probably due to mixing of organic matter from the topsoil. Sodium in the 20−30 cm layer was reduced from 1.54 me% to 0.137 me% in the plots treated with gypsum and deep ripping.

CONCLUSION

Yield responses

The most consistent responses in the experiment on Camp paddock were to 2 t/ha of lime and to tactical N applied during the season after heavy rainfall events. This suggests that the major limiting factors at this site were an acid subsoil and loss of N related to leaching and poor nutrient-holding capacity of the soil. There were responses to deep applied K and to claying, but they were less consistent. The only extra cost of splitting the N dose for cereal and canola crops is for application so it is relatively easy to adopt. Lime had been applied at the surface on this paddock previously but apparently it had not been applied at a high enough rate to move into the lower soil layers. Further surface applications would seem advisable. Neither potassium application nor claying gave responses consistent enough to warrant immediate adoption on this soil type.

Similar yield increases to tactical N were found in the experiment in the One Tree paddock. While the response to deep ripping was positive in the first year it was the gypsum response that showed up later. This suggests that low nutrient-holding capacity, which exacerbates losses of N during the season, and high sodium in the subsoil were the major limiting factors. The response to gypsum may have been partly due to sulphur nutrition since the initial clover tissue analysis showed a marginal S deficiency (data not shown).

There was a very positive response to the raised beds in the wettest year and it could be argued that this response alone would make them profitable.

These data will need a thorough economic analysis before a strategy for improvement of under-performing paddocks can be outlined. However, our experience has shown that the major limiting factors can be identified using experiments based on objective tests and that crop and pasture yields can be raised much closer to those of well-managed crops on better paddocks.

Yield relative to Yman

The data have shown that the yields from appropriate treatments on these two paddocks can approach or exceed the estimates used here of yields of well-managed crops. It is important to observe that we have not used an estimate of the potential yield as described by French and Schultz (1984). The Yman estimate uses a fixed percentage of seasonal rainfall to estimate losses of soil water. Estimated losses are therefore less than the French and Schultz figure of 110 mm when seasonal rainfall is less than 310 mm. In the wetter seasons the estimate of losses of water exceed the average of 110 mm used by French and Schultz (1984).
KEY WORDS

cropping systems, barley, canola, tactical N, gypsum, deep ripping, raised beds, lime, potassium

ACKNOWLEDGMENTS

Mike and Rose Easton, Neville and Val Shearer for the use of land. Tim Overheu, Ron McTaggart, Sally Peltzer, Dan Carter, Derk Bakker, Ross Brennan, Norm McQuade, Paul Matson, Grey Poulish, Rob Hetherington for advice and technical support. DAFWA for financial support.

REFERENCE


Project No.: Supported by DAFWA
Paper reviewed by: Prof R. Belford
Facey Group rotations for profit: Five years on and where to next?

Gary Lang and David McCarthy, Facey Group, Wickepin, WA

KEY MESSAGES

Since the establishment of the Facey Group’s Rotations for Profit in 2004 there has been very little long term rotation effect on yield within continuous rotations of cereal on cereal.

Over a five year period continuous barley has performed well with the highest gross margin of $1,706/ha, followed by lupin/wheat/barley/lupins/wheat with a five year gross margin of $1,620/ha.

AIMS

• To determine the profitability and sustainability of various rotations over five years.
• To determine the impact of rotation on weed populations, disease and nutrition.
• To evaluate profitability based on gross margins within years and across years.

INTRODUCTION

Based in Wickepin, Western Australia, the Facey Group is an innovative, highly motivated, organised grower group with a strong local focus aiming to achieve economic, social and environmental sustainability for the region.

Historically, the southern wheat belt has predominately followed a year-in year-out pasture/crop rotation. Recently, land use has shifted towards more cropping as sheep returns have declined and no-till systems have advanced. In addition, the development of new varieties and technologies has enabled a greater diversity of crop rotations in the form of canola, field peas and new pasture species.

The Facey Group ‘Rotations for Profit’ was established in 2004 to evaluate the profitability and sustainability of various rotations over five years.

METHOD

Trial Site

The trial was situated on the Facey Group’s main trial site located 2 km south of Wickepin, Western Australia. Narrogin, 39 km south-west of Wickepin has a mean annual rainfall of 495 mm and a mean annual growing season rainfall of 382 mm. The 2008 growing season rainfall (May to October) was 311 mm.

2008 was the final year of the five-year rotation. The trial was established in 2004 in a completely randomised block design with nine treatments and three replications (Table 1). Plots were 9.8 m wide, 20 m long and sown at 22 cm row spacings. The 2008 treatments were sown into a moist seedbed using knifepoints.
Table 1  *Species and cultivars used in the Facey Group Rotations for Profit, 2004–2008*

<table>
<thead>
<tr>
<th>Rotation</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dalkeith Clover</td>
<td>Wyalkatchem Wheat</td>
<td>Natural Pasture</td>
<td>Yitpi Wheat</td>
<td>Pasture. Volunteer</td>
</tr>
<tr>
<td>2</td>
<td>Belara Lupins</td>
<td>Wyalkatchem Wheat</td>
<td>Baudin Barley</td>
<td>Mandelup Lupins</td>
<td>Wyalkatchem Wheat</td>
</tr>
<tr>
<td>3</td>
<td>Belara Lupins</td>
<td>Wyalkatchem Wheat</td>
<td>Tornado Canola</td>
<td>Yitpi Wheat</td>
<td>Vlamingh Barley</td>
</tr>
<tr>
<td>4</td>
<td>Arrino Wheat</td>
<td>Arrino Wheat</td>
<td>Calingiri Wheat</td>
<td>EGA 2248 Wheat</td>
<td>Eagle Rock Wheat</td>
</tr>
<tr>
<td>5</td>
<td>Parafield Peas</td>
<td>Wyalkatchem Wheat</td>
<td>Calingiri Wheat</td>
<td>Bravo Canola</td>
<td>Wyalkatchem Wheat</td>
</tr>
<tr>
<td>6</td>
<td>Morova Vetch</td>
<td>Wyalkatchem Wheat</td>
<td>Calingiri Wheat</td>
<td>Yitpi Wheat</td>
<td>Wyalkatchem Wheat</td>
</tr>
<tr>
<td>7</td>
<td>Stubby Canola</td>
<td>Wyalkatchem Wheat</td>
<td>Dalkeith Pasture</td>
<td>Vol.Dalkeith Pasture</td>
<td>Wyalkatchem Wheat</td>
</tr>
<tr>
<td>8</td>
<td>Summer Crop/Fallow</td>
<td>Wyalkatchem Wheat</td>
<td>Calingiri Wheat</td>
<td>Vlamingh Barley</td>
<td>Tanami Canola</td>
</tr>
<tr>
<td>9</td>
<td>Hamelin Barley</td>
<td>Baudin Barley</td>
<td>Baudin Barley</td>
<td>Vlamingh Barley</td>
<td>Vlamingh Barley</td>
</tr>
</tbody>
</table>

At the start of each season the Facey Group’s cropping specialty group planned the course of action for the upcoming season. These actions were then carried out by Kalyx Agriculture—a leading provider of independent research. Crop vigour, weed counts, and disease status were assessed during the growing season and the information relayed to the cropping group who then decided on the course of action to be taken. Plots were harvested using a Kingaroy harvester and samples were assessed by CBH. The statistical analysis performed on the raw data was Fisher’s l.s.d. Test with a significance level of 95%.

**RESULTS**

**Crop vigour and weed densities 2008**

Observations for crop vigour were completed at 6 WA-S, with good early vigour ratings between 7 and 9. Early broadleaf weed densities were measured at the same stage as crop vigour of 6 WA-S with low weed levels present ranging from 0–11 total weeds/m². Late germinating grass weeds were also present with low densities of 7 to 19 per m² in all rotations excluding the continuous wheat treatment (Treatment 4), which had 40 plants per m² (NSD).

**Yield 2008**

The highest yielding crop in 2008 was Wyalkatchem wheat at 3.64 t/ha within the lupins/wheat/barley/lupins/wheat treatment. The Tanami canola yielded poorly at 0.58 t/ha—due to it being sown so late within the season on 4 August. The continuous five-year barley treatment yielded 2.76 t/ha while the continuous wheat treatment was the second lowest yielding of the wheats at 2.3 t/ha.

**Grain Quality 2008**

There were no differences in grain quality in 2008 arising from different rotations, with all wheat crops showing statistically similar protein, moisture, specific weight and screenings levels.

**Gross Margins 2008**

For the 2008 season the gross margins ranged from $588.00/ha for wheat and $225/ha for the barley. A loss of $67/ha was made on the canola due to the late sowing and poor yield of 0.58 t/ha. The annual gross margins for each year (2004–2008) and treatment are shown in Figure 1.
Five year gross margins

Across the five years, the most profitable treatment (based on actual prices) was the barley/barley/barley/barley/barley at $1,706/ha (Figure 2). This finding was also supported by the average five year gross margin of $1785/ha (Figure 3). The lupin/wheat/barley/lupin/wheat came in second behind the barley on barley with an (actual price) gross margin of $1,620/ha (Figure 2).
CONCLUSION

Since the establishment of the Rotations for Profit in 2004 there has been very little long term rotation effect on yield. The continuous rotation of barley on barley has been the most profitable over a five year period with a gross margin of $1 706/ha and weed densities remaining low.

In the case of the continuous wheat, the lack of a break crop in combination with the wheat varieties and seasonal conditions may be starting to lower vigour, yield and protein levels and increase weed densities.

Due to the great amount of interest in this trial it will continue into the future.

KEY WORDS

rotation, yield, gross margin, sustainability

ACKNOWLEDGMENTS

Kalyx Agriculture, FARMANCO Management Consultants, Facey Group Cropping Group, Shire of Wickepin, Summit Fertilisers, GRDC.
Saline groundwater use by lucerne and its biomass production in relation to groundwater salinity

Ruhi Ferdowsian, Ian Rose and Andrew Van Burgel, Department of Agriculture and Food, Western Australia, Albany Highway, Albany WA 6330

KEY MESSAGES

Lucerne is capable of using large amounts of saline groundwater but its rate of dry matter production decreases as groundwater salinity increases.

The results suggest that lucerne could be sown lower in the landscape and closer to shallower groundwater than previously thought.

AIMS

Lucerne (Medicago sativa) has deep roots with the potential for broad ground cover and is considered one of the best perennial pastures for preventing salinity. During a 4−6 year lucerne phase of a cropping rotation, excess soil moisture is used by lucerne and recharge is reduced or eliminated. Ferdowsian et al. (2002) showed that lucerne’s effectiveness in controlling salinity depended on the attributes of the groundwater flow system. In many areas lucerne is grown close to the edge of salt-affected land, where its roots encounter saline groundwater. We carried out an experiment to determine if:

1. lucerne was capable of extracting water from these saline aquifers; and
2. lucerne productivity was affected by groundwater salinity.

We established lucerne in 12 lysimeters (PVC tubes, 2 m x 250 mm) under field conditions. So far, the trial has been going for more than two years and is expected to continue for another year.

METHOD

The trial consisted of four salinity treatments typical of more than 80% of the lucerne growing areas in Western Australia. Saline groundwater was collected and pooled from bores in an agricultural area. The electrical conductivity of the collected water was 1660 mS/m. To achieve the four treatment salinity levels, salt or rain water was added to the bore water to generate total soluble salt levels of 2750, 5500, 8800 and 13750 mg/L. Each treatment was replicated three times.

The winter active lucerne cultivar, Sardi 10, was inoculated and planted into twelve, two-metre long lysimeters made of 250 mm PVC storm-water pipe. Each tube had 300 mm of blue metal for storing groundwater; a filter above the blue metal to prevent sand and soil movement; 50 mm of quarry dust over the filter; 1.7 m of subsoil (sourced from 1 to 3 m depth in lucerne growing areas) and 100 mm of topsoil (gravelly-sandy–loam) from a lucerne paddock. Lime equivalent to 2.8 t/ha was added to the topsoil to increase its pH from 4.7 to 6.2 (in water). Water was extracted or added to the lysimeters via an inlet/outlet pipe at the bottom of the lysimeters.

At the start of each month, 4.5 L of new water was added to each lysimeter. The remaining water was drained at the start of every month and discarded. To estimate the salt loss, the electrical conductivity of the remaining groundwater was measured. Plants were cut when they started to flower. Plant material was dried to measure their biomass production. Linear regression models were fitted to the dry matter and water use data.

RESULTS

Groundwater use and dry matter production in relation to groundwater salinities

Lucerne groundwater use and dry matter production decreased as the salinity of the groundwater increased (Table 1 and Figure 1). While the lucerne used even the saltiest groundwater, its daily water use was more than halved as the groundwater salinity increased from 500 mS/m to 2500 mS/m (Table 1).
Table 1  
**Dry matter production and water use reduced as groundwater salinities increased**

<table>
<thead>
<tr>
<th>Salinity of groundwater (mS/m)</th>
<th>500</th>
<th>1000</th>
<th>1600</th>
<th>2500</th>
<th>p-value¹</th>
<th>R-squared¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Use (mL/day)</td>
<td>71.4</td>
<td>55.8</td>
<td>48.4</td>
<td>29.6</td>
<td>&lt; 0.001</td>
<td>83%</td>
</tr>
<tr>
<td>Dry Matter Production (kg/ha/day)</td>
<td>41.0</td>
<td>33.1</td>
<td>32.8</td>
<td>24.2</td>
<td>0.001</td>
<td>60%</td>
</tr>
</tbody>
</table>

¹ From linear regression on the replicate data

**Note:** Figures in the above table and the following graphs are extrapolated from lysimeters with an area of 0.045 m².

**Figure 1**  
Groundwater use and dry matter production decreased as groundwater salinities increased.

**Seasonal variability in dry matter production in relation to rainfall and salinity**

Lucerne produced more dry matter during spring than autumn, regardless of the salinity treatment. More than 70 mm of rainfall during April 2007 increased the dry matter production from the three saltiest treatments (1000, 1600 and 2500 mS/m) to that of freshest one (500 mS/m; Figure 2).

**Figure 2**  
Dry matter production in relation to rainfall and groundwater salinities.

The ratio of dry matter production from the saltiest groundwater (2500 mS/m) as a percentage of the lucerne yield grown at 500 mS/m, increased significantly (R² = 0.84, p = 0.001) in relation to rainfall (Figure 3a). In contrast, the ratio of dry matter production from the lucerne grown at 1000mS/m as a percentage of yield from the lucerne grown at 500 mS/m did not change (p = 0.18) in relation to rainfall (Figure 3b). The case for the1600 mS/m treatment (not presented) had also a significant trend (R² = 0.70, p = 0.009), but was not as pronounced as the 2500 mS/m trend relationship. While the
pattern of seasonal groundwater use was similar for all salinity treatments, lucerne productivity increased as salinity levels declined. Unlike dry matter, the ratio of water use from the highest to lowest salinity did not correlate well with applied rainfall.

![Figure 3a and 3b Dry matter production 2500 and 1000 mS/m as a percentage of 500 mS/m.](image)

![Figure 4 Seasonal variability in groundwater use in relation to rainfall and groundwater salinities.](image)

**CONCLUSIONS**

Lucerne is capable of drying out the soil water profile and of using large amounts of saline groundwater indicating it may be possible to grow lucerne lower in the landscape and closer to shallower groundwater than previously thought.

The results show that (a) there were large differences in lucerne productivity due to salinity of the groundwater; (b) lucerne used large amounts of saline groundwater but the rate of groundwater extraction significantly decreased as salinity increased; and (c) rainfall enhanced the productivity of lucerne and its impact was more pronounced as the groundwater salinity increased.

**REFERENCES**


**KEY WORDS**

lucerne, productivity, salinity, groundwater

**Paper reviewed by:** Dr Richard George, Department of Agriculture and Food, Western Australia, Bunbury
Autumn cleaning yellow serradella pastures with broad spectrum herbicides—a novel weed control strategy that exploits delayed germination

Dr David Ferris, Department of Agriculture and Food, Western Australia, Northam

KEY MESSAGES

Applying glyphosate to yellow serradella pastures (cvv. Santorini, Charano, Yelbini) after the break of season (termed autumn cleaning) is a very robust weed control strategy as yellow serradella emerges over a wide time period. However, DO NOT use this strategy on French serradella varieties (cvv. Cadiz, Erica, and Margurita).

This low cost weed control strategy should be used routinely to renovate yellow serradella pastures and may also be useful for depleting the seed bank of herbicide resistant weeds in a non-crop phase.

The optimum knockdown date for autumn weed cleaning is a trade-off between available feed-on-offer and level of weed control desired.

To minimise the autumn-winter feed gap, defer grazing on other pasture paddocks by utilising feed on serradella pastures before spraying these with a knockdown. In seasons with a late break, heavy grazing alone may be sufficient to suppress weeds and lift legume content in serradella pastures.

AIMS

Currently options for selective weed control in serradella based pastures are limited and generally expensive (Valentine and Ferris 2006). Yellow serradella, an annual pasture legume adapted to deep, sandy, acidic soils, is known to have a delayed germination pattern at the break of season (Taylor and Revell 2002). The delay in germination between yellow serradella and many weed species could provide a window of opportunity for controlling weeds with low cost, broad spectrum herbicides after the break of season without jeopardising legume persistence.

The aim of this study was to evaluate the robustness of this novel weed control strategy in long term serradella (cv Santorini) based pastures.

METHOD

Two sites with an established serradella seed bank (cv Santorini) were selected near Cunderdin and Tincurrin. A spray bike was used to apply three ‘autumn weed cleaning’ treatments in 2007, using glyphosate (450 g ai/ha). As the break of season was not decisive, the herbicide was applied around 7–10 days after germination inducing rainfall events. There were 5 replicates per treatment at Cunderdin and 3 at Tincurrin; plots were 5 m x 20 m and were not grazed. See Table 1 for the timing of knockdown sprays.

Table 1 Timing of knockdown ‘autumn cleaning’ treatments applied across yellow serradella based pastures at Cunderdin and Tincurrin, 2007

<table>
<thead>
<tr>
<th>Knockdown spray</th>
<th>Cunderdin</th>
<th>Tincurrin</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 (early)</td>
<td>Glyphosate 450 g ai/ha</td>
<td>7 May</td>
</tr>
<tr>
<td>S2 (mid)</td>
<td>Glyphosate 450 g ai/ha</td>
<td>8 June</td>
</tr>
<tr>
<td>S3 (late)</td>
<td>Glyphosate 450 g ai/ha</td>
<td>4 July</td>
</tr>
</tbody>
</table>

The impact of knockdown treatments on pasture density was measured by counting the number and type of seedlings within 12 cores (84 mm diameter) per plot in August. Feed-on-offer was measured by cutting biomass from random quadrats within each plot (6 x 0.05 m², Cunderdin; 4 x 0.1 m², Tincurrin) at the end of winter. The initial size of the legume seed bank was estimated (April 2007) by collecting soil cores (84 mm diameter, depth ~8 cm) across each site (8 cores per replicate). A similar
method was used to assess the seed bank size at the end of the growing season (March 2008) at Cunderdin (10 cores per plot); while at Tincurrin the estimate was based on 4 × 0.05 m² quadrats per plot (depth ~3 cm). Free seed was extracted from pod segments by hand. Analyses of variance (GenStat© 2007) for seedling density, composition and FOO were conducted on square root transformed data.

RESULTS

Site and seasonal conditions

Before the break of season (2007) the size of the serradella seed bank was approximately 365 kg/ha at Cunderdin and 45 kg/ha at Tincurrin; there was also 250 kg/ha of dormant sub. clover seed at Tincurrin. The break of season was not decisive: rainfall events in April, May and June were sporadic and generally less than 10 mm (Figure 1). Consequently, the three knockdown treatments were implemented over a wider time period (8 weeks) than originally planned (4 weeks).

Impact of knockdown date on serradella density

Knockdown date had a significant impact on serradella density, biomass composition and FOO at the end of winter (Table 2). The glyphosate knockdown effectively killed serradella and weed seedlings that emerged prior to spraying, thus pasture production was dependent on subsequent regeneration from serradella and weed seed banks.

At Cunderdin, the number of serradella seedlings that re-established after the first (7 May) and second (8 June) knockdown treatments was significantly (P < 0.001) greater than in the unsprayed control on the 9 August (Table 2a).

At Tincurrin, serradella density after knockdown treatments was much lower than at Cunderdin; a reflection of an eight fold difference in the size of the initial seed bank. Nevertheless, serradella re-established and its density, though similar across all treatments on 22 August (130–270 pl/m²), comprised a greater proportion of the total number of seedlings with successive knockdown date, increasing from 6 to 48% of seedlings (Table 2b).

Figure 1 Daily rainfall during January-July at Cunderdin and Tincurrin. Arrows show dates when glyphosate (450 g ai/ha) was applied as a knockdown ‘autumn cleaning’ treatment across yellow serradella based plots.
Overall, autumn cleaning date proved to be very robust as serradella emerged over a very wide time period (April to August) at both sites. By contrast most Mediterranean annual pasture species take just 1 or 2 days for soft seeds to fully imbibe and germinate. This was evident at Tincurrin, where very few clover seedlings regenerated after the first knockdown treatment.

Table 2  Seedling density and feed-on-offer (FOO) following a knockdown spray across an established yellow serradella pastures near Cunderdin and Tincurrin, WA

(a) Cunderdin

<table>
<thead>
<tr>
<th>Spray date</th>
<th>Density (pl/m²) 9 August 2007</th>
<th>FOO (kg/ha) 23 August 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Serradella</td>
<td>Capeweed</td>
</tr>
<tr>
<td>Control</td>
<td>1 580</td>
<td>63</td>
</tr>
<tr>
<td>S1 – 7 May</td>
<td>2 880</td>
<td>21</td>
</tr>
<tr>
<td>S2 – 8 June</td>
<td>3 050</td>
<td>9</td>
</tr>
<tr>
<td>S3 – 4 July</td>
<td>1 420</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

(b) Tincurrin

<table>
<thead>
<tr>
<th>Spray date</th>
<th>Density (pl/m²) 22 August 2007</th>
<th>FOO (kg/ha) 22 August 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Serradella</td>
<td>Ryegrass</td>
</tr>
<tr>
<td>Control</td>
<td>130</td>
<td>15</td>
</tr>
<tr>
<td>S1 – 4 May</td>
<td>220</td>
<td>100</td>
</tr>
<tr>
<td>S2 – 10 June</td>
<td>270</td>
<td>35</td>
</tr>
<tr>
<td>S3 – 21 June</td>
<td>220</td>
<td>20</td>
</tr>
</tbody>
</table>

* Bold values are significantly different from the control, l.s.d. (5%); see Ferris (2008) for square root transformed data.

**Impact on pasture composition and FOO**

Even though the absolute density of capeweed at Cunderdin was fairly low (4% of plants) in the unsprayed control plots (Table 2), individual plants were very large and comprised 51% of the pasture biomass on 23 August. Knockdown treatments resulted in significant gains in legume content (% biomass) and control of capeweed. The first knockdown treatment (7 May) depleted capeweed content to 12% (by weight) and the later knockdown treatment resulted in almost pure swards of serradella (> 90%). However, FOO foregone at the end of winter increased from 24 to 91% with successive knockdown dates.

At Tincurrin, annual ryegrass comprised 18% of total biomass in the unsprayed control treatment on 22 August. Interestingly, the first knockdown treatment (4 May) resulted in an increase in ryegrass plant density and relative content (65% of total biomass). The later knockdown treatments achieved greater control of ryegrass but foregone FOO was significant across all treatments (68–97%) on 22 August. The impact of the early knockdown treatment was likely due to the elimination of the dense sub. clover component from the pasture mix and, in turn, bare areas developing for other species to establish. Although plots were not grazed in this study, grazing prior to the application of a herbicide knockdown would help reduce the loss in pasture production.

**Impact on seed production**

The seed set of serradella pastures following autumn cleaning treatments was generally greater than in the control plots; an exception being after the late knockdown at Cunderdin (Table 3). All autumn cleaned plots remained green for about two weeks longer than control plots in spring. The knockdown treatments probably resulted in soil moisture being conserved for pasture growth in spring.
Table 3  The impact of autumn cleaning treatments on yellow serradella seedbanks

<table>
<thead>
<tr>
<th>Treatment²</th>
<th>Cunderdin (kg/ha)</th>
<th>Tincurren (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>236</td>
<td>45</td>
</tr>
<tr>
<td>S1</td>
<td>334</td>
<td>160</td>
</tr>
<tr>
<td>S2</td>
<td>370</td>
<td>225</td>
</tr>
<tr>
<td>S3</td>
<td>234</td>
<td>273</td>
</tr>
<tr>
<td>l.s.d. (5%)</td>
<td>125</td>
<td>52</td>
</tr>
</tbody>
</table>

¹ Values are the amount of dormant seed in the seed bank the summer (March 2008) after autumn cleaning treatments. In April the previous year (2007) the serradella seed bank was approximately 365 kg/ha at Cunderdin and 45 kg/ha at Tincurren.

² See Table 1 for treatment details.

CONCLUSION

The results from this study suggest that autumn cleaning with low cost, broad spectrum herbicides could be used routinely to renovate yellow serradella based pastures, particularly where capeweed is a problem weed. The size of the serradella seed bank, dominant weed species, knockdown date and presence of other pasture legume species collectively had a bearing on the results.

Overall, the success of autumn cleaning is related to the differential in germination pattern between serradella and weed species. When capeweed is the dominant weed, there appears to be little benefit in delaying beyond the first flush of weed emergence; by contrast, where annual ryegrass is the dominant weed, it appears that a greater delay in spray date is required to achieve adequate control.

If adequate feed is available to meet livestock demand, autumn cleaning might be used to control herbicide resistant ryegrass during a non-crop phase/year as part of an integrated weed management system. However, a very late knockdown (July-August) may limit serradella growth and seed-set if the season cuts off early. However, this should not compromise serradella persistence where the seed bank is already adequate (i.e. at least 200 kg/ha).

KEY WORDS

delayed germination, weed control, knockdown, serradella, ‘autumn cleaning’

ACKNOWLEDGMENTS

Rodney Rogers and Neil Ballard for hosting the experiments.

REFERENCES


Project No.: This research was supported by a Pastures Australia project WP 192.

Paper reviewed by: Clinton Revell
Decimating weed seed banks within non-crop phases for the benefit of subsequent crops

Dr David Ferris, Department of Agriculture and Food, Western Australia, Northam

KEY MESSAGES

A three year non-crop phase based on sub. clover, grazing, and chemical seed-set control can deplete a herbicide resistant ryegrass seed bank from > 1000 to < 40 seeds/m$^2$ over three years and enable a return to a multiple crop phase.

One year of total seed set control (e.g. brown manuring), though highly effective, is generally inadequate to drive down weed seed banks sufficiently for a return to consecutive cropping because ryegrass density tends to increase rapidly where selective herbicides are no longer effective in-crop.

The earlier corrective action is taken to get on top of a developing weed problem through the use of strategic non-crop phases, the less time out is required before returning to a more profitable cropping phase.

AIMS

The development of herbicide resistant ryegrass with multiple mechanisms of resistance is a threat to the productivity of current farming systems. New strategies which do not rely on the use of selective herbicide are needed to deplete ryegrass seed banks. Introducing a non-crop phase provides the opportunity to decimate weed seed banks using strategies not available in crop, such as brown and green manuring, and heavy grazing.

The aim of this study was to evaluate grazed and un-grazed strategies to drive down weed seed banks within non-crop phases.

This paper reports on changes in the size of a resistant ryegrass seed bank in response to various one and three 3 year break options.

METHOD

In 2003 a rotation trial was established at Avondale research station in Western Australia on a red clay loam to evaluate the benefits of introducing a non-crop phase into the rotation. The site had been cut for hay in 2002 but still had a large annual ryegrass seed bank (> 1000 seeds/m$^2$).

Ten seed bank management treatments were implemented in 2003 (Table 1). Strategies were based on either a grazed three year pasture phase (sub. clover, biserrula, lucerne or ryegrass) or a single year break with chemical seed-set control (green manured canola or field peas; and brown manured French serradella). Plots were 30 m long, and 7 or 11 m wide, and sown at commercial rates (Table 1).

Sheep grazed pasture plots during winter and spring to achieve a moderate grazing pressure. Glyphosate (900 g a.i./ha) was sprayed across all brown and green manured treatments just prior to ryegrass seed-set (2003). Biomass was incorporated with off-set discs (depth ~6 cm) in the green manured plots. Grazed pasture options were spraytopped (paraquat 125 g a.i./ha) in 2004, top-dressed with superphosphate (120 kg/ha) in 2005 and brown manured (glyphosate 900 g a.i./ha) the year before crop.

Wheat was sown at 70–80 kg/ha in 2004–06 (knife-points) after a knockdown herbicide, and only a broadleaf selective herbicide was applied in-crop. The trial was dismantled in 2007 and the area sown to Lupins. In 2003, soil cores were collected in mid winter from 12 positions distributed in a grid pattern across plots; in subsequent years cores were collected within 15 cm of the initial sampling positions. Free seed was extracted using wet and dry sieving techniques. Analysis of variance (Genstat®2007) was based on Log$_{10}$(x+10) transformed data.
Table 1 **Weed control treatments evaluated during non-crop phases**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Sowing rate kg/ha</th>
<th>Key management inputs</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>One year break</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1   Canola-GM</td>
<td>7</td>
<td>K, Canola, GM</td>
<td>K, wheat</td>
<td>B, K, wheat, M</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2   Field peas-GM</td>
<td>100</td>
<td>K, Peas, GM</td>
<td>K, wheat</td>
<td>B, K, wheat, M</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3   Serradella-BM</td>
<td>40</td>
<td>K, Cadiz, BM</td>
<td>K, wheat</td>
<td>B, K, wheat, M</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4   Serradella-BM-graze</td>
<td>40</td>
<td>K, Cadiz, BM, G</td>
<td>K, wheat</td>
<td>B, K, wheat, M</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5   Sub. clover-nil</td>
<td>10</td>
<td>K, Dalkeith</td>
<td>B, K, wheat</td>
<td>K, wheat</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Three year break</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6   Biserrula-graze</td>
<td>10</td>
<td>K, Casbah, G</td>
<td>Casbah, G, ST</td>
<td>G, BM</td>
<td>K, wheat</td>
<td>Lupin</td>
<td></td>
</tr>
<tr>
<td>7   Lucerne-graze</td>
<td>5</td>
<td>K, L69, G</td>
<td>G, K, L69</td>
<td>G, BM</td>
<td>K, wheat</td>
<td>Lupin</td>
<td></td>
</tr>
<tr>
<td>8   Sub. clover-graze</td>
<td>10</td>
<td>K, Dalkeith, G</td>
<td>G, ST</td>
<td>G, BM</td>
<td>K, wheat</td>
<td>Lupin</td>
<td></td>
</tr>
<tr>
<td>9   Sub. clover-ST-graze</td>
<td>10</td>
<td>K, Dalkeith, ST</td>
<td>G, ST</td>
<td>G, BM</td>
<td>K, wheat</td>
<td>Lupin</td>
<td></td>
</tr>
<tr>
<td>10  Ryegrass-graze</td>
<td>-</td>
<td>K</td>
<td>G, ST</td>
<td>G, BM</td>
<td>K, wheat</td>
<td>Lupin</td>
<td></td>
</tr>
</tbody>
</table>

1 Break years are shaded; pasture and crop species/varieties were sown in the years and at the rates listed (Cadiz as pod).

Inputs are given in chronological order. Key to abbreviations: B—stubble burnt; BM—brown manured; G—grazed; GM—green manured; K—knockdown herbicide; M—mown; ST—late spraytop with paraquat.

**RESULTS**

Initially the site had over 1000 ryegrass seeds/m². Even though treatments were established (2003) following a knockdown herbicide there was still around 370 dormant ryegrass seeds/m² in the soil seed bank in July; 82% of these being within 2 cm of the soil surface.

Over time significant differences (P < 0.001) became evident between treatments, particularly between the one and three year break strategies (Table 2).

Table 2 **Average number of dormant, ryegrass seeds in the seed bank after various non-crop treatments**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>2003</th>
<th>2004</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>One year break</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Canola-GM</td>
<td>313</td>
<td>200</td>
<td>(2.33)</td>
</tr>
<tr>
<td>2 Field peas-GM</td>
<td>347</td>
<td>180</td>
<td>(2.28)</td>
</tr>
<tr>
<td>3 Serradella-BM</td>
<td>327</td>
<td>130</td>
<td>(2.15)</td>
</tr>
<tr>
<td>4 Serradella-BM-graze</td>
<td>248</td>
<td>240</td>
<td>(2.40)</td>
</tr>
<tr>
<td>5 Sub. clover-nil</td>
<td>204</td>
<td>1 770</td>
<td>(3.25)</td>
</tr>
<tr>
<td><strong>Three year break</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Biserrula-graze</td>
<td>216</td>
<td>650</td>
<td>(2.82)</td>
</tr>
<tr>
<td>7 Lucerne-graze</td>
<td>572</td>
<td>660</td>
<td>(2.82)</td>
</tr>
<tr>
<td>8 Sub. clover-graze</td>
<td>376</td>
<td>340</td>
<td>(2.55)</td>
</tr>
<tr>
<td>9 Sub. clover-ST-graze</td>
<td>343</td>
<td>1 330</td>
<td>(3.13)</td>
</tr>
<tr>
<td>10 Ryegrass-graze</td>
<td>563</td>
<td>2 790</td>
<td>(3.45)</td>
</tr>
<tr>
<td>l.s.d. (5%)</td>
<td>ns</td>
<td>(0.40)</td>
<td>(0.63)</td>
</tr>
</tbody>
</table>

1 See Table 1 for treatment history. Values in parentheses are Log₁₀(x+10) transformations of the number of dormant ryegrass seeds/m² in the seed bank (mid winter). Use transformed means to assess for significant differences between treatments.
Green and brown manured treatments were very effective in containing the size of the annual ryegrass seed bank, at least initially. When these treatments were cropped (2004), the number of dormant ryegrass seeds in the soil was similar or lower than the previous year. By comparison, the penalty for not targeting seed-set control, for just one season, was a nine fold increase in the size of the annual ryegrass problem (treatment 5; sub. clover-nil).

Lucerne did not persist and resembled a fallow. By contrast, the three year pasture phase based on sub. clover, grazing and chemical seed-set control resulted in legume content rising from < 20 to > 90% (year 1 to 3); it also depleted the ryegrass seed bank more than any other strategy. Furthermore, in-crop ryegrass density in the subsequent wheat (2006) and lupin (2007) crops was less than 5 and 50 plants/m² respectively, and optimum yield was achieved without the addition of bag nitrogen (data not shown).

CONCLUSION
The most effective option to get on top of a large ryegrass problem was a three year pasture phase. This concurs with Roy (2005) and similar research on the rotational benefits of non-crop phases (Revell and Thomas 2004). In this study, the most effective strategy was a three year non-crop phase based on grazed sub. clover with chemical seed-set control. However, the particular strategy adopted by individual growers will ultimately depend on the initial size of the weed problem, enterprise mix, and overall economics.

Introducing a pasture legume into a large ryegrass population was difficult. The suggested strategy where the ryegrass seed bank is extremely large (> 1000 plants/m²) is as follows: manage the first year of the non-crop phase as a volunteer pasture and brown manure it in spring to achieve total seed-set control. In the second year establish a pasture legume and spray-top with paraquat in spring (i.e. a ‘softer’ option than glyphosate on legume seed set); and in the year before crop, brown or green manure. This will decimate ryegrass seed banks, lift soil nitrogen levels and enable a return to a multiple crop phase. Grazing in combination with chemical seed set control will reduce the risk of developing resistance to broad spectrum herbicides.

KEY WORDS
ryegrass, IWM, brown manuring, herbicide resistance, seed bank management

ACKNOWLEDGMENTS
This research was initially funded by the Cropping Program of the CRC for Australian Weed Management. I would like to thank Janey Arkle for processing soil cores and Mario D’Antuono for statistical analyses.

REFERENCES

Paper reviewed by: David Minkey
Making seasonal variability easier to deal with in a mixed farming enterprise!

Rob Grima, Department of Agriculture and Food, Western Australia

**KEY MESSAGES**

- Seasonal variability has failed the traditional mixed enterprise farming system.
- A new system that incorporates grazing cereals and perennial species reduces stock management risks, and whole farm average profit can be increased.
- Grazing cereals can play a major role in increasing whole farm stock levels.
- Overall business risk is reduced for those willing to adopt a flexible paddock utilisation model.

**AIMS**

To determine if a new and novel mixed enterprise farming system pioneered by an NAR grower can reduce the risks created from variable seasons, and to determine if whole farm profit is also increased.

**METHOD**

An economic analysis of two mixed enterprise farming systems was conducted. The first system is based on traditional cropping programmes where growers determine their crop and pasture areas prior to season break according to their rotation and financial parameters. This plan is fixed despite seasonal and economic indicators closer to season break often indicating a reduced profit scenario. Stock graze stubbles in summer, and volunteer pastures in winter at low stocking rates. The total flock number is usually dictated by what growers can handle in a below average season break without excessive handfeeding costs. The 2006/07 drought has revised that carrying capacity further down, indicating even lower winter stocking rates will occur!

The new system has more flexibility for paddock usage according to season type. On this particular farm sown cereals have shown to allow increased grazing than volunteer pastures, hence all paddocks are sown to something. Stock graze on stubbles in summer, and are confined to perennial pastures (shrubs and/or grasses) at seasons break. Once paddocks are established after the break, some can be utilised for grazing and still taken to harvest. This allows designated pasture paddocks to establish more quickly and allow greater grazing pressure. In dry years when pasture supply as well as crop yields are low, more land may be needed for the flock. In wet years when pasture supply and crop yields are high, less land is needed for the flock. This is demonstrated in Table 1 hence each paddock can be used for crop production, stock production, or both depending on the seasonal conditions that prevail.

<table>
<thead>
<tr>
<th>Season type</th>
<th>Wet</th>
<th>Average</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat yield</td>
<td>2.5</td>
<td>1.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Nitrogen rate (kg/ha)</td>
<td>60</td>
<td>36</td>
<td>10</td>
</tr>
<tr>
<td>Ha of wheat for grain</td>
<td>966</td>
<td>966</td>
<td>724</td>
</tr>
<tr>
<td>Ha of wheat for pasture and harvesting</td>
<td>242</td>
<td>0</td>
<td>242</td>
</tr>
<tr>
<td>Ha of wheat for pasture</td>
<td>0</td>
<td>242</td>
<td>242</td>
</tr>
<tr>
<td>Total</td>
<td>1208</td>
<td>1208</td>
<td>1208</td>
</tr>
</tbody>
</table>

The economic analysis was conducted using the STEP (Simulated Transition Economic Planning) model over a 10 year time frame. STEP is a computerised series of whole farm annual financial budgets. It uses real farm production data, from the case study farm, to investigate the progressive annual cash flow consequences of changing the enterprise mix. District average data from BankWest benchmarks is used for overheads as well as capital and personal expenditure. The main output is annual surplus or deficit. The model takes into account the cost price squeeze, and discounts future income. It should be noted that annual surplus is net of term debt, as this varies from farm to farm. An annual yield increase of 2 per cent is also included in this analysis, as research indicates this is the productivity improvement acquired over the last 20 years. There are two wet, two dry and 6 average years within the analysed timeframe, with yields for each year displayed in Table 1. The results of the analysis should only be a guide to compare relative differences between the two systems.
RESULTS

The profitability of the new system was greater than the traditional system (Table 2), even at traditional low stocking rates. If stocking rate is increased then profit also increases (data not shown). Going from 4 to 5 dse/winter grazed ha increases whole farm profit by 40 per cent. The effect of grazing a cereal crop on yield is relatively unknown. Trials have indicated losses of up to 50 per cent, but when grazing guidelines are adhered to the losses are minimised to approximately +/- 20 per cent. These results suggest yield losses due to grazing would need to be 50 per cent or more to reduce whole farm profits substantially.

CONCLUSION

Traditional system

Managing seasonal variability in a mixed farming enterprise has always been a challenge. The traditional farming system has its greatest feed requirement immediately prior to season break when feed supply from stubbles is at its lowest. Stock carrying capacity is governed by what sheep number can be sustained on a dry late season break, rather than an ‘average’ break. Hence in any season that breaks before the average or has favourable winter conditions, pasture utilisation is not maximised and maximum cropped hectares are often not achieved. In the NAR, the sowing window is so tight that the decision to crop a paddock or not is made over an extremely short period, reducing growers’ flexibility for optimal paddock utilisation. The severe feed shortages during the 2006/07 drought may have revised average farm carrying capacity down to a new level.

In dry years stock may be hand fed. If the drought persists stock feed costs rise and growers are ultimately forced to sell at least some of their stock at a time when everyone is also selling. Downward pressure on prices occurs and the stock are undervalued. When favourable seasons come along and stock are required again, growers find repurchase costs excessive. It is for this reason they are reluctant to sell in the first place but with little feed available they have few options.

New system

The main components of the new system are first overcoming the autumn feed gap and second overcoming the winter feed gap. The autumn feed gap was overcome with perennial shrubs and grasses on poorer soils. These allow the grower to make use of out of season rainfall, as well as reducing the need for hand feeding. On this particular farm they have been arranged in alleys so as the farmer can utilise the land between alleys for cropping in favourable seasons when these soils can provide positive returns. It is noted that farms without poorer less productive soils have a large opportunity cost when using their land for perennial feeds.

The winter feed gap was overcome by use of grazing cereals. This allowed other designated pasture paddocks to establish quicker and sustain a higher stocking rate once stock were moved in.

Benefits

The main benefit from the new system is the flexibility. How a cereal paddock is utilised as the season progresses is dependent on the season and not the rotation. If grazed properly, cereals can have little yield loss. If a seeding programme lasts for 20 days, the grower has a range of crops to utilise for grazing over an extended period. This allows designated pasture paddocks to remain ungrazed for longer than in the traditional system and achieve sufficient feed on offer. This ensures a ‘higher than district average’ stocking rate once stock are introduced. Hence the decision on appropriate paddock use is not made until well after sowing when growers have a much clearer picture if the season is dry, wet or average. At that point they can choose to invest in more nutrition (N and K) to boost crop potential in wet years, or they can reduce spending in drier years. This provides the increase in average whole farm profit.
In the wet years the pasture supply should be plentiful allowing reduced area required for the stock. Hence there are more hectares for harvest. In the drier years, poor performing paddocks return a negative cash result. Allowing them for stock use and/or taking them to harvest may provide a more robust profit result over the long term.

The new system allows growers the ability to maintain their flock during dry seasons. As stated in the traditional system, growers wish to maintain their stock for many reasons. Excessive costs can arise during drought years. This cost reduces whole farm average profit. The new system allows growers to keep their flock asset (ewes) throughout most seasons with reduced cost risks.

**Risks**

There are several risks to this system. Total costs will increase as the grower plans to sow every hectare. Pasture was not sown in the traditional system. Controlling the cost of seed, fertiliser and fuel/repairs will be crucial to the success of this system.

Yield losses will occur if cereals are grazed for too long. However the rules developed for this activity are stringent and losses are minimised when adhered to. This tool is still in development stage and has not been observed across many seasons. It was found in the 2006/07 droughts that stock still needed to be hand fed in the new system, and ultimately some were sold. These droughts were the worst on record, with no grain production achieved in the district in one of those years. It was estimated only 10 per cent of the original district stock number remained at the end of this period. The new system did not allow the grower to maintain all of his stock, and as such does not cater for such extreme poor seasons. However, paddock utilisation in the 2008 season was exceptional, and the system appeared to work well in the wet season. As a result of these findings the farmer believes a different flock structure may be required to minimise the poor season risk. A flock structure that utilises wethers is expected to help, allowing these animals to be sold in the drier years without the loss of genetics or breeding stock.

**Work to be done**

This system is still being developed by the grower, his consultant, and DAFWA development officers. Many unknowns about this system still exist. The impact on weeds, stocking rate, crop diseases, total stock structure, management difficulties, labour requirements, and whole farm profit need to be addressed. Whilst this analysis suggests profit will be increased and the grower’s indications are favourable, it is still unknown how transferable this system is to other growers. The required skill set to ensure the success of this system is also unknown.

**KEY WORDS**

farming system, whole farm profit, grazing cereals, stocking rate

**ACKNOWLEDGMENTS**

Funding bodies NLP, MIG and NACC.

**Project No.:** NLP 053076

**Paper reviewed by:** Wayne Parker
How widely have new annual legume pastures been adopted in the low to medium rainfall zones of Western Australia?

Natalie Hogg, Department of Agriculture and Food, Western Australia, Northam
John Davis, Institute for Sustainability and Technology Policy, Murdoch University

KEY MESSAGES

- Pink Serradella (Cadiz®) and Biserrula (Casbah®) are the most widely grown new annual legumes, grown by 22% and 20% of respondents respectively.
- Cost of establishment and difficulties in managing weeds are the main barriers to adoption of new annual legumes.
- The recent droughts and unpredictable seasons in Western Australia have had a significant impact on the performance and perceptions of the new annual pasture legumes, hindering their adoption to date.
- Pastures continue to contain a significant proportion of subterranean clover, present on 83% of farms, in spite of the superior production values of new annual pasture legumes.

AIMS

Assess grower use of annual pasture legumes: both the traditional (subterranean clover) and new (biserrula, yellow and pink serradellas and gland clover) species.

Identify constraints to the adoption and management of new annual pasture legumes.

Determine the level of awareness and knowledge of new pasture technologies: twin-sowing, autumn cleaning and strategies to limit photosensitivity in biserrula.

METHOD

A survey was conducted at the onset of seeding 2008, mainly by telephone. Some surveys were distributed through grower groups, with respondents returning their questionnaires by email or fax. A total of 69 questionnaires were completed by growers from 37 shires across the low (275–325 mm) to medium (325–400 mm) rainfall zones of the wheat belt of Western Australia: 32 from the central agricultural region, 21 from the northern agricultural region and 16 from the southern agricultural region. 60% of respondents were a member of a grower group, the majority were from the Corrigin Farm Improvement Group, Ravensthorpe Agricultural Initiative Network, Liebe or Western Australia No-Tillage Farmers Association.

The questionnaire used mainly open-ended questions and had three variations, which depended on whether respondents currently grow new annual pasture legumes (biserrula, yellow serradella, pink serradella and gland clover). The survey asked:

- how pastures are being used in respondents farming system;
- the limitations/constraints to further adoption of new annual pastures;
- key considerations for farmers wanting to manage/establish new annual pasture legumes;
- awareness of ‘twin-sowing’, ‘autumn-cleaning’ and knowledge on photosensitivity in biserrula.

RESULTS

Experience with pastures

Subterranean clover was the most widely grown (83% of respondents) pasture legume in all three agricultural regions. Burr, strand and barrel medics, balansa, rose and persian clovers were also grown. On average 81% of respondents’ pastures were self regenerating. Respondents indicated that the main purpose for pastures in their farming systems was for livestock feed (92%), nitrogen fixing abilities (51%), weed control (26%) or part a rotation (21%).
Experience with new annual pasture legumes

Twenty-five per cent of the respondents had not grown annual pasture legumes other than subterranean clover. Half of them were actively seeking information about annual pasture legumes with their main interests being hard-seeded serradellas and aerial seeded clovers, in particular gland and bladder clover.

Twenty per cent of respondents previously grew annual pasture legumes other than subterranean clover, but no longer do so. Species previously grown included pink serradella: Cadiz (57% of former growers), biserrula (43% of former growers), yellow serradella varieties (21% of former growers) and 7% of former growers had un-adopted both pink serradella (Margurita) and gland clover (Prima).

The main reasons for ceasing to grow the legumes were technical problems relating to performance, including unreliable establishment and persistence (50%) and weed management problems (36%); financial considerations (36%) and the inability of these species to cope with seasonal variation (21%) were also major deterrents.

Pink Serradella, especially Cadiz was the most widely grown of the new annual legumes (22% of all respondents). Casbah biserrula was grown by 20% of respondents (Table 1). This survey was unable to determine the area over which these new annual pasture legumes are grown as many respondents grow mixed pastures, however the areas reported ranged between 25 and 700 ha. Some respondents did not specify which cultivars of biserrula (2), yellow serradella (3) and pink serradella (4) they were growing.

<table>
<thead>
<tr>
<th>Species</th>
<th>Cultivar</th>
<th>Number of respondents</th>
<th>Per cent of 69 survey respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biserrula</td>
<td>Casbah</td>
<td>14</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>Mauro</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>Yellow Serradella</td>
<td>Santorini</td>
<td>3</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Charano</td>
<td>7</td>
<td>10%</td>
</tr>
<tr>
<td>Pink Serradella</td>
<td>Cadiz</td>
<td>15</td>
<td>22%</td>
</tr>
<tr>
<td></td>
<td>Erica</td>
<td>3</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Margurita</td>
<td>4</td>
<td>6%</td>
</tr>
<tr>
<td>Gland Clover</td>
<td>Prima</td>
<td>5</td>
<td>7%</td>
</tr>
</tbody>
</table>

Issues to consider when establishing and managing new annual pasture legumes

Respondents who still grow a new annual pasture legumes suggested pest control (79%) together with paddock preparation (41%) were the key issues when establishing these new annual pasture legumes. Weeds were identified as a particular problem in biserrula because of the lack of registered herbicide.

Constraints to wider adoption

Unreliable and/or unpredictable seasons emerged as a major barrier to adoption of the new annual pasture legumes in all 3 agricultural regions (Table 2). Several years of drought in the northern agricultural region and unpredictable/unreliable seasons in the central and southern agricultural regions had been experienced prior to this survey. New cultivars introduced into these drought conditions have not yet had a chance to show their full potential. The cost of establishment was considered a barrier to adoption by almost half of the respondents from the southern (44%) and central (47%) agricultural regions but only 24% of respondents in the northern region. In the central region, 34% of respondents suggested that the increasing and greater profitability of cropping enterprises in comparison to sheep production was a disincentive to adoption of any new annual pasture legumes. The inter-related problems of weed control and impact of herbicide residues on growth and seed-set were also considered barriers to adoption.
Table 2 Respondents perception of the main barriers to adoption of new annual pasture legumes

<table>
<thead>
<tr>
<th>Constraints to adoption</th>
<th>Northern (%)</th>
<th>Central (%)</th>
<th>Southern (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unreliable/unpredictable seasons</td>
<td>38</td>
<td>38</td>
<td>44</td>
</tr>
<tr>
<td>Cost of Establishment</td>
<td>24</td>
<td>47</td>
<td>44</td>
</tr>
<tr>
<td>Weed Control</td>
<td>29</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>Problem soils and inability to match to right soil</td>
<td>5</td>
<td>6</td>
<td>38</td>
</tr>
<tr>
<td>Relative economics of sheep and crop</td>
<td>14</td>
<td>34</td>
<td>13</td>
</tr>
<tr>
<td>Herbicide residue problems</td>
<td>14</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Pest Problems</td>
<td>10</td>
<td>3</td>
<td>31</td>
</tr>
<tr>
<td>Lack of persistence</td>
<td>10</td>
<td>19</td>
<td>6</td>
</tr>
<tr>
<td>Lost time and grazing during establishment</td>
<td>10</td>
<td>9</td>
<td>25</td>
</tr>
</tbody>
</table>

Desirable qualities of annual pasture legumes

Respondents across all three regions indicated that the most desirable characteristic of an ideal annual pasture legume was production of large amounts of fodder for grazing and the ability to self-regenerate. However there was some regional variation. Over one third of respondents in the northern agricultural region suggested the ideal pasture legume should contribute to cropping rotations and allows easy weed control. In the southern agricultural region respondents placed greater priority on insect resistance whereas in the central region seed production was considered an important trait (Table 3).

Table 3 Characteristics of the ‘perfect’ annual pasture legume, according to farmers

<table>
<thead>
<tr>
<th>Plant attribute</th>
<th>Northern (%)</th>
<th>Central (%)</th>
<th>Southern (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High fodder production</td>
<td>43</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Self regenerating</td>
<td>43</td>
<td>47</td>
<td>56</td>
</tr>
<tr>
<td>Asset to rotations</td>
<td>38</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>Easy weed control</td>
<td>38</td>
<td>31</td>
<td>19</td>
</tr>
<tr>
<td>Good grazing</td>
<td>38</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>Drought tolerant</td>
<td>33</td>
<td>22</td>
<td>31</td>
</tr>
<tr>
<td>Insect resistant</td>
<td>14</td>
<td>16</td>
<td>38</td>
</tr>
<tr>
<td>Easy seed producer</td>
<td>10</td>
<td>38</td>
<td>31</td>
</tr>
</tbody>
</table>

Awareness of this project’s technologies

This Pastures Australia Project focuses on three new technologies:

1. ‘Twin-sowing’: sowing hard seeded annual legumes with grain crop to enable establishment of the pasture legume the following year (Loi et al. 2008).
2. ‘Autumn-cleaning’: exploiting delayed germination of yellow serradella and eastern star clover pastures for weed control using broad spectrum herbicides (Ferris 2009).
3. Developing effective management systems for biserrula to reduce the risk of photosensitivity.

Awareness of ‘autumn-cleaning’ is limited (30% of respondents) in comparison ‘twin-sowing’ which was known to 85% of respondents. Although most respondents had heard about ‘twin-sowing’ there were a variety of practices that they confused with the specific technology being developed by the project. Some said they had under-sown crops with subterranean clover, others with lucerne.

More than 60% of respondents were aware of the photosensitivity risk of pastures dominated by biserrula. Many of these had not actually grown biserrula. Only 29% of respondents had grown biserrula, the remainder obtaining their knowledge from agricultural magazines and newspapers.
CONCLUSION

Pink Serradella (Cadiz®) and Biserrula (Casbah®) are the most widely grown of all new annual pasture legumes.

The recent droughts and unpredictable seasons in Western Australia have had a significant impact on the performance and perceptions of the new annual pasture legumes, hindering their adoption to date. There should be ongoing trials and extension activities across all regions as climate conditions tend to cycle through wet and dry years.

Pastures in the Wheatbelt of Western Australia continue to contain a significant proportion of subterranean clover (present in 83% of respondents’ farming systems).

The new annual pasture legumes are sometimes perceived as inferior to subterranean clover due to cost of establishment and difficulties in managing weeds and insect pests. In order to improve perceptions and ultimately increase adoption of new annual pasture legumes, ‘twin-sowing’ establishment techniques and ‘autumn-cleaning’ weed control techniques need to be refined and their comparative economics calculated. In due course the presentation of these techniques in management packages will provide consultants a basis in which to advise farmers for long-term farm system sustainability and profitability.

KEY WORDS

annual pasture legumes, adoption of pastures, serradellas, biserrula

ACKNOWLEDGMENTS

This project receives financial support from Pastures Australia. We are most grateful to growers who responded to the survey and value partnership with growers who have been involved trials of the new technologies.

REFERENCES


Project No.: WP192

Paper reviewed by: David Ferris
Economic evaluation of dual purpose cereals in the Central wheatbelt of Western Australia

Jarrad Martin, Pippa Michael and Robert Belford, School of Agriculture and Environment, Curtin University of Technology, Muresk Campus, Northam

KEY MESSAGES

- There was little depression in grain yield after early ‘grazing’ of a range of cereal varieties in 2008, when rainfall in September and October was above average.
- The economic returns from grazing matched those from grain yield at yield levels of around 2 t/ha; thus the total return from grazing and grain yield was more than double that from grain yield alone.
- These results suggest there is potential to develop dual purpose (grain and graze) cereal systems for the Central wheatbelt of WA.

AIMS

Growing cereals for grazing and grain yield has been carried out in Australia for many years and was common practice in the 1930s. Earlier work has shown the suitability of dual purpose winter wheats in higher rainfall areas of WA and Eastern Australia, with high grazing value, grain yield and overall profitability after early sowing. Short season cereal varieties that suit much of WA’s grain growing area are theoretically less suitable for dual purpose use as they have limited time to recover from loss of leaf area after grazing, and are at risk of moisture stress during grain filling. However, interest was reignited after the 2002 drought when there were reports of higher yields in grazed crops, due to the reduced leaf area and lower transpiration, than in ungrazed crops.

This project tested the performance of seven cereals (five wheat, one oat, one barley) following grazing in the Central wheatbelt of WA in 2008. We report on the grazing value and grain yield, and present a simple economic comparison of the varieties and treatments used in the project.

METHODS

Site and season

The trial was carried out in 2008 at Curtin University’s Muresk campus, near Northam, on a red/brown loamy duplex soil. The trial was a block design incorporating 7 varieties and 4 replicates, i.e. a total of 28 main plots. Each main plot was 40 metres long by 2 metres wide, with seeds sown in 22.5 cm rows.

Seeding was carried out on 1 May 2008 to give the cereals, especially the longer season winter wheats, a chance to perform to their potential. The site was sprayed before sowing with 2 L/ha of Round-up® (450 g/L Glyphosate), 1.5 L/ha of Treflan® (Trifluralin 480 g/L) and 500 mL/ha of Sonic 200EC® (Cypermethrin 200 g/L). Nitrogen (urea—60 kg/ha) was applied in front of the cone seeder and 150 kg/ha of Macro Pro Extra® was banded with the seed. The high fertiliser rates were used to compensate for the large amounts of nutrients removed by oaten hay crops on the site in both 2006 and 2007.

Treatments

We used 3 long season wheats (Wylah, Wedgetail, Tennant); 2 spring wheats (Calingiri, Yitpi); a barley variety (Vlamingh); and one oat variety (Carrolup). Each main plot was split for four grazing treatments—ungrazed; grazed once (either early, or late); or grazed twice (i.e. both early and late grazing). ‘Grazing’ was carried out with a ride-on lawnmower to avoid the complications of using and handling livestock in small plot areas. Nitrogen fertiliser (21 kgN/ha as Flexi-N) was applied to the treatments after each time of grazing.

Measurements were taken of plant emergence, dry matter and growth stage at the time of grazing, and grain yield and yield components. The economic evaluation was carried out assuming fixed values for liveweight gain and price to determine the dollar return from grazing. Typical prices (December 2008) for wheat, barley and oats were used to calculate the value of harvested grain.
RESULTS

Season

Rainfall at Muresk in 2008 was below the long term average, but above average in the critical months of September and October.

Table 1  Annual and growing season rainfall (mm) at Muresk in 2008, and the 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>GSR</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>0</td>
<td>48</td>
<td>7</td>
<td>82</td>
<td>14</td>
<td>33</td>
<td>79</td>
<td>70</td>
<td>42</td>
<td>13</td>
<td>10</td>
<td>244</td>
<td>403</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>13</td>
<td>13</td>
<td>19</td>
<td>24</td>
<td>57</td>
<td>84</td>
<td>85</td>
<td>62</td>
<td>36</td>
<td>25</td>
<td>12</td>
<td>9</td>
<td>349</td>
<td>439</td>
</tr>
</tbody>
</table>

Dry matter cuts and liveweight gain

Dry matter (DM) yield after early grazing (24 June) was highest for Vlamingh barley (1.9 t/ha), followed by Carrolup oats and Calingiri and Yitpi wheats. The winter wheats developed more slowly and produced less dry matter, with Tennant being the lowest (1.1 t/ha) (Figure 1A).

The late grazing (15 July) treatment showed a greater difference between varieties in DM production (Figure 1B). The greatest dry matter production was again recorded for the spring cereals with Carrolup oats and Vlamingh barley the highest, followed by the spring wheats. The winter wheats produced significantly less dry matter. Variety had a large effect on DM yield (P < 0.001).

The comparison of late grazing and the second grazing of the double grazed treatment showed winter wheats had similar DM production for both treatments. The spring cereals produced less dry matter on the second grazing than for a single, late grazing (Figure 1C). Variety and the interaction of treatment and variety had significant effects on DM yield (P < 0.001).

Total production from grazing twice (i.e. 24 June and 15 July) followed a similar pattern of production; Carrolup oats produced the highest total dry matter yield (4.7 t/ha), followed by Vlamingh barley and the spring wheats (Figure 1D). The winter wheats recorded lower production with Tennant the lowest (3.2 t/ha). Variety did not have a significant effect on dry matter yields from the double cuts.

Grain yield and yield components

The timing of grazing is critical if grain yield potential is to be maintained; grazing after GS30 is not recommended to avoid damage to the ear. In this trial most varieties were grazed before GS30, although the faster developing spring cereals were close to GS30 at the time of the second grazing in July.

The weight of straw, and the number of heads was greatest for treatments either ungrazed or grazed early; however, 1000 grain weight was greatest for treatments where grazing was late. The net effect was that grazing had only a small (but significant: P > 0.001) effect on grain yield. Average grain yield across varieties and treatments was 2.1 t/ha.

However, yields of the varieties varied greatly (Figure 2), with Carrolup oats showing the highest yields (mean 2.9 t/ha) and the greatest yields if ungrazed, or grazed early. The three long season wheats averaged 2.4 t/ha, and showed relatively little yield variation in relation to grazing treatment. By contrast, the spring wheats Calingiri and Yitpi which would be expected to yield well in this environment and season, averaged only 1.2 t/ha but, as for Vlamingh barley, yielded more after late grazing or grazing on both occasions—observations suggest that frost damage in mid-August was greatest on these early flowering varieties, particularly where development was not slowed by grazing.
Early Cut Dry Matter Yields

Late Cut Dry Matter

15 July Comparison of DM Cuts

Dry Matter Yield from Double Grazing

**Figure 1** Dry matter production (kg/ha) from different varieties and grazing treatments. Vertical bars indicate 1 SED of mean within each variety.

**Figure 2** Yields (t/ha) of seven cereal varieties in relation to grazing treatment.

**Economic evaluation**

Sheep weight gains were calculated from dry matter at each grazing, assuming an 8:1 feed conversion ratio for all varieties and at both times of grazing—in practice there are likely to be differences in digestibility, palatability and thus weight gain between varieties and times of grazing. The effects of treatment and variety were significant (P < 0.001), but there were no significant interactions. Dollar returns on liveweight gains were calculated using a dressing percentage of 47% and $3.00/kg dressed weight.

Economic value of grain was calculated using prices (December 2008) of $300/t for wheats, $230/t for Vlamingh barley, and $180/t for Carrolup oats. In practice, the wheat varieties are likely to attract differing premiums, but the information to test this was not available at the time of writing.
Values of grazing, grain, and total value of grain and grazing, are shown below in Table 2. Grazing, particularly late grazing singly or combined with an earlier grazing, greatly increased the returns from all varieties in this trial.

### Table 2 Dollar returns from grazing, grain and both in relation to cereal variety and grazing treatment

<table>
<thead>
<tr>
<th></th>
<th>Ungrazed</th>
<th>Early grazing</th>
<th>Late grazing</th>
<th>Double grazing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grain $$</td>
<td>Total $$</td>
<td>Grain $$</td>
<td>Sheep $$</td>
</tr>
<tr>
<td>Vlamingh</td>
<td>411</td>
<td>411</td>
<td>313</td>
<td>320</td>
</tr>
<tr>
<td>Carrolup</td>
<td>599</td>
<td>599</td>
<td>596</td>
<td>230</td>
</tr>
<tr>
<td>Yitpi</td>
<td>323</td>
<td>323</td>
<td>303</td>
<td>205</td>
</tr>
<tr>
<td>Calingiri</td>
<td>342</td>
<td>342</td>
<td>271</td>
<td>210</td>
</tr>
<tr>
<td>Wylah</td>
<td>560</td>
<td>559</td>
<td>600</td>
<td>200</td>
</tr>
<tr>
<td>Wedgetail</td>
<td>767</td>
<td>766</td>
<td>721</td>
<td>240</td>
</tr>
<tr>
<td>Tennant</td>
<td>834</td>
<td>833</td>
<td>773</td>
<td>200</td>
</tr>
</tbody>
</table>

### CONCLUSIONS

- In 2008, the long season wheats tolerated grazing, avoided frost damage and capitalised on above average rain in September and October to produce good grain yields—this is not always likely to be the case.
- There is considerable potential to grow a range of cereals for both early season grazing and grain yield in the Central wheatbelt of WA. If using long season or winter wheats, early sowing is critical to get the best grazing value from these varieties whilst maintaining the possibility of reasonable grain yield.
- There was no consistent loss of grain yield after early grazing, and this was more than offset by the increased $$ return from combined grain production and liveweight gain.
- More work is needed to test the concept in a wider range of seasons; to develop more sophisticated economic analysis of such systems; and to model the potential biological and economic performance of such systems for a range of seasonal rainfall forecasts and sowing opportunities.

### KEY WORDS

dual purpose cereals, dry matter, grazing value, grain yield, Central wheatbelt

### ACKNOWLEDGMENTS

We would like to thank Landmark (Darren Chitty) for support in trial design, sowing and harvest, and Curtin University for Jarrad Martin’s Honours project.

**Paper reviewed by:** Dr WK Anderson, Dr R Mandel
A system for improving the fit of annual pasture legumes under Western Australian farming systems

Kawsar P Salam¹,², Roy Murray-Prior¹, David Bowran² and Moin U. Salam², ¹Curtin University of Technology, ²Department of Agriculture and Food, Western Australia

KEY MESSAGES
A model was developed to describe adoption of pasture legumes in WA based on biological and agronomic characteristics. It accurately described the adoption of Biserrula Casbah but overestimated the adoption of French serradella Cadiz when based on breeders’ assessment of the cultivar. Using farmers’ assessment of the cultivar gave an accurate estimation of adoption. The model can be used to determine what characteristics of a cultivar need to be improved for greater adoption.

INTRODUCTION
Over 20 new annual pasture legumes (APL) have been released in Western Australia (WA) since 1991 (Nichols et al. 2007). However, there is a lack of understanding of whether the adoption of these APLs has been successful or not (Salam et al. 2007). This is due to the lack of a proper technique of quantifying adoption of an APL for Western Australian farming systems. In this paper, we describe a newly developed system and apply it for improving the fit of two APLs, French serradella Cadiz and biserrula Casbah, in WA.

The system
The system (Figure 1) consists of three major components, the maximum attainable adoption potential (MAAP), the annual pasture legume framework (APL-framework) for WA and achievable adoption potential (AAP).

Figure 1 The layout of the system for improving the fit of annual pasture legumes in Western Australian farming systems.

The APL-framework for WA was developed through qualitative analysis and using a systems approach. We used a survey, conducted in 2007, of 78 farmers to characterise the desired attributes of annual pasture legumes. Altogether farmers mentioned 47 attributes in relation to a ‘dream’ annual

152
pasture legume. These attributes were analysed using a systems approach and a framework to evaluate annual pasture legumes (APL-framework) in Western Australia was developed. This framework consists of six sub-systems: establishment and growth, abiotic stress, insect tolerance, feed quality and supply, weed control, and economics. The components and sub-components for each sub-system were also identified. Interactions of the sub-systems of the APL-framework were analysed (for details see Salam et al. 2008).

The achievable adoption potential, or AAP, was calculated from the newly developed model (Figure 2) as follows:

$$AAP = AAAR \times TRMAP$$

Where, AAAR is the averaged annual adoption rate (as the percentage of all pasture species/cultivars) of the APL, and TRMAP is the time, in years, required to reach the maximum adoption potential of the APL. The AAAR and TRMAP are the two components of the model. The AAAR is related to the agronomic characteristics of the APL and 'inter-competition' factor (competition among the existing cultivars), whereas the TRMAP is attributed to its scope of adaptation. For details of the model and its algorithms and testing, see Salam et al. (2009b).

As mentioned earlier, the adoption scenarios of two well known APLs of Western Australia were used in this study. Here, it was assumed that the adoption of French serradella Cadiz, released in 1996, and biserrula Casbah, released in 1997, would be around the peak of adoption in 2005 when the data was collected by Nichols et al. (2007). The scores of the independent variables of the AAAR component of the model were collected from two sources, from the breeders who developed those APLs, and from the farmers of Western Australia.

Figure 2 The schematic diagram, showing input and output sections, of the model that predicts the achievable adoption potential of any annual pasture legumes under Western Australian farming systems.

The model was run to show ‘how’ and to quantify ‘to what extent’ the achievable adoption potential of the two APLs can be increased with the scenario of improved weed control potential and improved superiority in establishment and growth characteristics over existing cultivars. All the outputs of adoption were converted to per cent agricultural land.

RESULTS

The estimated maximum attainable adoption potential (MAAP) for Cadiz and Casbah was about 9% and 6% of agricultural land, respectively (Figure 3). When adjusted with seasonal certainty, this potential was 5.53% for Cadiz and 4.56% for Casbah. The achievable adoption potential (AAP), calculated using the score from breeders, was predicted as 1.70% for Cadiz and 1.03% for Casbah, compared to the measured adoption of 1.22% and 0.95%, respectively. Thus, this study indicates that adoption of Cadiz was below the adoption potential that the breeders would have expected, whereas Casbah reached its adoption potential. When the model was run with scores given by the farmers, the predicted adoption potential was very close (Figure 4, average of all farmers) to the achieved adoption (Figure 3) for both APLs. This indicates that with Cadiz, while a few farmers did, the most could not realize the superior agronomic traits that breeders expected in farm situations. It was not clear, however, why it happened with Cadiz, but not with Casbah.
The adoption potential of both APLs can be increased with the improvement of agronomic traits in the existing cultivars. For example, if the ability to control weeds, and establishment and growth, were improved, the AAP for Cadiz could be increased by about 41%. On the other hand, the achievable adoption potential for Casbah could be increased by about 71% with similar improvements.

Figure 3 The estimated adoption of two annual pasture legumes in Western Australia under different scenarios compared with measured adoption.

Figure 4 The distribution of predicted achievable adoption potential of two annual pasture legumes in Western Australia based on scores from individual farmers. Boxes contain the middle 50% the data, where the lower and upper edge of each box denotes the lower and upper quartiles. The solid horizontal line in each box represents the median and the triangle is the average. The outliers are the bottom and top of the data range. The square with plus sign indicates the prediction based on scores from breeders.
REFERENCES


KEY WORDS

annual pasture legume, pasture characteristics, pasture improvement system, predicting pasture adoption

ACKNOWLEDGEMENTS

This study is a part of PhD work being conducted by the senior author at the Curtin University of Technology, Western Australia. The senior author thankfully acknowledges the Australian Commonwealth Government for financial support through the Australian Postgraduate Award and the Department of Agriculture and Food, Western Australia for generous research support. The senior author thanks help from the pasture management unit (‘Profitable Pastures’) of the Department of Agriculture and Food, Western Australia (DAFWA) especially to Dr Angelo Loi for consultations and providing valuable information in relation to model development and testing, and Dr Phil Nichols for allowing access and use of some of data gathered from a survey conducted in 2006. The senior author would like to extend her thanks to the second reviewer (anonymous) for constructive suggestion on improvement of the manuscript.

Paper reviewed by: Dr Angelo Loi, Research Officer, Pasture Management, DAFWA
Perception versus reality: Why we should measure our pastures

Tim Scanlon, Department of Agriculture and Food, Western Australia, Merredin
Len Wade, Charles Sturt University
Megan Ryan, University of Western Australia

KEY MESSAGES
- Farmers overestimate the proportion of sub. clover in their pastures, and likewise underestimate the degree of soil acidity.
- Regular measurement of these factors is required for better pasture management.
- This may require training in pasture species identification and transect sampling methods, as well as regular soil testing.

BACKGROUND
Researchers and farmers have previously identified a significant decline in the productivity of subterranean clover in southern Australia (Osborne et al. 1978). More recently, surveys of farmers in the pasture grazing areas of south-eastern Australia confirmed that producers perceive a decline in legume pasture vigour, quality and persistence (Reeve et al. 2000). Farmers believed pasture decline manifested as an increase in weeds and a decrease in pasture legumes, as well as fewer grasses and perennials (Reeve et al. 2000). Pastures in the south-west of Western Australia (WA) differ from those in other areas of southern Australia, by generally being based on soils of lower fertility. Subterranean clover decline has been reported in the south-west of WA (Gillespie 1983), but the causes and producer perceptions of it have yet to be measured and understood.

AIMS
The aim of this farmer funded project was to investigate pasture productivity and persistence in WA, through farmer survey and field sampling.

METHOD
In the growing season of 2004, 65 farmers responded to the survey assessing the performance of subterranean clover-based pastures in WA (20% response rate). The survey asked questions related to the farming system and its changes over the past 30 years as well as specific questions about pasture performance and possible limitations from acidity, pests, diseases and nutrition. The respondents were from across the south-west of WA and included the shires of Albany, Darkan, Denmark, Merredin, Mt Barker, Narembeen, South Stirlings, Three Springs and Wagin. From these respondents, 16 were chosen as a representative sample of the respondents for field sampling. Pasture species composition was assessed for 6 quadrats of 30 cm by 30 cm, at 3 sites in 2 paddocks at each of the 16 farms, using the BOTANAL method (Tothill et al. 1992). Soil samples collected to 10 cm depth from each pasture quadrat were bulked for each site and soil pH was assessed in 1:5 CaCl₂ solution. Responses were collated and analysed by analysis of variance and time series using Genstat 8th Edition (Genstat 2005).

RESULTS
The results found that there was a marked difference between what farmers reported and what was measured. The proportion of subterranean clover in pasture was overestimated by 20.5% (measured value 18.0%, reported value 38.5%). This difference was due to underestimation of the grass proportion (farmer estimate 36.5%, measured value 53.4%, Figure 1).
Farmers also believed their soils to be more alkaline than they were, with only 40.6% reporting soils of pH less than 5.0, but measurements showing 80.6% of sites to have pH less than 5.0.

CONCLUSION
The differences between the measured and reported values for Western Australian pasture composition could be impacting upon the profitability of grazing and cropping enterprises. Without adequate sub. clover composition, volunteer pastures will fail to regenerate and persist. This will also limit the valuable input of biological nitrogen into the soil for subsequent crops in the rotation. Use of pasture quadrats and performing transect sampling is required to objectively assess pastures. Training may be required to enable farmers to accurately estimate sub. clover and grass proportions.

The inaccuracy of pH values reported in the survey could be due to lack of adequate soil testing across paddocks or overestimation of average farm values. Soil pH test results are usually given in CaCl₂ and this was the case in all the farms sampled. Some of the survey responses could have reported pH values measured in water; however the question did provide the option to indicate the appropriate measure. These results highlight the importance of regular soil testing, with professional advice to interpret the results and regular liming of paddocks.

KEY WORDS
pasture decline, sub. clover, soil acidity, on-farm monitoring

ACKNOWLEDGMENTS
This research was generously funded by retired farmer, the late Frank Ford. The distribution of this survey was made possible through the efforts of Bevan Addison (formerly of Elders Rural Pty Ltd) and his fellow Elders Agronomists, Chris Robinson (CRT Rural), Phillip Marshall (Albany Prograze farmer group), and Bob Hall (Hall Agronomy). This paper forms part of a scientific paper submitted to Crop and Pasture Science (formerly Australian Journal of Agricultural Research) (Scanlon et al. 2009).

REFERENCES


**Paper reviewed by:** Dr Chris Schelfhout, Dr Catherine Borger, Dr Bob French
Potential impact of climate change on the profitability of cropping systems in the medium and high rainfall areas of the northern wheatbelt

Megan Abrahams, Chad Reynolds, Caroline Peek, Dennis van Gool, Kari-Lee Falconer and Daniel Gardiner, Department of Agriculture and Food, Western Australia

KEY MESSAGES

• Current practice for the medium rainfall system may become unprofitable within 15 years due to predicted declining crop yields under climate change combined with declining terms of trade.

• Two potential medium rainfall adaptations more profitable than the current practice under climate change are using new technology to counteract the predicted yield declines and increasing cropping to compensate for reduced income from declining yields.

• Even with the small predicted decline in crop yields for the high rainfall system under climate change, current practice may become unprofitable within 20 years due to the high cost of inputs combined with declining terms of trade.

AIMS

Understanding how climate change could impact on farm businesses will facilitate planning, strategic decision making and policy processes at a farm, regional, state and national level. We used the STEP (Simulated Transitional Economic Planning) tool to examine the consequences of predicted climate change on the productivity and profitability of cropping in the medium and high rainfall farming systems of the Northern Agricultural Region (NAR).

METHOD

The model farms

Two farms were constructed in STEP to represent cropping systems in the medium and high rainfall areas of the NAR.

The medium rainfall farm (325–450 mm annual rainfall) was based on a grower case study of a sandplain farm in the NAR. The farm comprised 80% cropping, in a wheat–lupin rotation and 20% volunteer pasture supporting a self-replacing merino flock of 2058 DSE. Cropping 80% of the farm was considered the optimal enterprise mix for maximising profit while achieving good weed control (Grima 2007).

The high rainfall farm (450–750 mm annual rainfall) was also based on a grower case study in the high rainfall zone (450–750 mm annual rainfall) of the NAR. The farm had an enterprise mix of 55% cropping and 45% livestock, running trade wethers at 12 000 DSE. The cropping phase, consisting of five years of a wheat-lupin rotation, was followed by pasture for three to six years depending on the soil type. The farm had a range of different soil types from high yielding gravelly loams (4.5t/ha wheat) through to lower yielding white/yellow sands (3 t/ha wheat). Traditionally, farming systems in the high rainfall area of the NAR have been livestock-based but cropping has increased over the past 10–15 years.

Financial data was obtained from grower case studies and checked against Bankwest and/or Planfarm benchmarks. Crop input costs and prices are shown in Tables 1 and 2. To simulate declining terms of trade, costs were increased at 3% per annum and returns only at 2% per annum. To simulate productivity growth through technological advances in management and breeding, long-term crop yields for the current system were increased by 2% per annum; the average yield increase for all crops in the State over the past 20 years.
Table 1a **Medium rainfall farm: Crop and pasture variable costs ($/ha)**

<table>
<thead>
<tr>
<th>Input</th>
<th>Wheat</th>
<th>Lupins</th>
<th>Pasture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser</td>
<td>212</td>
<td>105</td>
<td>27</td>
</tr>
<tr>
<td>Sprays</td>
<td>54</td>
<td>74</td>
<td>10</td>
</tr>
<tr>
<td>Fuel/oil/grease</td>
<td>44</td>
<td>44</td>
<td>12</td>
</tr>
<tr>
<td>Repairs</td>
<td>25</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Crop insurance</td>
<td>3.5</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Seed and/or treatment</td>
<td>25</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Contractor</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1b **High rainfall farm: Crop and pasture variable costs ($/ha)**

<table>
<thead>
<tr>
<th>Input</th>
<th>Wheat</th>
<th>Lupins</th>
<th>Pasture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser</td>
<td>380</td>
<td>155</td>
<td>84</td>
</tr>
<tr>
<td>Sprays</td>
<td>50</td>
<td>70</td>
<td>4.4</td>
</tr>
<tr>
<td>Fuel/oil/grease</td>
<td>50</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>Repairs</td>
<td>35</td>
<td>35</td>
<td>5</td>
</tr>
<tr>
<td>Crop insurance</td>
<td>7</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>Seed and/or treatment</td>
<td>7</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>Contractor</td>
<td>13</td>
<td>13</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2 **Crop yields per soil type and crop prices**

<table>
<thead>
<tr>
<th>Input</th>
<th>Wheat</th>
<th>Lupins</th>
<th>Pasture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser</td>
<td>212</td>
<td>105</td>
<td>27</td>
</tr>
<tr>
<td>Sprays</td>
<td>54</td>
<td>74</td>
<td>10</td>
</tr>
<tr>
<td>Fuel/oil/grease</td>
<td>44</td>
<td>44</td>
<td>12</td>
</tr>
<tr>
<td>Repairs</td>
<td>25</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Crop insurance</td>
<td>3.5</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Seed and/or treatment</td>
<td>25</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Contractor</td>
<td>-</td>
<td>-</td>
<td>10</td>
</tr>
</tbody>
</table>

**Impact of climate change**

Climate change scenarios were developed based on the CSIRO Mk II and Hadley Centre climate change models. Projected impacts of the climate change scenarios on crop and pasture production were calculated using the methodology described in Abrahams et al. 2008. The effect of the forecast decline in production was analysed in STEP by tracking the annual surplus or deficit of the farms over 50 years. The farm’s annual surplus or deficit was calculated as the farm income net of all capital, fixed and variable costs, taxation and personal drawings. The sum of these surpluses and deficits is an indicator of the financial health of the farm business. Hence, the model reveals the financial viability of a farm reliant on the current farming system, yet experiencing a different climate scenario.

**Testing adaptations to climate change using STEP (Medium rainfall farm)**

For the medium rainfall farming system, STEP was used to test the financial viability of two adaptation strategies under climate change as compared to the current system:

(i) Investment in technology to overcome a yield decline. It was assumed that the yield decline predicted for the CSIRO Mk II scenario could be overcome through investment in new technology. The annual yield for the medium rainfall farm was held at either a 0% change or a 1% increase over 25 years. The annual surplus or deficit of the farm was determined under increasing increments of additional annual capital investment. The adaptation strategy was considered financially viable if the farm’s average annual surplus was better than under the CSIRO Mk II (1% yield decline) scenario.

(ii) Increasing cropping through use of genetically-modified (GM) crops for dealing with herbicide resistance. The current 80% wheat-lupin rotation, the economically optimal enterprise mix for weed control under herbicide resistance, was replaced with a 100% cropping rotation consisting of wheat with Round-up Ready canola and lupins. It was assumed that the GM crops were available in 2011 and that weed control in this system also included burning of windrows in the canola and lupin crops.

As it is difficult to predict advancements in technology, it was considered more realistic to investigate the adaptation strategies over a shorter time frame (25 years). The shorter time frame allowed the average annual surplus or deficit to be discounted at 8%, expressing it in today’s dollar value. Discounting becomes irrelevant over longer time periods.
RESULTS

Effect of climate change on the medium rainfall farm

Crop modelling predicted an annual yield decline under climate change at the rate of 1% for the CSIRO Mk II scenario and 1.1% for the Hadley scenario. To represent a range of possible scenarios, the financial viability of the medium rainfall farm was tested under different rates of annual yield change. The CSIRO Mk II scenario models a 1% annual yield decline in response to reduced rainfall and increased temperatures. This yield decline combined with declining terms of trade renders the farm financially unviable within 15 years (Figure 1). The scenarios modelling no yield change and a 1% yield increase were also included to represent a combination of yield decline due to climate change and a level of yield increase due to improvements in technology and management. Improving yield to a 0% annual yield change allowed the farm to overcome declining terms of trade for a further 25 years (Figure 1). In comparison, both the 1% yield increase and the no climate change (2% yield increase) scenarios maintained an annual surplus despite declining terms of trade.

The annual surplus or deficit of the medium rainfall farm was also tested for its sensitivity to changes in crop yield and terms of trade (Figure 2). Higher yields (3.1 t/ha wheat, 2 t/ha lupins) extended the life of the farm by a further 15 years. However, the farm was not financially viable with low yields (2 t/ha wheat, 1.5 t/ha lupins) currently achieved by growers in the eastern edge of the medium rainfall zone (Figure 2). This is driven by the marked increase in fertiliser costs which occurred in 2008. Because the long term trend of declining terms of trade slowed in recent years (ABARE 2004), declining terms of trade (T of T ↓) was compared to neutral terms of trade, where costs and returns both increased at the same rate. When terms of trade were improved to a neutral status, the average crop yield (2.5 t/ha wheat, 2 t/ha lupins) was profitable under the CSIRO climate change scenario (Figure 2).

Effect of climate change on the high rainfall farm

Crop modelling predicted an annual yield decline under climate change at the rate of 0.04% for the CSIRO Mk II scenario and 0.14% for the Hadley scenario. The financial viability of the high rainfall
farm was tested for both scenarios to show the effect of predicted yield declines on the financial performance of the farm (Figure 3). These were compared to the current system with no climate change (2% yield increase) and a 1% yield increase scenario, incorporating a yield decline due to climate change and a level of yield increase due to improvements in technology and management. Even with the small annual yield declines predicted under both the CSIRO Mk II (0.04% yield decline) and Hadley (0.14% yield decline) climate scenarios, the farm went into deficit within 20 years. Declining yields combined with declining terms of trade caused the production of both lupins and wheat, on the poorer soils to become unprofitable. In comparison, the farm was financially viable for both yield increase scenarios, where production increases outweighed the effects of declining terms of trade.

The annual surplus or deficit of the high rainfall farm was also tested for sensitivity to crop price and terms of trade. Due to the farm’s high input costs, a reduction in the price of wheat and lupins of $40/t caused the farm to be unprofitable (data not shown) unless annual yield increases of more than 1% could be achieved. Similarly, the high input costs of the system make the farm very sensitive to changing terms of trade. When terms of trade were improved to ‘neutral’, the financial viability of the farm increased markedly for the farm under both the CSIRO and Hadley climate scenarios (Figure 4). Hence, the decline in profitability of the high rainfall farm is driven by declining terms of trade rather than the yield reductions under predicted climate change.

Testing adaptations to climate change using STEP (Medium rainfall farm)

Assuming a 1% yield increase can be maintained through use of a new technology, the medium rainfall farm can be quite profitable (Table 3). Even with an extra $250 000 capital invested annually, the farm can achieve an average annual surplus better than the CSIRO climate scenario. If yield decline can be overcome to only a 0% yield change, extra capital investment of $50 000 per year allows the farm to become more profitable than the CSIRO climate scenario.

The GM adaptation strategy enables the farm to operate with a 100% cropping program and extends the farm’s period of profitability by delaying the onset of herbicide resistance. Increased wheat production, together with the addition of canola in the rotation (at the price of $560/t farm-gate) increases the potential income stream of the farm. The average annual surplus of $83 000 over 25 years for the GM adaptation is far above the current system ($36 000) for the CSIRO climate scenario (Table 4) and comparable to the current system under the 0% yield change scenario (data not shown).

Table 3 Average annual surplus of the farm achieving a 0% or 1% annual yield increase at different levels of extra capital investment

<table>
<thead>
<tr>
<th>Extra annual capital investment in technology (today’s $)</th>
<th>1% annual yield increase</th>
<th>0% annual yield change</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0</td>
<td>$164 300</td>
<td>$87 100</td>
</tr>
<tr>
<td>$50 000</td>
<td>$142 300</td>
<td>$65 100</td>
</tr>
<tr>
<td>$100 000</td>
<td>$120 300</td>
<td>$43 100</td>
</tr>
<tr>
<td>$200 000</td>
<td>$ 76 300</td>
<td>-$900</td>
</tr>
<tr>
<td>$250 000</td>
<td>$ 54 300</td>
<td>-</td>
</tr>
<tr>
<td>$300 000</td>
<td>$ 32 600</td>
<td>-</td>
</tr>
<tr>
<td>$350 000</td>
<td>$ 12 300</td>
<td>-</td>
</tr>
</tbody>
</table>

NB: Average annual surplus more than that of the CSIRO climate scenario ($43 280) is shown in bold.

Table 4 Average annual surplus of the farm for the CSIRO Mk II climate scenario with and without the GM crop adaptation

<table>
<thead>
<tr>
<th>No adaptation to climate change</th>
<th>Average 25-year annual surplus (today’s $)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$36 000</td>
</tr>
<tr>
<td>GM adaptation to climate change</td>
<td>$83 000</td>
</tr>
</tbody>
</table>
CONCLUSION

The wheat lupin rotation has been a very profitable rotation on the sandplain of the NAR’s medium rainfall area. However, if the effect of climate change on crop yield is as severe as the CSIRO MK II (1% yield decline) scenario and input costs remain high, the medium rainfall farm may need to adapt to a more sustainable enterprise within the next 15 years. However, if yield losses can be minimised through improvements in management or technology, terms of trade and/or higher wheat prices, then the medium rainfall farming system could remain quite profitable. In fact, other risks such as the development of herbicide resistance, rising fertiliser and fuel costs, and increasing climatic variability may be more immediate threats than climate change alone.

The potential adaptation strategies tested for the medium rainfall farming system focussed on changes in technology or management to offset the impact of declining rainfall on yield or overcome the risk of herbicide resistance. If a new technology was able to counteract the crop yield decline predicted under climate change, then the medium rainfall areas of the NAR could remain profitable for the next 25 years despite climate change and the costs associated with the new technology. The adaptation using GM crops is also a profitable option as it increases the farm’s cropping area and allows the addition of canola in the rotation, thereby overcoming the income loss from declining yields under climate change.

In the long term, the high rainfall cropping system is not financially viable under the yield declines predicted for both the CSIRO and Hadley climate scenarios. However, declining terms of trade is also a major driver of the downward trend in farm profitability due to the high level of inputs in the system combined with the current high prices. Potential adaptations to the current farming system may involve optimising the profitability of the existing enterprises rather than moving to a new system. This includes balancing the relationship between input reductions and sacrificing yield, not cropping on poor-performing paddocks and maximising the profitability of the livestock enterprise by optimising stocking rates.

The severity of the impact of climate change depends on the accuracy and validity of future climate projections, crop yield estimates and the economic conditions used in the STEP model. Uncertainties include the future wheat price, the direction of the terms of trade and the effect that new technologies, new markets and other factors may have in alleviating the impact of reduced yields on farm profitability. Future work will focus on potential adaptations for the high rainfall farm to optimise the profitability of both the cropping and livestock enterprises. However, further exploration of alternatives for the medium rainfall is also necessary before policy decisions are made on its future.

REFERENCES


Grima R (2007) Economic analysis of a high production yellow sand farm in the Northern Agricultural Region. Department of Agriculture and Food, Western Australia in collaboration with Mingenew Irwin Group, National Landcare Program and Northern Agricultural Catchment Council.

KEY WORDS
climate change, STEP, medium and high rainfall, NAR, farming system, financial viability

ACKNOWLEDGMENTS

Funding provided by the Department of Climate Change, Rob Grima for development of the medium rainfall farm, Sam Harburg for assistance in developing the medium rainfall adaptation strategies, Ian Foster for climate advice.

Project No.: AGO 0069–0506

Paper reviewed by: Andrew Blake
### Prediction of wheat grain yield using Yield Prophet®

**Geoff Anderson** and **Siva Sivapalan**, Department of Agriculture and Food, Western Australia, Three Springs, WA 6519

#### KEY MESSAGES
- In 2008, wheat yield at a number of farmer sites in the North Eastern Agricultural Region was observed to range from 2.7 to 3.9 t/ha, while the yield range predicted by Yield Prophet® in September was between 2.0 to 3.9 t/ha.
- Yield Prophet® was able to predict wheat grain yield at 7 of the 10 sites but was unable to predict the yield at three sites where:
  - Yield was over predicted at one site (site 6) due to the presence of a number of other issues (delay emergence, presence of disease, flag smut, and sub soil acidity) which were not included in Yield Prophet®.
  - Yield was under predicted at sites 8 and 9, due to the plant roots having the capacity to explore the soil to a greater depth than what was used in the model.

#### AIMS

Rainfall and soil type are the main drivers of wheat grain yield in the dry land cropping environment of Australia. Information on grain yield is important for determining nitrogen fertiliser and fungicide applications. Crop simulation models such as Yield Prophet® are currently being used to predict wheat grain yield through the season but there has been little evaluation of this model using soils and climate of the low rainfall North Eastern Agricultural Region. The aim of this investigation was to evaluate the ability of the model Yield Prophet® to predict wheat grain yield in the low rainfall North Eastern Agricultural Region (NEAR).

#### METHOD

**Monitor sites**

Grain yield was monitored at ten farmer sites within the North Eastern Agricultural Region (NEAR) during 2008 (Table 1). Wheat was grown using the varieties and fertilisers listed in Table 1. Most sites were sown in the first two weeks in May. The exceptions were site 9 which was sown on 27 May, and site 10 which was sown on 9 June. Grain yield was assessed by harvesting strips, using the farmers’ headers (200 m by header width 9–11 m), next to each site during November and December.

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Wheat variety</th>
<th>Sowing date</th>
<th>Seeding fertiliser</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 2</td>
<td>N Yuna – 25 km N</td>
<td>Wyalkatchem</td>
<td>6 May</td>
<td>60 kg Agstar/ha</td>
</tr>
<tr>
<td>3 and 4</td>
<td>Morawa – 25 km N-W</td>
<td>Tammarin Rock</td>
<td>6 May</td>
<td>40 kg Agstar/ha</td>
</tr>
<tr>
<td>5 and 6</td>
<td>Perenjori – 25 km SE</td>
<td>Bonnie Rock</td>
<td>8 May</td>
<td>35 kg DAP/ha</td>
</tr>
<tr>
<td>7 and 8</td>
<td>Mullewa – 25 km E</td>
<td>Bonnie Rock</td>
<td>12 May</td>
<td>40 kg Econo-flow/ha</td>
</tr>
<tr>
<td>9</td>
<td>Yuna – 25 km N</td>
<td>Camamah</td>
<td>27 May</td>
<td>57 Agstar extra kg/ha</td>
</tr>
<tr>
<td>10</td>
<td>Yuna – 5 km W</td>
<td>Bonnie Rock</td>
<td>9 June</td>
<td>40 kg Agstar extra kg/ha</td>
</tr>
</tbody>
</table>

Summer rainfall (1 November 2007–31 March 2008) ranged between 66 mm at the Morawa sites to 196 mm at the North Yuna sites (Table 2). Growing season rainfall (1 April to 31 October) ranged between 217 mm at the North Yuna sites to 292 mm at the Morawa sites. Annual rainfall ranged between 327 mm at the Yuna sites to 392 mm at the Mullewa sites. These rainfall figures correspond to a decile 5 rainfall year.
Table 2  Actual and long term average (1900–2007) monthly rainfall (mm) for the various sites during 2008

<table>
<thead>
<tr>
<th>Month</th>
<th>Perenjori</th>
<th>Morawa</th>
<th>Mullewa</th>
<th>Yuna</th>
<th>North Yuna</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Av Actual</td>
<td>Av Actual</td>
<td>Av Actual</td>
<td>Av Actual</td>
<td>Av Actual</td>
</tr>
<tr>
<td>November</td>
<td>10 0</td>
<td>10 0</td>
<td>22 1</td>
<td>8 0</td>
<td>0 0</td>
</tr>
<tr>
<td>December</td>
<td>8 6</td>
<td>8 6</td>
<td>12 33</td>
<td>6 42</td>
<td>42</td>
</tr>
<tr>
<td>January</td>
<td>14 0</td>
<td>14 0</td>
<td>13 0</td>
<td>9 0</td>
<td>0 0</td>
</tr>
<tr>
<td>February</td>
<td>17 111</td>
<td>17 59</td>
<td>16 116</td>
<td>15 28</td>
<td>59</td>
</tr>
<tr>
<td>March</td>
<td>23 10</td>
<td>23 1</td>
<td>20 17</td>
<td>18 43</td>
<td>95</td>
</tr>
<tr>
<td>Summer rainfall</td>
<td>72 127</td>
<td>72 66</td>
<td>83 167</td>
<td>56 113</td>
<td>196</td>
</tr>
<tr>
<td>April</td>
<td>25 37</td>
<td>25 55</td>
<td>20 62</td>
<td>21 34</td>
<td>38</td>
</tr>
<tr>
<td>May</td>
<td>47 0</td>
<td>47 9</td>
<td>46 0</td>
<td>51 5</td>
<td>8</td>
</tr>
<tr>
<td>June</td>
<td>61 67</td>
<td>61 56</td>
<td>64 40</td>
<td>70 69</td>
<td>51</td>
</tr>
<tr>
<td>July</td>
<td>54 88</td>
<td>54 90</td>
<td>59 82</td>
<td>66 88</td>
<td>75</td>
</tr>
<tr>
<td>August</td>
<td>41 19</td>
<td>39 33</td>
<td>42 18</td>
<td>46 16</td>
<td>7</td>
</tr>
<tr>
<td>September</td>
<td>20 24</td>
<td>22 25</td>
<td>22 24</td>
<td>24 20</td>
<td>17</td>
</tr>
<tr>
<td>October</td>
<td>14 5</td>
<td>15 24</td>
<td>13 26</td>
<td>15 10</td>
<td>21</td>
</tr>
<tr>
<td>Growing Season</td>
<td>262 240</td>
<td>263 292</td>
<td>266 250</td>
<td>293 242</td>
<td>217</td>
</tr>
<tr>
<td>November</td>
<td>9 0</td>
<td>11 5</td>
<td>9 2</td>
<td>8 8</td>
<td>5</td>
</tr>
<tr>
<td>December</td>
<td>8 5</td>
<td>9 6</td>
<td>7 7</td>
<td>7 6</td>
<td>3</td>
</tr>
<tr>
<td>Annual</td>
<td>333 366</td>
<td>337 363</td>
<td>331 392</td>
<td>350 327</td>
<td>379</td>
</tr>
</tbody>
</table>

Soil samples for soil chemical analyses were collected on 17–19 March for sites 1–8 and on 1 May for sites 9 and 10. These soil samples were collected using a 5 cm diameter soil auger at 10 cm intervals to a depth of 90 cm at six sites (1, 2, 3, 4, 6, and 10). At the other four sites (5, 7, 8 and 9) the soil profile was only sampled to a depth of 50 cm due to the presence of a compacted soil or rock layer (sites 5 and 7) or to a depth of 70 cm due to the presence of a gravel layer (8 and 9). Ponding experiments were set up at each site to determine drained upper limit (DUL) during April. Crop lower limits (CLL) were measured in October 2008. It was assumed that CLL was equal to the air dry water content so the model could be run during the 2008 growing season. Soil profiles samples for the measurement of the initial water content were collected from 21 April to 2 May.

Bulk density ranged between 1.2–1.5 g/cm3 in the 0–10 cm soil layer and between 1.5–1.8 g/cm3 for soil layer below 10 cm. Soil carbon content ranged from 0.50% to 0.95% in the 0–10 cm soil layer. Soil pH ranged from 4.3 to 5.9 in the 0–10 cm soil layer. Sites 6 and 7 had low soil pH (4.2–4.4) in the 10–30 cm soil layer. The soil aluminium levels for these samples ranged between 1.5–14.0 ppm. At a level of greater than 2.5 ppm soil Al will have an adverse impact on root growth. The nutrient concentrations of the 0–10 cm layer of the soils were observed to range between 18–50 ppm for P, 5–36 ppm for S and 59–423 ppm for K.

Model parameters

Soil inorganic N content, measured before seeding, to a depth of 50 cm ranged from 73 to 184 kg N/ha (Table 3). These are relatively high levels of soil inorganic N and are a result of drought conditions in the previous two years combined with summer rainfall over 2007/08 (Table 2). Plant available water capacity (PAWC), or the difference between drained upper limit (DUL) and air dry water content, was observed to range between 41–100 mm. The soils profiles were observed to have high initial water levels 32–80 mm due to late April rainfall and significant rainfall events during summer.
RESULTS

Grain yield

Actual yield was observed to range from 2.3 to 3.9 t/ha compared to Yield Prophet® predictions in September of 2.0 to 3.8 t/ha (Table 4). Yield Prophet® was able to predict the measured wheat grain yield at most sites. The exceptions were an over prediction of wheat grain yield at site 6 and under predictions at sites 8 and 9. This was due to other factors than water and nitrogen having an impact on yield. At site 6 these factors included delayed emergence, presence of disease—flag smut, and sub soil acidity. Soil sampling problems, presence of sub soil characteristics, which made it difficult to sample the soil profile (compaction layer, rocks and gravel) resulted in an under estimation of rooting depth at sites 8 and 9. These results are consistent with Whitbread and Hancock (2008) who observed APSIM, the model used to run Yield Prophet®, predicting wheat grain yield over a range of seasonal conditions and soil types ($r^2 = 0.79$). These researchers also noted that APSIM predictions were improved when the soils were characterised for their water holding capacity, rooting depth, and chemical and physical constraints; and this information was combined with information about crop variety, seeding time, fertiliser application and daily climate.

Table 3 Model parameters used to run Yield Prophet®

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Soil type</th>
<th>Location</th>
<th>Rooting depth (cm)</th>
<th>Soil inorganic N$^a$ (kg N/ha)</th>
<th>PAW capacity$^b$ (mm)</th>
<th>PAW initial$^b$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yellow sand</td>
<td>N Yuna</td>
<td>90</td>
<td>83</td>
<td>51</td>
<td>55</td>
</tr>
<tr>
<td>2</td>
<td>Red Duplex</td>
<td>N Yuna</td>
<td>150</td>
<td>110</td>
<td>96$^c$</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>Yellow sand</td>
<td>Morawa</td>
<td>70</td>
<td>120</td>
<td>75</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>Red loam</td>
<td>Morawa</td>
<td>50</td>
<td>152</td>
<td>84</td>
<td>67</td>
</tr>
<tr>
<td>5</td>
<td>Red loam</td>
<td>Perenjori</td>
<td>50</td>
<td>136</td>
<td>50</td>
<td>31</td>
</tr>
<tr>
<td>6</td>
<td>Brown clay</td>
<td>Perenjori</td>
<td>70</td>
<td>184</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>7</td>
<td>Red loam</td>
<td>Mullewa</td>
<td>50</td>
<td>84</td>
<td>64</td>
<td>74</td>
</tr>
<tr>
<td>8</td>
<td>Yellow sand</td>
<td>Mullewa</td>
<td>30</td>
<td>105</td>
<td>41</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>Yellow sand</td>
<td>Yuna</td>
<td>70</td>
<td>119</td>
<td>58</td>
<td>54</td>
</tr>
<tr>
<td>10</td>
<td>Red loam</td>
<td>Yuna</td>
<td>90</td>
<td>73</td>
<td>92</td>
<td>41</td>
</tr>
</tbody>
</table>

$^a$ Measured to a depth of 50 cm. $^b$ Measured to rooting depth. $^c$ Measured to a depth of 100 cm.

Table 4 Actual wheat grain yield (t/ha) measured in November and December compared to final yield predictions by Yield Prophet® obtained on 25 September

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Soil type</th>
<th>Location</th>
<th>Yield predictions (t/ha) 25 September</th>
<th>Actual yields (t/ha) Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yellow sand</td>
<td>N Yuna</td>
<td>3.1$^a$</td>
<td>3.0</td>
</tr>
<tr>
<td>2</td>
<td>Red Duplex</td>
<td>N Yuna</td>
<td>3.4</td>
<td>3.1</td>
</tr>
<tr>
<td>3</td>
<td>Yellow sand</td>
<td>Morawa</td>
<td>2.7</td>
<td>2.9</td>
</tr>
<tr>
<td>4</td>
<td>Red Loam</td>
<td>Morawa</td>
<td>3.4</td>
<td>3.2</td>
</tr>
<tr>
<td>5</td>
<td>Red loam</td>
<td>Perenjori</td>
<td>2.8</td>
<td>3.2</td>
</tr>
<tr>
<td>6</td>
<td>Brown Clay</td>
<td>Perenjori</td>
<td>3.8</td>
<td>2.3</td>
</tr>
<tr>
<td>7</td>
<td>Yellow sand</td>
<td>Mullewa</td>
<td>2.0</td>
<td>2.4</td>
</tr>
<tr>
<td>8</td>
<td>Red Loam</td>
<td>Mullewa</td>
<td>2.4</td>
<td>3.9</td>
</tr>
<tr>
<td>9</td>
<td>Yellow sand</td>
<td>Yuna</td>
<td>2.4</td>
<td>3.2</td>
</tr>
<tr>
<td>10</td>
<td>Red Loam</td>
<td>Yuna</td>
<td>2.4</td>
<td>2.7</td>
</tr>
</tbody>
</table>

$^a$ Grain yield predicted assuming adequate soil N.
**Water and nitrogen loss**

Yield Prophet® predictions of leakage, or the loss of water below the rooting depth, and nitrate leached are presented in Table 5. The interaction between rainfall and soil plant available water capacity was sufficient to result in no leakage or nitrate leaching at sites 2, 3, 4, 6, 7, and 10. In contrast, the low water holding capacity of the soils at sites 1, 5, 8 and 9 combined with sufficient rainfall resulted in leakage of water and leaching of nitrate below the estimated rooting depth of wheat. For sites 1, 5 and 9, this loss of water and nitrate early in the growing season was large enough to have resulted in reduced grain yield and increased nitrogen fertiliser requirements of the crop as well as impacting on rates of soil acidification, soil salinity and ground water quality.

Site 1 was the only site predicted to be responsive to applied N. At this site the soil profile contained 83 kg N/ha within the top 50 cm measured on the 18 March (Table 3). Autumn rainfall (95 mm after soil sampling in March) and winter rainfall (50 mm in June and 75 mm in July) combined with the low plant available water capacity (55 mm) resulted in the leakage of 50 mm of water below the root zone and the associated leaching of 61 kg N/ha. The net effect was that the site was very responsive to N fertiliser application. Yield Prophet® predicted a wheat grain yield of 1.7 t/ha for the nil N fertiliser treatment (data not presented) compared to 3.1 t/ha when N supply is predicted to be non-limiting. To overcome this nitrogen deficiency the farmer applied 30 L Flexi N/ha to the whole paddock on 16 July.

All other sites had high levels of inorganic nitrogen (73–184 kg N/ha) at the start of the growing season with minimal nitrate leached during the season. The exception was for site 9, which had significant amounts of leakage (50 mm). But the high inorganic N status (119 kg N/ha), partly due to growing lupins at the site in 2007, was predicted to have supplied sufficient soil N to prevent the crop from developing N deficiency.

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Soil type</th>
<th>Location</th>
<th>Leakage (mm)</th>
<th>Nitrate leached (kg N/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yellow sand</td>
<td>N Yuna</td>
<td>50</td>
<td>61</td>
</tr>
<tr>
<td>2</td>
<td>Red Duplex</td>
<td>N Yuna</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Yellow sand</td>
<td>Morawa</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Red loam</td>
<td>Morawa</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Red loam</td>
<td>Perenjori</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>6</td>
<td>Brown non cracking clay</td>
<td>Perenjori</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Yellow sand</td>
<td>Mullewa</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>Red loam</td>
<td>Mullewa</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>Yellow sand</td>
<td>Yuna</td>
<td>52</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>Red loam</td>
<td>Yuna</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**CONCLUSION**

Yield Prophet® is a powerful tool for making wheat yield predictions in relation to seasonal conditions and soil types. It also provides predictions of the wheat crop’s N fertiliser requirement. However, it requires the measurement of the soil profile inorganic N and soil water characteristics which require time and money to be obtained.

**REFERENCES**


**KEY WORDS**

Yield Prophet®
ACKNOWLEDGMENTS

I would like to thank Gary Collins, Tony Mason, Tony Tropiano, Chris Johnson, Richard and Leon Allen and Avon and Brett Warr who provided on farm assistance in running the monitor sites. The assistance provided by Yvette Oliver (CSIRO), James Hunt (Birchip Cropping Group) and Tim McClelland (Birchip Cropping Group) in setting up and running Yield Prophet® was greatly appreciated. Cameron Weeks (Planfarm Agricultural Consultancy) provided the contact details of all farmers, except for Garry Collins and Tony Mason.

Project No.: 05N114–01
Paper reviewed by: Jeremy Lemon (DAFWA, Albany) and Yvette Oliver (CSIRO, Perth)
Using Yield Prophet® to determine the likely impacts of climate change on wheat production

Tim McClelland¹, James Hunt¹, Zvi Hochman², Bill Long³, Dean Holzworth⁴, Anthony Whitbread⁵, Stephen van Rees¹ and Peter DeVoil⁶
¹ Birchip Cropping Group, PO Box 85, Birchip, Vic 3483, email yieldprophet@bcg.org.au
² Agricultural Production Systems Research Unit (APSRU), CSIRO Sustainable Ecosystems, Climate Adaptation Flagship, 306 Carmody Road, St Lucia Qld 4067
³ AgConsulting, PO Box 70, Ardrossan SA 5571
⁴ Agricultural Production Systems Research Unit (APSRU), CSIRO Sustainable Ecosystems, PO Box 102, Toowoomba Qld 4350
⁵ CSIRO Sustainable Ecosystems, PMB2, Glen Osmond SA 5064
⁶ Agricultural Production Systems Research Unit (APSRU), Department of Agriculture and Fisheries, Queensland PO Box 102, Toowoomba Qld 4350, Australia

KEY MESSAGES

• The Yield Prophet Climate Change Report provides an easily accessible way for grain growers to assess how climate change scenarios will impact on crop yields.

• The information in the report enables growers and consultants to detect the occurrence of climate change and estimate how current IPCC climate change scenarios for 2030 will affect the productivity of their farm.

• Growers and advisors can use the report to assist with strategic decisions and planning tactical applications including farming systems adaptation and design.

AIM

To simulate the impacts of likely climate change scenarios on wheat production using the Yield Prophet® Climate Change Report.

METHOD

The Yield Prophet® Climate Change Report is broken up into three sections:

• Section 1 relates to the impacts of historic climate variability on potential grain yield.

• Section 2 relates to the impacts of recent climate change on grain yield; and

• Section 3 shows the potential change in temperature and rainfall in the year 2030 using the OzClim scenarios and its effect on yield relative to the historic records.

To generate a climate change report, Yield Prophet runs a number of simulations using base-line crop information from a current Yield Prophet paddock for example:

Location: Merredin
Sowing date: 10 May
Seeding density: 100 plants/m²
Crop type: Wyalkatchem Wheat
Soil type: Loamy Sand (Merredin No401)
Weather station: Merredin
Stubble type: Wheat
Stubble amount: 1,000 kg/ha
Nitrogen: Unlimited

The simulations generated in sections 1 and 2 use historic climate data from the Bureau of Meteorology (BOM) Patched Point Dataset (PPD).
The simulations generated in section 3 use two climate change scenarios (‘best case’ and ‘worst case’) for the year 2030 from the CSIRO OzClim website (www.csiro.au/ozclim/home.do) and the historic climate data. All the climate data used in the climate change report reported here relate to the Merredin BOM station.

The ‘best case’ scenario is based on low emissions and a climate model with low sensitivity to increases in CO₂. The ‘worst case’ scenario is based on high emissions and high climate sensitivity.

The CO₂ emissions under these scenarios were determined at the second International Governmental Panel on Climate Change (IPCC) assessment report in 1995. It should be noted that CO₂ emissions in 2008 are exceeding the 1995 ‘worst case’ forecast, a consequence of the strong global economic growth over recent years and the lack of a coordinated mitigation response.

Under the ‘worst case’ scenario if CO₂ emissions continue at the 1995 rate, then by the year 2030 the estimated atmospheric CO₂ concentration will have reached 460 parts per million (ppm). If CO₂ emissions are mitigated, the estimated ‘best case’ scenario for the atmospheric CO₂ concentration is forecast to be 420 ppm by 2030.

The atmospheric CO₂ concentrations from each scenario are then provided as inputs to different general circulation models (GCMs) to determine the change in temperature and rainfall at the location of the nominated weather station, in this case Merredin. GCMs are computer models used for weather forecasting, understanding climate and projecting climate change.

RESULTS

The 2008 cropping season has come to an end and once again a number of major cropping regions in Australia have received well below average spring rainfall. Another poor year raises questions about the future and the effect climate change may have on crop production in Australia’s cropping regions.

Section 1

Figure 1 shows historic potential yield, given unlimited nitrogen, the phenology of Wyalkatchem wheat and modern agronomic practices. The vertical bars represent the potential yield of the crop in each year since 1889 based on the climate data from the Merredin BOM station selected. The black line denotes the 10-year rolling average yield.

![Figure 1](attachment:image1.png)

Figure 1 Historic potential yield (nitrogen unlimited) of the current crop.

It is evident from Figure 1 that there has been variation in the potential yields over the 119 year period with simulated yields ranging from < 0.5 t/ha to 4.5 t/ha. (NB. Yield Prophet simulations do not account for external factors such as frost, disease, poor weed management.) It is apparent from the rolling average that there have been periods of consecutive years of both high and low yield potential. Interestingly, despite consecutive poor seasons over the past two years, the current ten year period is not the worst on record with the 1893 to 1903 and 1975 to 1985 periods experiencing lower average yields. It is also evident that it is not uncommon to have two consecutive poor years with four occurrences over the last 119 years.
Section 2

Most of Australia has recorded a warming trend (as well as rising CO₂ levels) over the past 50 years. By comparing the yield potential over the past 30 years with that of preceding years, it is possible to get an impression of whether climate change has already had an impact on yield potential. The ‘gateway’ year of 1977 is used as there is a consensus in the scientific community that some effects of climate change became apparent at this time.

As there is little difference between the potential yields from 1889 to 1976 and 1977 to 2008 (Figure 2), it is evident that to date climate change has had minimal effect on potential yield. The slight discrepancies at the 100%, 60% and 20% probabilities could be due to the small sample size (30 years) of the recent probability distribution curve.

![Figure 2](attachment:figure2.png)

**Figure 2** Comparison of the potential yield from 1889 to 1976 versus the potential yield from 1977 to 2008 of the current crop.

Section 3

Using CSIRO GCMs, Figure 3 shows that the Merredin weather station, under the ‘best case’ scenario, would be expected to experience a slight (< 1 °C) increase in temperature across each month relative to the 1889 to 2008 period. The concurrent change in rainfall has small but noteworthy deviations in both directions, with increases in rainfall over the summer and autumn months and decreases during winter and spring. The net change in annual rainfall is estimated to decrease by 16.5 mm, a -5.26% deviation from the mean of 313.5 mm.

![Climate Change Scenarios from CSIRO's OzCLIM website](attachment:climate_change_scenarios.png)

**Figure 3** 2030 climate change scenarios for the Merredin BOM station from the CSIRO’s OZCLIM website (www.cmar.csiro.au/ozclim).
Using the worst case scenario, estimated increases in temperature in each month will be larger than those under the ‘best case’ scenario (Figure 3). The largest monthly increase in temperature is estimated to occur in January with a 1.5 °C change. Of greater note is the predicted effect on rainfall that the ‘worst case’ scenario is expected to generate.

The net change in annual rainfall is estimated to decrease by 64.8mm, a -21.8% deviation from the mean of 313.5 mm, with the majority of this change expected to occur in winter and spring. The net change in winter and spring rainfall is estimated to decrease by 34.0 mm and 19.6 mm respectively—equating to deviations of -25.3% (winter mean; 134.2 mm) and -36.2% (spring mean; 54.2 mm). It is important to note that higher atmospheric CO₂ may partially compensate for warmer temperatures and lower rainfall provided adequate nitrogen is available.

The output shown in Figure 4 uses the temperature and rainfall results in Figure 3 to generate three ‘probability of exceedence’ curves for comparison (‘historic’, ‘best case’ and ‘worst case’ scenarios). The forecast changes to temperature and rainfall under both the ‘best’ and ‘worst case’ scenarios are predicted to have an effect on the yield potential of wheat crops grown at this site. It is forecast that wheat crops will benefit from climate change under the ‘best’ case scenario with yields expected to increase in about three out of five years and to maintain historical yield levels in the other two years.

However, if the ‘worst case’ scenario eventuates it is apparent that wheat yields could be reduced in two out of three years with increases realised in only one of the remaining three seasons. It is important to remember that these outputs relate to current farming practices and varieties. With some changes to current management practices some of the reductions in potential yield may be ameliorated. A Climate Adaptation Report is under development that will allow farmers to investigate the likely impacts of such management options.

Figure 4 Impact of climate change scenarios at the Merredin weather station on the potential yield (nitrogen unlimited) of the current crop.

Using the ‘historic’ ‘best case’ and ‘worst case’ simulations from Figure 4, Yield Prophet evaluates the likelihood of frost and heat shock on the crop (Figure 5). As would be expected, it is forecast that under the ‘best’ and ‘worst’ case scenarios the number of mild, moderate and severe frost events decrease from the ‘historic’. Conversely, the forecast incidence of heat shock does not follow intuition in the same way as the frost results. The number of heat shock events under both the ‘best’ and ‘worst’ case scenarios decreases despite the increase in temperature. This counterintuitive result can be explained by the increase in winter temperatures causing the crop to mature faster. This results in the crop reaching grain filling earlier in the year and reducing its exposure to heat shock events in the late spring and early spring period.
Another interesting observation is that reaching maturity faster reduces the crop’s exposure to the forecast reduction in spring rainfall under the ‘worst case’ scenario. However, under this scenario the reliance on winter rainfall and stored soil water becomes more pronounced. These changes will force growers to make adjustments to their agronomic decisions and to explore different techniques to compensate.

An obvious response to the forecast changes in the Climate Change Report is to adapt agronomic practices, e.g. sowing date. Under climate change it may be beneficial to sow crops earlier than current practice. Even though this may increase exposure to frost, it may become a viable management option if frost resistant crops were to become available.

The Climate Change Report presented here is now available to Yield Prophet subscribers. Yield Prophet subscribers will soon have the ability to investigate the effects of adjusting their agronomic practices in response to changed climatic conditions through the Climate Adaptation Report.

CONCLUSION

The information presented in Figures 1–5 provide growers and consultants with a means to detect the occurrence of climate change, and an estimate of how current IPCC climate change scenarios for 2030 will affect productivity on their farm. In the example above, changes in attainable wheat yields at Merredin is highly sensitive to the future scenarios. In both cases there will be opportunities created by years with higher yield potentials. However, the best case scenario has more opportunities for high yielding crops without significantly reducing yields in poorer years, while for the worst case scenario; poorer yield will be twice as likely as better yields.

Growers and advisors can use this information to assist with strategic decisions such as succession planning, acquisition of new land, etc. as well as in tactical applications including farming systems adaptation and design. The forecast reduction in frequency of frost and heat shock, increased drought intensity and a decrease in magnitude, frequency or altered timing of seasonal breaks under climate change will all have serious implications for crop yields. The Yield Prophet Climate Change Report provides what is to-date the only easily accessible means for grain growers to assess how climate change scenarios will impact crop yields on their own farms.

KEY WORDS
climate change, Yield Prophet, wheat, modelling

ACKNOWLEDGMENTS
The Managing Climate Variability Program from Land and Water Australia for ongoing support.

Paper reviewed by: James Hunt, Zvi Hochman
Simple methods to predict yield potential: Improvements to the French and Schultz formula to account for soil type and within-season rainfall

Yvette Oliver, Michael Robertson and Peter Stone, CSIRO Sustainable Ecosystems

KEY MESSAGES

- The French and Schultz (F&S) equation (1984) is commonly used to determine the upper limit of water-limited yield potential using the total growing season rainfall (GSR). However, F&S generally under-predicts the yield potential at low rainfall and over-predicts yield at high rainfall with a high error (RMSE) of 1343 kg/ha.

- In low rainfall years (GSR < 220 mm), yield potential predictions were improved by adjusting F&S to include stored soil water at sowing and a lower intercept of 90 mm when GSR < 180 mm.

- In high rainfall years (GSR > 220 mm), F&S generally over-predicted the yield due to drainage and runoff reducing actual rainfall available to the crops, and which differs according to soil type. F&S can be adjusted to account for the soil type using the PAR_{GSR} model which uses an upper limit of GSR according to the soil plant available water capacity (PAWC), includes stored soil water and increased the intercept to 130 mm when GSR > 180 mm. This method was able to improve the prediction of the yield potential better than methods that adjust the WUE to account for soil type.

- In years with large episodic events and average/high rainfall, F&S generally over-predicts the yield as large monthly rainfall events often causes runoff or drainage depending on the soil. Yield predictions were improved by using a monthly model (PAR_{m}) which accounts for soil type using PAWC.

- Simple adjustments can improve the prediction of yield to similar levels achieved by more complicated models such as APSIM or Yield Prophet®. The error (RMSE) in yield prediction was improved from 1343 kg/ha with F&S, to 624 kg/ha with the PAR_{m} model and 660 kg/ha with the PAR_{GSR} model compared to 419 kg/ha using the crop simulation model APSIM.

AIMS

Rainfall is the main driver of yield potential in the dryland cropping environment of Australia and, hence, rainfall-based models like French and Schultz (F&S) can be used to determine an upper limit of yield potential (French and Schultz 1984). However, F&S often overestimates yield as it does not account for rainfall distribution, runoff, drainage or access to stored soil water (Robertson and Kirkegaard 2005). More complex models are available to predict yield potentials more accurately, i.e. APSIM or Yield Prophet®, however these can be complex to use and require large amounts of data. Therefore farmers and advisors still require a simple method to estimate yield potential using a simple spreadsheet or ‘back of the envelope’ type calculations. We compare a number of simple modifications to F&S which can improve yield potential predictions, without requiring the inputs of a complicated model.

METHOD

 Sites and data collected

Various models, relating rainfall totals to water-limited grain yield of wheat, were tested against a dataset of measured wheat yields from 146 dryland crops managed to water limited yield potential, covering the 1996 to 2006 seasons. The data was collected from the Western Australian wheatbelt areas of Mingenew-Irwin region and Kellerberrin (Oliver and Robertson 2009), Buntine (Oliver et al. 2006) and, Esperance (Hall pers. comm.) and the upper Eyre Peninsula of South Australian sites of Minnipa, Mudamuckla and Tuckey (Whitbread and Hancock 2008). The grain yield was estimated from quadrat cuts (replicates of 0.5–1 m²) at the majority of sites, with some yield monitor data used in Buntine.
The crop yield data was collected from sites adjacent to where the soil type, soil PAWC and soil chemistry were measured. The soil types included shallow sands, gravels, deep sands, duplex soils (sand over clays, loams over clays), loams and clays. The data for each crop also included the daily rainfall from the closest rainfall station or measured at the locations. The APSIM crop simulation model was used to estimate measured yield (with applied nitrogen) and non-nitrogen limited yield potential using daily climate data (temperature, evaporation) from the closest rainfall station and crop management information required to run APSIM (e.g. sowing date, cultivar, nitrogen applied).

Models to predict yield potential

The models were based on French and Schultz (F&S) equation (1984) which uses the total growing season rainfall (GSR) to determine the upper limit of water-limited yield potential. We use the growing season as May to September in Northern regions and May to October in Southern regions. Common adaptations to F&S include the addition of stored soil water, variable intercept and variable water use efficiency terms:

\[
\text{Yield Potential (kg/ha)} = (\text{GSR} + \text{Stored soil water} - \text{Intercept}) \times \text{Water Use Efficiency}
\]

Three adjustments to F&S are:

(a) Stored soil water—The stored soil water at sowing (in units of mm) can be either set to zero in the original F&S or use a measured value. If this stored soil water is unknown then it can be estimated as 30% of summer rainfall (Jan and April) (but cannot exceed the PAWC of the soil).

(b) Variable intercept—The intercept is the threshold rainfall required before a crop will yield which was 110 mm in the original F&S, but here we suggest using 130 mm if GSR > 180 mm and 90 mm if GSR < 180 mm.

(c) Variable water use efficiency (WUE)—The WUE was 20 kg/ha/mm in the original F&S but has been adjusted for soil type using values from the Northern Agriculture region of WA base on historical yields and local knowledge (Weeks et al. 2007) where WUE = 15 kg/ha/mm for red loam, red sandy loam and good yellow sand and loamy soil over light clay, 12 kg/ha/mm for heavy clay, sand over gravel and good sands in higher rainfall locations, 10 kg/ha/mm for poorer cropping sands and 7–10 kg/ha/mm for leachable and waterlogged soils.

Two new methods of estimated yield potential, still use the F&S equation but alter the GSR based on the soil PAWC or ‘bucket’, use WUE of 20 kg/ha/mm, calculated stored soil water and variable intercept.

1. GSR was computed using a quasi water balance with a monthly time-step—\( \text{PAR}_m \).
2. GSR with an upper limit as a function of PAWC—\( \text{PAR}_{GSR} \).

The \( \text{PAR}_m \) uses monthly rainfall data (or a monthly time-step) to calculate how much rainfall can enter the soil each month depending on the PAWC or soil ‘bucket’, how much soil water is in the bucket (PAW), and how much the crop could remove that month (potential evapotranspiration). As large monthly rainfall cannot enter the soil, this model can account for rainfall which runs off or drains below the roots of the crop by reducing the GSR. These calculations can be performed using monthly rainfall records in a simple Excel spreadsheet, available from the authors.

\( \text{PAR}_m \) has been simplified to the \( \text{PAR}_{GSR} \), which uses either GSR or an upper limit of GSR which depends on the soil PAWC (Figure 1). Beyond this upper limit there is a cap on GSR contributing to yield, so that yield is not over-estimated in wet seasons/locations (Table 1).

<table>
<thead>
<tr>
<th>PAWC (mm)</th>
<th>GSR upper limit (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>210</td>
</tr>
<tr>
<td>50</td>
<td>220</td>
</tr>
<tr>
<td>60</td>
<td>230</td>
</tr>
<tr>
<td>70</td>
<td>240</td>
</tr>
<tr>
<td>80</td>
<td>250</td>
</tr>
<tr>
<td>90</td>
<td>260</td>
</tr>
<tr>
<td>100</td>
<td>270</td>
</tr>
<tr>
<td>130</td>
<td>305</td>
</tr>
<tr>
<td>150</td>
<td>325</td>
</tr>
</tbody>
</table>
RESULTS
The wheat yields (n = 146) and GSR ranged from 220 to 5200 kg/ha (2212 ± 965 kg/ha) and 85 to 439 mm (243 mm ± 88 mm), respectively. The yield data was collected over drought periods, high rainfall seasons and a range of sowing dates.

F&S overestimated measured yields particularly at high rainfall (GSR > 220 mm) and underestimated yield at low rainfall (GSR < 220 mm) (Figure 2), with a high RMSE 1343 kg/ha (Table 2). Overestimation could be caused by drainage below the root zone or runoff, whereas underestimation may be caused by not including stored water or using an intercept value that is too high.

The inclusion of stored soil water generally reduced the under-prediction of yield in lower rainfall (< 220 mm) but increased the predicted yield at high rainfall (GSR > 220 mm) (Figure 2), thus increased the error in predicted yields across the range of GSR (Table 2). Adjusting the intercept in the F&S model reduced the amount of under-prediction at GSR < 220 mm and reduced the over-prediction at GSR > 220 mm (Figure 2), which improved the ability of F&S to predict yield (Table 2). This suggests that including stored soil water and a lower intercept value in the F&S will improve the prediction of yield at low GSR.

Accounting for soil type by adjusting the WUE did improve the overall prediction compared to F&S and reduced the RMSE to 920 kg/ha (Table 2). The large over-prediction at high rainfall was removed, but the yields were generally under-predicted in the 200–300 mm rainfall range (Figure 3). This was caused by the lower WUE used for the majority of soils not being able to predict the high yields that occur in years with good rainfall distribution.

We accounted for soil type by using the soil’s plant available water capacity (PAWC) to cap the maximum rainfall using the PAR_{GSR} model, which estimated the yield potential with an RMSE of 660 kg/ha. This model was able to reduce GSR for high rainfall years on poorer (low PAWC) soil to account for drainage, but still could account for good yields on these soils in other seasons. As this model did not take into account the rainfall distribution, it over-estimates yield in years with large episodic events that would cause leaching and runoff. The PAR_{m} model does account for monthly rainfall distribution and soil PAWC but only slightly improves on the PAR_{GSR} model (RMSE from 660 to 624 kg/ha). For seasons with large episodic events, the PAR_{m} model will give a better estimate of yield potential, otherwise the simple PAR_{GSR} model will be sufficient. Both the models which adjust GSR according to PAWC almost halve the error in prediction of yield compared to F&S (Table 2, Figure 3).
A more complex model like APSIM was able to predict yield with a smaller error (RMSE) of 419 kg/ha (Table 2, Figure 3). Models like APSIM and Yield Prophet®, however, require much more detailed soil and agronomic information than that required by simple models such as F&S or the PAR models presented here.

### Table 2
**Error of prediction in yield (RMSE)** for all the data and for GSR < 200 mm and GSR > 220 mm for the different adjustments to F&S which include using stored soil water, 2 intercept values, adjusting the WUE or adjusting the GSR

<table>
<thead>
<tr>
<th>Method</th>
<th>Adjustments to FS</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GSR</td>
<td>Stored soil water</td>
</tr>
<tr>
<td>F&amp;S original</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated</td>
<td>0</td>
<td>110</td>
</tr>
<tr>
<td>F&amp;S adjustments Total daily rainfall from May to Sept or Oct</td>
<td>Estimated</td>
<td>Two values</td>
</tr>
<tr>
<td>F&amp;S adjustments Estimated</td>
<td>Two values</td>
<td>20</td>
</tr>
<tr>
<td>PARgsr estimated Two values</td>
<td>Soil type</td>
<td>920</td>
</tr>
<tr>
<td>PARm</td>
<td>Estimated</td>
<td>Two values</td>
</tr>
<tr>
<td>APSIM</td>
<td>Estimated</td>
<td>Two values</td>
</tr>
</tbody>
</table>

### CONCLUSION

For the majority of cases, where a simple estimate of yield potential is required in the absence of highly detailed soil and agronomic data, the modifications to the F&S models presented here, PARm and PARgsr, provide a comparably accurate and reliable estimate of yield potential. The PARm spreadsheet model is able to account for soil type and stored water but still uses a simple equation based on F&S. It predicted yield with about half the error of F&S (624 cf. 1343 kg/ha). A simplified version of this model, PARgsr improved the prediction of yield in the higher rainfall years with an error of 660 kg/ha. This simplified version is ‘farmer friendly’ and yield can be calculated on ‘the back on the envelope’ provided GSR and estimate of PAWC is known.

A spreadsheet version, or more information is available from the author.

### ACKNOWLEDGEMENTS

We are grateful to the GRDC for supporting this work as part of its Precision Agriculture SIP09 initiative and Nutrient Management Initiative.

### REFERENCES


**Project No:** GRDC CSA0007, CS000017

**Paper Reviewed by:** Roger Lawes
Ability of various yield forecasting models to estimate soil water at the start of the growing season

Siva Sivapalan\textsuperscript{a}, Kari-Lee Falconer\textsuperscript{b} and Geoff Anderson\textsuperscript{a}, Department of Agriculture and Food, Western Australia; \textsuperscript{a}Three Springs, \textsuperscript{b}Moora

KEY MESSAGES
• Key yield forecasting models (PYCAL, STIN XL, Yield Prophet and APSIM) were compared for their ability to estimate soil water status prior to sowing.
• There are major differences between these models in the way they calculate the amount of stored soil water at the time of sowing.
• Different models result in different quantities of stored soil water and hence influence the potential yield calculated by these models.
• It is apparent that a model like APSIM or Yield Prophet which takes account of many factors affecting soil water status results in more realistic estimates of soil water but requires more data and is more difficult to use.

AIMS
Information on the amount of soil water at the start of the season assists farmers making decisions relating to sowing time and fertiliser rates. It is critical information used in predicting yield potential of various crops during the growing season. Yield estimates are considered by many growers as vital information to make important management decisions such as fertiliser inputs.

French and Schultz (1984) developed a relationship between the upper limit of yield potential and crop water use during the growing season. Their results also indicated the importance of stored water at sowing to supplement seasonal rainfall. They found that stored water is more effective in promoting yield than rainfall from sowing to maturity at some locations. Several authors have pointed out the limitations of the French and Schultz (1984) approach: it takes no account of the timing of rainfall in relation to crop development, it assumes that runoff and deep drainage losses are negligible, it ignores the contribution that stored soil water may make to crop water use, and assumes that all rainfall received during the season contributes to yield. Therefore this method often overestimates the yield.

Hence several models have been developed with a range of sophistications to more accurately estimate yield potential. Most of these computer models are based on modifications to the French and Schultz (1984) relationship. However, several authors [Weeks et al. (2007); Sherriff et al. (2008); Oliver et al. (2008); Whitbread and Hancock (2008)] have observed significant differences in estimated potential yields by these models. These differences in the estimated yields can be explained partly by differences in the amount of stored soil moisture at the start of the season estimated by these models.

Greater understanding is necessary of the way these computer models estimate soil water status and predict yield potential as the season progresses. This paper compares the ability of Potential Yield Calculator (PYCAL), Stress Index XL (STIN XL), Yield Prophet and Agricultural Production Systems Simulator (APSIM) to estimate soil water in a range of soil types in the low rainfall areas of the Northern Agricultural Region during the 2008 cropping season.

METHOD
A total of 12 sites were selected in farmer paddocks to cover a range of soil types in the low rainfall areas of the Northern Agricultural Region. In early April 2008, each of these soil types were characterised for drained upper limit (DUL), air-dry moisture content and bulk density for every 10 cm layer of the soil profile. For some soil types, the depth of soil was limited by the presence of rocks, hardpan or impervious layers.
Soil samples were collected to a depth of 100 cm for every 10 cm interval from 4 sites (Sites 5, 6, 11 and 12) on 21 April 2008 and from 8 sites (the rest) on 2 May 2008 (Table 2) to determine the soil moisture content by oven-drying method. Daily rainfall values from 1 November 2007 to 1 May 2008 as recorded by each farmer or from the nearest meteorological weather station were used in the analysis.

Table 1 The assumptions made for the PYCAL, STIN XL and APSIM models include

<table>
<thead>
<tr>
<th></th>
<th>PYCAL</th>
<th>STIN XL</th>
<th>APSIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall at nearest site</td>
<td>Climate = either Mullewa/Morawa/Camamah</td>
<td>Rainfall = data from 1907–2008 for each site and a calibration for either Mullewa/Morawa/Perenjori/Three Springs</td>
<td>Climate data from SILO (<a href="http://www.bom.gov.au/silo">http://www.bom.gov.au/silo</a>) (radiation, max temperature, min temperature, rainfall, evaporation and vapour pressure)</td>
</tr>
<tr>
<td>Summer Rainfall = 1 November-31 March</td>
<td>Soil Parameter U = 13</td>
<td>Soil Parameter U = 6</td>
<td>Soil parameter c = 3</td>
</tr>
<tr>
<td></td>
<td>Water Capacity = 60</td>
<td>Soil parameter U = 6</td>
<td>Soil parameter con = 3.5</td>
</tr>
<tr>
<td>Year = 2008</td>
<td>Calculates the soil water content above air-dry moisture using summer rainfall minus soil evaporation</td>
<td>Calculates the soil water content above air-dry moisture from daily rainfall and regional calibrations</td>
<td>Calculates the soil water content from rainfall and evaporation but also considers deep drainage and runoff losses</td>
</tr>
</tbody>
</table>

Since Yield Prophet is a web-based modelling system, it does not allow the user to do a calculation for past date. Because of this limitation, APSIM was used to generate the required soil moisture status data. APSIM model configuration includes the initial soil water set to air-dry water content for all depths and soil types and plant available water capacity (PAWC) set from drained upper limit (DUL) and crop lower limit (CLL). Daily outputs from APSIM include a soil water parameter, sw_dep (soil water layered in mm) which is the water held for each 10 cm depth of the soil profile.

Soil parameters u, c and con used in PYCAL and APSIM relate to Ritchie’s (1972) two-stage evaporation parameters. To compare soil water measured in the field with the output of these models, air-dry moisture content values were added to the estimated values from PYCAL and STIN XL.

**RESULTS**

The rainfall in February, March and April 2008 has contributed to greater stored soil moisture values at these sites as indicated by the soil moisture values measured on the 21 April 2008 or 1 May 2008. Special attention should be paid to 3 soil types (Sites 4, 6 and 10) which are heavy-textured and deep (Table 2). These two features can aid in storing moisture deeper in the profile against evaporation for a long time.

PYCAL calculates the available water (this is referred to as stored soil water by the model) by first estimating water lost through soil evaporation using the Ritchie (1972) bare soil evaporation model and then subtracting this estimate from total rainfall received. The calculation assumes (i) that soil evaporation is the major source of water loss over summer; and (ii) that all water that is not lost through evaporation is stored in the soil. Water loss through run off and deep drainage are not addressed. Consequences of impermeable/restricting layers on storage capacity are also not addressed. Other major limitations of PYCAL include that only available water is calculated (not plant available water); applicable to bare soil only (therefore not to be used to calculate AW after sowing or crop emergence); and only considers evaporation from 0–20 cm surface layer (neglects subsoil moisture storage).
Table 2 Measured versus model estimates of soil water (in mm) at 12 sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil type</th>
<th>Location</th>
<th>Measured</th>
<th>PYCAL</th>
<th>STIN XL</th>
<th>APSIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yellow sand</td>
<td>Yuna</td>
<td>71.1</td>
<td>78.5</td>
<td>48.3</td>
<td>79.1</td>
</tr>
<tr>
<td>2</td>
<td>Red duplex</td>
<td>Yuna</td>
<td>129.6</td>
<td>&lt; 117.8</td>
<td>87.6</td>
<td>147.6</td>
</tr>
<tr>
<td>3</td>
<td>Yellow sand</td>
<td>Morawa</td>
<td>N/A</td>
<td>60.0</td>
<td>51.6</td>
<td>82.7</td>
</tr>
<tr>
<td>4</td>
<td>Red loam</td>
<td>Morawa</td>
<td>116.0</td>
<td>&lt; 80.2</td>
<td>71.8</td>
<td>97.9</td>
</tr>
<tr>
<td>5*</td>
<td>Red sandy loam</td>
<td>Perenjori</td>
<td>74.2</td>
<td>72.9</td>
<td>46.8</td>
<td>97.5</td>
</tr>
<tr>
<td>6*</td>
<td>Brown non-cracking clay</td>
<td>Perenjori</td>
<td>153.4</td>
<td>&lt; 121.8</td>
<td>95.7</td>
<td>157.9</td>
</tr>
<tr>
<td>7</td>
<td>Yellow sand</td>
<td>Mullewa</td>
<td>63.2</td>
<td>114.9</td>
<td>71.6</td>
<td>79.3</td>
</tr>
<tr>
<td>8</td>
<td>Red loam</td>
<td>Mullewa</td>
<td>105.2</td>
<td>&lt; 111.4</td>
<td>78.1</td>
<td>105.5</td>
</tr>
<tr>
<td>9</td>
<td>Yellow sand</td>
<td>Yuna</td>
<td>68.1</td>
<td>48.6</td>
<td>35.1</td>
<td>58.1</td>
</tr>
<tr>
<td>10</td>
<td>Red loam</td>
<td>Yuna</td>
<td>117.1</td>
<td>&lt; 93.4</td>
<td>79.9</td>
<td>103.1</td>
</tr>
<tr>
<td>11*</td>
<td>Red sandy loam</td>
<td>Three Springs</td>
<td>70.7</td>
<td>51.1</td>
<td>49.4</td>
<td>81.1</td>
</tr>
<tr>
<td>12*</td>
<td>Yellow deep sand</td>
<td>Perenjori</td>
<td>67.3</td>
<td>59.2</td>
<td>33.1</td>
<td>56.5</td>
</tr>
</tbody>
</table>

* Readings relate to 21 April; PYCAL and STIN XL values have been adjusted to include air-dry moisture.

The choice of values for soil parameters U and c will determine the amount of stored soil moisture at any given time as calculated by PYCAL. It is important to note that the U and c values relate to the surface 20 cm of soil only, not the whole soil profile. Since clay soils can hold more water than sandy soils, the amount of water lost during the first stage soil evaporation (U) in clay is usually more than about 12 mm. On the other hand, for sandy soils, the U value is less than about 6 mm. In addition, the unsaturated water movement from sub-layers to top soil in sandy soils is quite low compared to that in clay soils. These two phenomena are responsible for more rapid loss of water from clay soils than sandy soils for the same quantity of water.

Reducing the default value of U (13) to represent different soil types (sand or loam) results in higher stored soil moisture values for sand and loam compared to clay. This should not be the case as clay soils can store large quantities of water, especially in subsoil layers, for a longer time. The main reason for this type of calculation by PYCAL is that it assumes all water is stored in the top layer and subjected to evaporation according to the Ritchie (1972) model. This assumption is not true as water can be stored deeper in the soil where it is not subject to evaporation.

Generally, PYCAL estimates were lower than the measured soil moisture values (Table 2). There were three instances when PYCAL over-estimated the soil moisture. Seven out of 11 times, PYCAL estimates were closer to the measured values within 20 mm. However, deviations as high as 52 mm from measured values have been observed among the results from PYCAL.

STIN XL uses the PYCAL procedure to calculate soil water (STIN XL refers this as PAW) up to 31 March. It gives this value as PAW on the 31 March (at sowing) and there is no provision for the user to go for an earlier date. STIN XL assumes the presence of a crop on 1 April and performs calculations differently after this date. From 1 April, on a weekly basis, it adds the rainfall figure during that week to the stored soil moisture calculated at the end of the previous week and then subtracts a defined value (for example, 11.9 for the period from 1 April to 7 April) to get the stored soil moisture at the end of that week. Regardless of location, the defined value is based on $E_{pot} \times CF \times 7$ where $E_{pot}$ = potential evaporation, $CF$ = crop factor, and 7 = number of days in the week. And if the calculated stored soil moisture value is greater than the Water Capacity value assumed, then the Water Capacity value is used for the stored soil moisture for that week. The Water Capacity is similar to Drained Upper Limit (DUL) to accommodate runoff and leaching processes. Negative values of stored soil moisture are assumed to be zero.

The major limitation of STIN XL is the assumption of sowing date as 1 April. If sowing occurred later than 1 April, this cannot be changed in STIN XL and it continues to calculate soil moisture assuming the sowing date as 1 April. The amount of water loss from a cropped area is generally higher than the evaporation loss from a bare soil. Therefore the soil moisture values calculated by STIN XL for sowing dates later than 1 April were seen as an underestimate. This is evident from the values of soil moisture.
calculated by STIN XL in Table 2. The paddocks were bare at the time of sampling on 21 April or 2 May. Therefore STIN XL values were much lower than the measured values for the reasons stated above. Another limitation of STIN XL is that it generates soil moisture values on a weekly basis and not daily values.

When comparing PYCAL estimates with STIN XL estimates, it is interesting to note that both methods use a similar approach to estimate stored soil moisture up to 31 March. Thereafter PYCAL continues to assume no crop (bare soil) for the purpose of calculating stored soil moisture at any given time, whereas STIN XL assumes the presence of a crop from 1 April. Therefore STIN XL estimates are lower than those from PYCAL for a date after 1 April. This might have implications on the potential yield calculated by these models. That is, STIN XL might indicate a lower potential yield for a crop planted after 1 April.

Yield Prophet uses the APSIM model in the background to simulate soil water estimates for the current date when the model was run. Results are shown as plant available water (PAW which is the difference between soil water content and crop lower limit, CLL). Since it is a web interface, the major limitation of Yield Prophet is that it cannot be used for simulation of soil water status for a date in the past. For this reason, the stand alone model APSIM was used to simulate soil water status of all 12 sites.

APSIM uses the same Ritchie (1972) water balance model as PYCAL. But the difference is that the model allows water to drain out of the surface to layers underneath where it is not susceptible to evaporation. The soil water status reported by APSIM includes air-dry moisture content. This is mainly due to the model assuming air-dry moisture content as the initial moisture which cannot be depleted by normal evaporation or plant absorption. Generally, the soil moisture values from APSIM were higher than the estimates from PYCAL or STIN XL. In addition, the APSIM estimates were closer to the actual measurement than the other two models (PYCAL and STIN XL), on 10 out of 11 occasions within 20 mm. There were only one time when APSIM results deviated by about 23 mm. Hence among these models, APSIM and Yield Prophet can be regarded as reliable or useful for predicting soil moisture. Since both the APSIM and Yield Prophet models takes into account many factors which affect soil water status, they result in more realistic estimates of soil moisture. APSIM and Yield Prophet are complex models and require lot of information to do the simulation. How you define each of the variables will determine the output from these models. These initial setbacks are remedied by the superior performance of APSIM and Yield Prophet compared to other models in estimating soil water status.

As a result of widespread rainfall in the North Eastern Agricultural Region (NEAR) during the summer-autumn period, there were significant levels of stored soil water at the start of the 2008 growing season. This stored soil moisture played an important role in determining the time and rate of sowing and the degree of successful crop establishment. In 2008, this study on monitoring soil water content in the low rainfall areas has also highlighted that annual crops made little contribution to the water table by deep drainage and there was minimal nitrogen leaching except on soils with low water holding capacity. This has highlighted areas in the production system which should be more closely monitored for their impact on water quality and salinity issues. The information on plant available water at sowing was crucial for many farmers to make important crop management decisions.

CONCLUSION

This work has shown that there are several limitations in using PYCAL and STIN XL to estimate stored soil moisture. On the other hand, APSIM and Yield Prophet were observed to give useful estimates. However, APSIM and Yield Prophet require large amount of data input and are difficult to use. Further evaluation of these models may be needed since they may behave differently in different seasons.

KEY WORDS

yield forecasting models, stored soil moisture, yield potential

ACKNOWLEDGMENTS

Thank you to those involved in the AcCLIMATise and Farming to the Climate projects, with particular thanks to the farmers with on-farm trials. Assistance for modelling provided by Meredith Fairbanks (DAFWA) and Yvette Oliver (CSIRO) is greatly acknowledged. Thanks also to Christopher Murphy (APSRU) for allowing use of APSIM. This work has been supported by a NAP/NACC funded project.
REFERENCES


Project No.: 05N1144–01
Paper reviewed by: Caroline Peek, DAFWA, Geraldton; Meredith Fairbanks, DAFWA/CSIRO Floreat; Yvette Oliver, CSIRO Floreat