Crop Updates 2008 - Farming Systems

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# FARMING SYSTEMS, 2008

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Many thanks to Chiquita Butler. Her continued efforts with the formatting of the farming systems papers for the proceedings are greatly appreciated.

Doug Abrecht
FARMING SYSTEMS CONVENOR
Developments in grain end use

Dr John de Majnik, New Grain Products, GRDC
Mr Paul Meibusch, New Farm Products and Services, GRDC
Mr Vince Logan, New Products Executive Manager, GRDC

The GRDC has four lines of business. They are: (1) Varieties, which is concerned with all aspects of varietal development; (2) Practices, concerned with all aspects of on-farm management; (3) Corporate Services, concerned with all aspects of running GRDC; and (4) New Products, which invests in research, development and commercialisation opportunities at all stages of the value chain in grain and farm products.

The scope of the New Product Output Group’s activities includes:

- developing and delivering new products and services to growers;
- accessing and applying intellectual property to help speed the delivery of new technology to the Australian grains industry;
- identifying suitable structures and partnerships to attract third-party investment;
- developing robust business cases that demonstrate market demand and value to support any product or service that the GRDC and its research partners propose investing in.

A product produced from a project in this line of business must return a commercial value back to the grain grower’s business.

The New Products portfolio is split between New Grain Products (Dr John de Majnik, Manager) and New Farm Products and Services (Mr Paul Meibusch, Manager). The New Grain Products portfolio is chartered with the areas of new grain uses for food (which Matthew Morell from CSIRO will be discussing); new grain uses for industrial applications; commercial feed grain development; and food and feed safety. The New Farm Products and Services portfolio is chartered with soil biology; export opportunities; objective measurement and quality assurance; and biopesticides. The two portfolios share responsibility for grain storage and hygiene.

The New Products portfolio is focussed on delivery of future products to assist the differentiation of income streams, and value creation or value retention for Australian grain growers. We briefly outline some examples in progress that will have an impact in Western Australia.

NEW GRAIN PRODUCTS

New grain uses

The objective of investing in new grain uses is to endeavour to capture more value for farmers through increased prices for grain by making innovations further down the value chain. Another objective is to participate in value-adding or ownership of intellectual property, and/or to develop new market segments for Australian Grain. New grain uses separates into the three areas of food, feed and industrial uses.

Food: Australian grain growers want to add value to the grain that they produce and so want to participate at different points in the value chain. This area is looking at non-traditional uses of grains for food. Dr Matthew Morell is going to cover much of the activities in this area. CSIRO and GRDC are involved in some exciting work in a number of areas, taking full advantage of the integrated technical prowess of the CSIRO Flagship teams and the continual pressure of commercial focus from new grain products management.

One area that Matthew won’t cover is lupins. GRDC has been working with DAFWA on potential food uses for lupins. Currently, potential allergenicity is being examined, which should be completed by the end of this year. The GRDC hopes to be able to work with DAFWA in finding a suitable target market for lupin product development within three years, focussing on the novel health aspects and taste of lupins.
Feed: The rationale of this area is to equip the industry to meet the rising demand for feed grains in Australia by establishing a better way of assessing the value of feed grain. This will involve matching quality to particular industries, focussing on specialised products and getting away from a lowest cost market, and creating better collaboration within this sector with a whole of chain approach. To achieve these aims:

- Aquaculture has been examined to increase markets where lupins are included as an essential ingredient in the feed ration.
- The Premium Grains for Livestock Program has almost completed the rollout of the licence to use the Near Infra-Red Spectrophotometer (NIR) mathematical regression models (or ‘calibrations’) to plant breeding organisations to predict the presence of:
  - Pig faecal digestable energy (DE) (MJ/kg as fed)
  - Pig faecal DE (MJ/kg dry matter)
  - Pig ileal DE (MJ/kg)
  - Pig Ileal/Faecal DE Ratio
  - Pig DE intake index (0-100+)
  - Ruminant metabolic energy (ME) (MJ/kg)
  - Ruminant acidosis index (0-100)
  - Broiler AME (MJ/kg as fed)
  - Broiler AME (MJ/kg dry matter)
  - Broiler AME intake index (0-100)
  - Crude fibre
  - Starch
  - Total soluble NSP
  - Insoluble arabinoxylans
  - B-glucans
  - Xylose (%)
  - Specific weight
  - Hydration capacity

- The Feed Grain Partnership has been formed, bringing together all RDC agencies from grains and livestock to focus resources towards a common end point. It also brings together most areas of the delivery chain to identify gaps holding back the generation of greater value at all points of the value chain. The web site address is [www.grdc.com.au/feedgrains](http://www.grdc.com.au/feedgrains) and should be available by the end of March.

Industrial products: The rationale is to diversify the crops and crop uses available to farmers through identification and development of new crop uses, where possible by increasing demand and/or value, and to build intellectual property for the Australian industry. Diversifying the portfolio further into industrial products facilitates potential access to large sectors and capitalises on emergent uses for cereals. One such use is as biofuels and bioproducts. GRDC is examining the feasibility of second generation biofuels (lignocellulosic) and the part that grain growers could play in their production. The GRDC is also examining the most profitable research investments to make in the oil area. The GRDC has not yet seen a convincing case for research investment in biodiesel. The GRDC has invested in crops as biofactories to produce high value oil products for current and future markets hungry for green petrochemical replacements and novel plant-based polymers and monomers.

Grain storage and hygiene

The rationale for investment in grain hygiene is to ensure there is broad industry buy-in for the need to take a whole-of-industry approach to clean grain to maintain the industry reputation for clean grain. The development of sustainable grain storage technologies continues to be a key investment area for the GRDC. Ongoing research to improve our understanding of the mechanisms behind insect resistance to phosphine, with the objective of maintaining phosphine’s effective use as a stored-grain fumigant, is another key area. This is why the GRDC has invested in the CRC for National Plant Biosecurity as a vehicle to deliver a national approach, to maintain close industry ties, to ensure the right people are on the ground, and to look at novel approaches that can be delivered within a four year time frame as solutions to the growing problems facing farmers in this area.
Food and feed safety

Food safety demands will be customer driven, as consumers are highly interested in product attributes that affect them directly. Food safety is important to consumers and organisations. The GRDC investments in food safety are to ensure there is broad industry buy-in to a whole of industry approach to safe grain to minimise food safety issues. Much of this work revolves around mycotoxins, and Aflatoxins. Also, a large part of the GRDC involvement in this area is in providing resources for emergency management planning and preventative risk management. Food safety risks, if not managed, could threaten market access and the reputation of Australian grain.

NEW FARM PRODUCTS AND SERVICES

Soil biology

This broader theme is jointly managed by Paul Meibusch and Martin Blumenthal from Practices. Current projects in New Products are working to commercialise a number of soil inoculants through our joint venture company Philom Bios Australia. These include both products developed by GRDC-funded projects, and commercial products from our Canadian partner that are being trialled under our conditions. By 2010 we hope to be launching microbial inoculants for the control of several key soil-borne diseases such as take-all and Fusarium.

Following a workshop and discussion paper in 2007, a new range of projects are being evaluated that will build on the five year Soil Biology Initiative that finished last year. Focus is being placed on carbon fractionation and accumulation in soil, phosphorus pools, and potentially a new investment in a biological control for Rhizoctonia.

Export opportunities

This is a new focus of the portfolio, and works to create opportunities for Australian grain in key export markets by developing technologies and knowledge taking advantage of the unique qualities of our product.

Recently, the first of these projects successfully concluded and the results were passed on to a number of grain exporting companies. This project partnered experienced researchers from BRI Research with a Taiwanese noodle manufacturer, and examined the key protein and starch attributes that made specific Australian grain ideal for production of instant noodles. The expectation is that in the medium term this work will lead to between 200 000 t and 400,000 t of new export business.

Objective measurement and quality assurance

This theme focuses on the development of new tools for faster, cheaper and more accurate objective measurements. In 2007, commercialisation began of a new technology that will potentially replace the Falling Number machine to measure weather damaged in grain. It promises a fast reliable measurement in a format ideal for grain receival points.

In another area of this theme, NIR calibrations for soil are being developed in a practical and applicable format. Based at UWA, the project has focused on WA soils initially and details can be found at www.soilquality.org.au.

Biopesticides

Several long term programs have been working on microbial and metabolite based pesticides. While still in their infancy, some good progress has been made on control agents for snails and slugs, and ryegrass, as well as a biological control for myrids and thrips.
Global warming potential of wheat production in Western Australia: A life cycle assessment

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KEY MESSAGES

Greenhouse gases (GHG) emitted from agricultural systems include carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). Assessing greenhouse gas emissions from wheat production relies on correctly identifying and quantifying all emission sources. In Western Australia, there is great uncertainty surrounding N₂O emissions from the application of N fertiliser to land.

Utilising regionally specific soil N₂O emissions (from one field site), we calculated 259 kg of CO₂-equ were produced during the production and delivery of one tonne of wheat to port. Carbon dioxide contributed 196 kg (75% of total), CH₄ contributed 8 kg CO₂-equ (3%) and N₂O contributed 56 kg CO₂-equ (22%).

Utilising the international default value for soil N₂O emissions overestimated GHG by 52%, and identified N₂O from the application of N fertiliser to land as the single largest source of emissions.

We recommend utilising regionally specific data for soil N₂O emissions, rather than international default values, when assessing and developing strategies for minimising GHG from agricultural production systems.

INTRODUCTION

Greenhouse gases (GHG) emitted from agricultural systems mainly include carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). All GHG need to be accounted for when assessing the overall impact of agricultural production systems on our atmosphere. ‘Life Cycle Assessment’ (LCA) is an internationally recognised approach for calculating greenhouse gas emissions from production systems. A LCA compiles the inputs and outputs from a production system, and in turn evaluates their potential environmental impacts (e.g. emissions of GHG). This has the advantage of identifying the environmental impacts at all stages in the production cycle, rather than focusing on a single source of GHG; thus ensuring that mitigation strategies focus on the primary sources of GHG.

The accuracy of a LCA of greenhouse gas emissions relies on correctly identifying and quantifying emission sources. In Western Australia, there is great uncertainty surrounding N₂O emissions from the application of N fertiliser to land. Although N₂O is only present as a trace gas in the earth’s atmosphere, it has 310 times the global warming potential of carbon dioxide (CO₂) and a lifespan of ~120 years (Crutzen, 1981). As a consequence of its high global warming potential, N₂O emissions from land can have a large bearing on the assessment of GHG from cropping systems.

Overseas estimates suggest that 1% of all N applied to soil will be emitted as N₂O (IPCC, 2006). However, extrapolating international emission factors to estimate N₂O emissions from the Western Australian grainbelt is not appropriate due to differences in N fertiliser management, soil types and climate: Factors demonstrated to influence annual agricultural N₂O emissions (Stehfest and Bouwman, 2006). Consequently, the overall aim of our paper is to present the life cycle global warming potential of wheat production in south-western Australian by: a) quantifying N₂O emissions from the Western Australian grainbelt; and b) incorporating the local N₂O emission data into a LCA of greenhouse emissions from the production of one tonne of wheat, and comparing these results with those derived from utilising international default factor for N₂O emissions from the application of N fertiliser to land.
METHOD

Measuring $N_2O$ emissions from a cropped site

Nitrous oxide emissions were measured for two years at a cropped site at Cunderdin in Western Australia, on a yellow/brown sandy duplex soil. A randomised plot design with three replications was employed. The treatments consisted of either plus N fertiliser or no N fertiliser (i.e. control). In the plus N treatment either 100 (Year 1) or 75 kg N/ha/yr (Year 2) were applied as urea (25 kg N/ha drilled at seeding, 50-75 kg N/ha topdressed 6 weeks after seeding). The N application rate was based on site history (rotation and yield), season, crop and soil chemical composition. In addition, all treatments plots received 15 kg P/ha at seeding as ‘Superphosphate CuZnMo®’.

Measurements of nitrous oxide emissions commenced on the 19 May 2005, with sowing on the 1 June 2005 (Year 1) and the 26 June 2006 (Year 2). Emissions were measured in each treatment plot up to six times per day using soil chambers (one per plot) connected to a fully automated system that enabled simultaneous determination of $N_2O$ and $CO_2$ emissions. Briefly, the system consisted of a gas chromatograph fitted with a $^{63}$Ni electron capture detector for $N_2O$ analysis, an infra-red analyser for $CO_2$ analysis, an automated sampling unit for collecting and distributing gas samples, and six chambers (one per treatment plots). Chambers (500 mm x 500 mm, varying height depending on crop height) were placed on metal bases inserted into the ground (100 mm), and fitted with a top that could be automatically opened and closed. Four bases were located in each treatment plot to enable the chambers to be moved to a new position every week so as to minimise the effect of chambers on soil properties and plant growth. The height of the chambers was progressively increased to accommodate crop growth, with a maximum height of 950 mm. For further details of the design and operation of the chambers the reader is referred to Barton et al. (2008).

In addition to $N_2O$ emissions, a number of soil, plant and climatic variables were measured to assist in the explanation of $N_2O$ emissions. These included soil mineral N, soil water contents, $CO_2$ fluxes, soil temperature, rainfall and plant growth parameters.

Life cycle assessment

Life Cycle Assessment was undertaken to identify and calculate the amount of greenhouse gas emitted from wheat production. The assessment was conducted by compiling and evaluating inputs (e.g. fertiliser, pesticide, lime), and outputs (e.g. $CO_2$, $CH_4$ and $N_2O$), from production and transport of one tonne of wheat to port (Kwinana). The analysis examined ‘pre-farm’, ‘on-farm’ and ‘post-farm’ emissions. The pre-farm stage included greenhouse gas emissions from agricultural machinery, fertiliser and pesticide production. The on-farm stage included greenhouse gas emissions derived from growing and harvesting wheat, and was based on the activities undertaken during the first year of $N_2O$ emissions (May 2005 to May 2006). Either $N_2O$ data collected from the field study, or $N_2O$ emissions calculated using the international default value for $N_2O$ emissions from land (1.0% of applied N), was used in the analysis. An equivalent of 2.7 t ha$^{-1}$ of wheat was harvested from the site in Year 1, and we therefore assessed the GHG from the production and transport of one tonne of wheat from 0.43 hectares of N fertilised land. A land preparation stage was not included in the analysis, as the crop was sown with zero tillage techniques. The post-farm stage included emissions resulting from grain storage and transportation to the port.

The first step of the LCA was to compile the inputs and outputs for each production process (e.g. manufacture of fertiliser, seeding) known to result in GHG. Such a compilation is called a Life Cycle Inventory (LCI) and included data derived from local growers in the region. The GHG resulting from each production process were calculated by inserting LCI data into a LCA software package (Simapro, 2006). The software package includes a number of ‘libraries’ (e.g. chemical, machinery, energy) to facilitate the calculation of GHG from each of the production processes. Local information was substituted for that provided by the libraries when library data were absent or inaccurate. For example, the emissions factor for producing single super phosphate was obtained from the local fertiliser manufacturer (CSBP). Each greenhouse gas ($CO_2$, $CH_4$, $N_2O$) was compiled for each production process, and values then converted to $CO_2$ equ (kg $CO_2$) by multiplying $CH_4$ (kg $CH_4$) by 21 and $N_2O$ (kg $N_2O$) by 310.

Carbon dioxide uptake from crop growth was not considered in the LCA as much of the plant material was retained on site following harvest, and we assumed that the sequestered $CO_2$ would be re-released with time. Soil C sequestration was also not included in our analysis as it is not
considered to be significant during a 12 month period. Soil CH₄ emission and/or uptake was not included due to the absence of data on rain-fed crops in semi-arid regions; furthermore CH₄ emissions/uptake are expected to be low from fertilised agricultural soils (Suwanwaree and Robertson, 2005).

RESULTS

Nitrous oxide emissions from a cropped soil

Daily N₂O emissions were low (-2 to 8 g N₂O-N/ha/day) and culminated in an annual loss of 0.09-0.11 kg N₂O-N/ha from N fertilised soil and 0.07-0.09 kg N₂O-N/ha from non-fertilised soil. Globally, N₂O emission have ranged from 0.3-16.8 kg N₂O-N/ha/yr for inorganically fertilised, rain-fed, cropped soils (mineral), when emissions have been measured for at least one year. In the first year, over half (55%) the annual N₂O emission occurred from both N treatments when the soil was fallow, and following a series of summer rainfall events. At this time of the year, conditions were conducive for soil microbial N₂O production with elevated soil water content, available N, soil temperatures generally > 25°C, and no active plant growth. The proportion of N fertiliser emitted as N₂O, after correction for the 'background' emission (no N fertiliser applied) was 0.02% for both years. The emission factor reported in this study is 50 times lower than IPCC default value for the application of synthetic fertilisers to land (1%), suggesting that the default value may not be suitable for cropped soils in our region. Applying N fertiliser did not significantly increase the annual N₂O emission, demonstrating that a proportion of N₂O emitted from agricultural soils may not be directly derived from the application of N fertiliser.

Greenhouse gas emissions from wheat production

Utilising regional specific N₂O emissions from the application of N fertiliser to land

The equivalent of 259 kg of CO₂ was produced during the production and delivery of one tonne of wheat to port. Carbon dioxide contributed 195 kg (75% of total), CH₄ contributed 8 kg CO₂-eq (3%) and N₂O contributed 56 kg of CO₂-eq (22%). Pre-farm, on-farm and post-farm stages accounted for 116 kg of CO₂-eq (45% of total), 114 kg of CO₂-eq (44%) and 29 kg of CO₂-eq (11%), respectively. For the pre-farm stage, CO₂ was the main GHG emitted (i.e. 83 kg of CO₂-eq), and resulted from the supply of diesel, fertilisers, pesticides and machinery. Carbon dioxide resulting from the combustion of diesel by farm machinery and the application of urea was the greatest source of GHG for the on-farm stage, followed by N₂O from the application of N fertiliser to land. Carbon dioxide emitted from transporting grain to port was the greatest source of GHG for the post-farm stage.

Overall, the production and supply of fertiliser accounted for a large proportion (35%) of the GHG produced from wheat production, and occurred in the pre-farm stage (Table 1). Other significant sources of greenhouse gas emissions included: CO₂ emission from the hydrolysis of urea applied to land (27%), transportation of inputs and wheat (12%), herbicide production (9%), N₂O emissions from the N fertiliser application (9%) and operation of farm machinery (8%).

Table 1. The contribution (%) of on-and off-farm activities to total GHG from the production of 1 tonne of wheat using either a regional or international default value (1.0%, IPCC 2006) for N₂O emissions from the application of N fertiliser to land

<table>
<thead>
<tr>
<th>Activity</th>
<th>Using regional N₂O data</th>
<th>Using IPCC value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser production</td>
<td>35%</td>
<td>23%</td>
</tr>
<tr>
<td>Herbicide production</td>
<td>9%</td>
<td>6%</td>
</tr>
<tr>
<td>N₂O emissions from paddock</td>
<td>9%</td>
<td>40%</td>
</tr>
<tr>
<td>CO₂ emission from urea hydrolysis (from paddock)</td>
<td>27%</td>
<td>17%</td>
</tr>
<tr>
<td>Farm machinery operation</td>
<td>8%</td>
<td>6%</td>
</tr>
<tr>
<td>Transportation of inputs and wheat</td>
<td>12%</td>
<td>8%</td>
</tr>
</tbody>
</table>
Utilising the international default value for N₂O emissions from the application of N fertiliser to land

Calculated GHG increased from 259 to 393 kg of CO₂-equ when the proportion of N₂O emitted from the application of N fertiliser to land was assumed to be 1.0% of N applied. Utilising the international default value also increased the relative contribution of on-farm emissions to total emissions resulting from the production and delivery of one tonne of wheat to port. Pre-farm, on-farm, and post-farm stages accounted for 116 kg of CO₂-equ (29% of total), 248 kg of CO₂-equ (63% of total), and 29 kg of CO₂-equ (8%), respectively. Nitrous oxide from N fertiliser application during the on-farm stage was the greatest single source of greenhouse gas (40% of total, 157 kg of CO₂-equ) (Table 1). The second largest source of GHG was the production of fertiliser in the pre-farm stage (23%, 89 kg of CO₂-equ) (Table 1).

CONCLUSIONS

Greenhouse gas emissions from the production and delivery of one tonne of wheat in south-western Australia was equivalent to 259 kg of CO₂ when regional soil N₂O emissions (from one field site) were utilised in the analysis. The pre-farm stage accounted for the significant portion (45%) of the total global warming potential, followed by on-farm (44%) and post-farm (11%) stages. Nitrogen fertiliser production was responsible for 47% of the GHG.

Utilising the international default value for N₂O emissions from land, rather than local data, would have overestimated GHG from wheat production by 52%. We would have concluded that 393 kg of CO₂ were emitted from the production and delivery of one tonne of wheat, with a large proportion (40%) due to soil N₂O emissions.

We recommend utilising regionally specific data for N₂O emissions from land, rather than international default values, when assessing and developing strategies for minimising GHG from agricultural production systems.

KEY WORDS

cereal production, global warming, life cycle assessment, nitrous oxide

REFERENCES


ACKNOWLEDGMENTS

We thank Klaus Butterbach-Bahl and Ralf Kiese (Institute of Meteorology and Climate Research, Germany) for assisting with the establishment of the automated gas chamber system. David Gatter for maintaining the field site and Renee Buck for technical assistance. The Cunderdin Agricultural College for providing the study site and assisting with its establishment. Tim Grant for discussions on LCA and the use of Simapro, Brett Cox for providing information on farm machinery and pesticides. Bill Bowden, Richard Eckard, Ian Galbally, and Peter Grace for assisting with the project development. We thank Bill Porter for input into the initial design and implementation of the project.

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Paper reviewed by: Dr Bill Bowden, Department of Agriculture and Food, Western Australia
How much fuel does your farm use for different farm operations?

Nicolyn Short1, Jodie Bowling1, Glen Riethmuller1, James Fisher2 and Moin Salam1

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KEY MESSAGES

- The ‘Farm Fuel Calculator’ is an easy-to-use electronic estimator of fuel consumption (L/ha) specific to farms; it allows the user to compare fuel use under various farm management options (e.g. tillage, sowing, hay production, harvesting, transport, etc.), soil types, crops and paddocks for the crop and livestock components of the farm.

- With rising pressure on farm profitability due to increasing fuel costs, the calculator provides farmers and advisors with important, quantitative information on fuel and energy use by the farm business to assist decision-making.

AIMS

Information about fuel use in agricultural systems exists in various forms and locations, but is not generally in a form that is easily accessible to farm decision-makers or advisers. As a result there is a need to collate, integrate and synthesise this information into a useable format. Along with this, there is little information available on fuel use in different farm operations. The ‘Farm Fuel Calculator’ is aimed to serve this purpose by allowing farmers to compare paddocks, crops, soil types and management options. Charged with this information, farmers and advisers will be able to evaluate options on a truly comparative basis and make informed decisions about ways, if any, in which they can decrease the fuel consumption of their enterprises. It also aims to increase awareness of the dependence many current agricultural systems have on oil-based products.

BACKGROUND

As energy costs climb, driven by the higher oil prices associated with oil depletion and the ever increasing global demand for the resource, pressures on farm profitability continue to increase dramatically (www.peakoil.net.au). Over recent years, many farmers, particularly those situated in the eastern areas of the wheatbelt, have altered their production methods as a consequence of the previously low oil and input prices. As a result, many farm businesses now have a system that increasingly revolves around cropping, an enterprise which when compared to a livestock enterprise, significantly relies on fuel and transport services, increasing many farmers dependency on oil prices. The increase in fuel prices has meant that there has not only been an increase in the cost of major on-farm operations, such as crop establishment and harvesting, but an increase in the cost of transporting agricultural products and inputs (e.g. grain, animals, fertilisers, etc.) by all forms of transport (e.g. road, rail, sea and air). In 2005, a Rabo Bank Rural Confidence Survey highlighted that increased fuel prices were having a large negative impact on farm businesses, with 47% of respondents nationally indicating that an increase in fuel price was negatively affecting profitability. However, not only do farmers have to deal with rising input costs, due to the increased prices and competition for oil, they are also faced with climate change and the decrease in rainfall in recent years. This reduction in rainfall has resulted in lower crop yields, highlighting the need for farmers to reduce the overall input costs.

In 2003-2004, ABARE reported that the direct cost of fuel and lubricants on Australian farms was already substantial, at around 9% of total farm costs, a figure comparable to the cost of other inputs such as fertilisers and chemicals. As the percentage of total farm costs spent on fuel and lubricants begins to rise, the export-orientated nature of most farm businesses has many farmers believing they will not be able to directly and fully pass on all increased costs of production. While alternative fuels, such as biodiesel, show some promise as substitutes for oil-based fuels, there will not be one alternative for all purposes. Efficiency of use and reduced consumption are an important part of the solution.
The use of oil-based fuels in farming practices results in the emission of carbon, methane and nitrous oxides into the atmosphere, all of which can have a detrimental effect on the environment. In terms of global emissions, modern processes in agriculture (e.g. machinery use and the increased use of fertilisers and other chemicals) are believed to be responsible for 25% of carbon dioxide, 65% of methane and 90% of nitrous oxide. Sources of carbon dioxide include burning of fossil fuels, tillage, deforestation, biomass burning and land degradation, sources of methane include rice and livestock production and sources of nitrous oxide emissions include manure, tillage and fertiliser use. However there may be the opportunity to sequester carbon in soil by altering these agricultural management practices. This may include decreased tillage and efficient use of fertilisers and irrigation which can result in a reduction of fuel use, agricultural inputs (e.g. chemicals) and the carbon emissions associated with fuel and chemical use. This will not only provide farmers with a chance to reduce their fuel use and hence reduce their costs, but also decrease their impact on the environment.

This paper presents the concept, construction and structure of the simple and easy-to-use ‘Farm Fuel Calculator’. The primary focus of the farm fuel calculator is on the fuel consumption (L/ha) specific to a farm under different management options. The calculator is built up in the form of a spreadsheet that enables the user to select various farm management options (e.g. tillage, sowing, hay production, harvesting, transport, etc.) for the crop and livestock components of a farm enterprise. The calculator will be designed to assess the internal energy usage on the farm and express it in terms of an estimated overall fuel use and cost. The calculator will provide farmers and farm advisers with important, quantitative information about the fuel use of the farm business as background to assist in decision-making. It will also contribute quantitative information to decisions about the possible use of alternative fuels, such as the on-farm production of biodiesel. The direct benefit to both producers and industry will come through the potential for decreasing the cost of production by reducing the use of fuel and lubricants below the current level of 9% of total farm costs. In addition, changes in fuel use will potentially help to reduce the environmental impact of agriculture through decreased energy inputs and hence lower greenhouse gas production.

METHOD

Concept

The ‘Farm Fuel Calculator’ has been constructed to provide farmers with an electronic estimator that enables them to calculate the amount of fuel used in both their crop and livestock enterprises. The calculator is a Microsoft Excel spreadsheet that allows users to enter general information about their farm and more specific information about their crop and livestock systems and the management options they choose. A Microsoft Excel spreadsheet was selected because of its wider availability and its familiarity to general users.

Construction

The initial workings and calculations were derived from a number of previously conducted studies. Many of the core calculations were based on work by Riethmuller in the 1980s where the effect of depth and speed on draft and estimated fuel consumption was measured. The paper also looked at the tractor power required of several tillage implements (disc plough, scarifier, combine, subsoiler and cultivator) over a range of soils. As more current measurements become available they will be included in the model.

Structure

The ‘Farm Fuel Calculator’ contains a number of worksheets, including two worksheets in which users enter information about their crop and/or pasture enterprise, two summary worksheets which detail what information the user has entered and a fuel comparison worksheet that details the fuel use per hectare and the overall fuel use and cost.

Crop and pasture worksheets

These two worksheets allow the users to add in specific information about their farm business for either the crop or livestock enterprise, or both. The ‘Crop’ worksheet asks the user to enter general information such as what crop they plan to sow, what is the clay content of the paddock, whether they use tramlines and the crop area. They are also asked information regarding pre- and post-emergent spraying, spreading, cultivation (no till, one cultivator or deep ripper), seeding (disc or tine), harvesting
(hay production, swathing or harvesting) and transport (on- and off-farm). Some of this information includes tractor power, type and speed, boom width, seeding depth, soil texture (soft, tilled or firm), harvest cut height, and straw toughness (Table 1). The ‘Pasture’ worksheet asks the user to enter similar information on pre- and post-emergent spraying, seeding and transport (on- and off-farm).

Options summary worksheets
These two worksheets, the ‘Options Summary – Crop’ and the ‘Options Summary – Pasture’ summarise the data entered by the use for each management option in the crop and livestock enterprises. For instance, in the ‘Options Summary – Pasture’ worksheet the six paddocks show the details of the management practices that are being carried out (Figure 1).

Fuel use comparison worksheet
The ‘Fuel Use Comparison’ worksheet is a concise summary of the fuel use in each farm process and a comparison of different scenarios. The worksheet also shows a comparison between the crops and pasture phases and provides an estimate of the total amount of fuel used. The total cost of fuel consumption and an estimate of the total carbon emissions as a result of the fuel use. For example, Figure 2 shows two different management practices for both the crop and pasture phase. In terms of the cropping phase, the fuel comparison worksheet shows paddock 1 is sprayed pre- and post emergent, is uncultivated and harvested, suggesting a low level of fuel consumption. On the other hand it shows that paddock 2 is also is sprayed pre- and post emergent but is cultivated and deep ripped, increasing its fuel consumption compared to paddock one. To complete the fuel use comparison section the worksheet calculates the overall fuel use and cost for the paddock, taking into account the area of the paddock and the current price of fuel. This fuel use is then converted into the amount of carbon (kg) produced from the management practices carried out in the paddock. As a result, Figure 2 shows that the total fuel use (L/ha) is more than five times higher in the crop phase Paddock 2 (48.05) than Paddock 1 (8.98). However, the total fuel use per paddock (total L/ha by area) is only twice as much (Paddock 2 = 24,026 L and Paddock 1 = 13,477 L) due to the paddock size.

CONCLUSION
As fuel and energy costs climb, pressures on farm profitability continue to increase dramatically, creating the need for a tool that provides farmers with an estimated farm fuel use and assists them in decisions regarding farm management. This calculator is designed to serve this purpose. It is now available for farmers and advisers for field testing.

KEY WORDS
farm fuel calculator, fuel consumption, profitability, management options

ACKNOWLEDGMENTS
Rural Industries Research and Development Corporation (RIRDC) for funding this research.

Project No.: DAW 122A (RIRDC)
Paper reviewed by: Dr Bill Bowden
### Types of questions asked about the cropping enterprise

<table>
<thead>
<tr>
<th>Table 1.</th>
<th>Types of questions asked about the cropping enterprise</th>
</tr>
</thead>
</table>
| **General information** | • Crop type?  
• Soil clay content?  
• Do you use tramline farming?  
• Area in crop?  |
| **Spraying (pre- and post-emergent)** | • How many sprays per season?  
• Tractor speed?  
• Boom width?  
• Tractor power?  |
| **Spreading** | • How many sprays per season?  
• Tractor speed?  
• Spreader width?  
• Tractor power?  |
| **Cultivation** | • No Till/One cultivation/Deep ripping?  
• Questions asked for both one cultivation and deep ripping:  
  • Tractor type and speed?  
  • Soil texture?  
  • Depth? |
| **Seeding** | • Type of disc/tine?  
• Questions asked for both:  
  • Tractor type and speed?  
  • Soil texture?  
  • Depth? |
| **Hay production** | • Mower type?  
• Estimated yield?  
• Tractor power?  
• Cut and crop height?  
• Straw toughness?  
• Mower conditioner, rake or baler used (tractor power/speed, baler width)?  |
| **Swathing** | • Estimated yield?  
• Tractor power?  
• Cut height?  
• Crop height?  |
| **Harvesting** | • Harvester type?  
• Estimated yield?  
• Tractor power?  
• Cut and crop height?  
• Straw toughness?  |
| **Transport** | • On-farm (car kilometres, fuel efficiency, area of farm in crop).  
• Off-farm (rail (km) and trucks (articulated/rigid)). |

### Farm fuel calculator

<table>
<thead>
<tr>
<th>Farm Processes</th>
<th>Pasture Options</th>
</tr>
</thead>
</table>
| **Paddock in use** | Yes  
Yes  
Yes  
Yes  
Yes  
No  |
| **Soil clay content** |  
6  
14  
29  
20  
6  
--  |
| **Pasture area (ha)** |  
1000  
500  
300  
100  
100  
--  |
| **Pre-em Spraying** |  
2  
1  
3  
1  
2  
--  |
| **How many per season?** |  
12  
12  
12  
12  
12  
--  |
| **Tractor speed (km/h)** |  
36  
36  
36  
36  
36  
--  |
| **Boom width (m) of sprayer** |  
100  
100  
100  
100  
100  
--  |
| **Sprayer tractor power (kW)** |  
100  
100  
100  
100  
100  
--  |
| **Post-em Spraying** |  
1  
3  
3  
1  
2  
--  |
| **How many per season?** |  
12  
12  
12  
12  
12  
--  |
| **Tractor speed (km/h)** |  
36  
36  
36  
36  
36  
--  |
| **Boom width (m) of sprayer** |  
100  
100  
100  
100  
100  
--  |
| **Sprayer tractor power (kW)** |  
100  
100  
100  
100  
100  
--  |
| **Seeding** |  
Yes  
No  
No  
Yes  
Yes  
--  |
| **Tractor speed (km/h)** |  
10  
--  
--  
10  
10  
--  |
| **Depth (mm)** |  
25  
--  
--  
25  
25  
--  |
| **Soil texture** | Firm  
--  
--  
Soft  
Soft  
--  |
| **Tractor type** | 2WD  
--  
--  
4WD  
2WD  
--  |
| **Disc Type** | No  
--  
--  
Light duty  
No  
--  |
| **Tine Type** | Full cut point  
--  
--  
Narrow point  
--  
--  |
| **Transport on farm** |  
5000  
1000  
1000  
5000  
5000  
--  |
| **Car (km) per season** |  
10  
10  
10  
12  
10  
--  |
| **Fuel efficiency (L/100Km)** |  
1000  
500  
500  
2500  
1000  
--  |

**Figure 1.** A snap shot of the ‘Options Summary – Pasture’ worksheet which summarises the information that the farmer has entered in the ‘Farm Fuel Calculator’.
<table>
<thead>
<tr>
<th>Estimated Fuel Use (L/ha)</th>
<th>Crop phase</th>
<th>Pasture phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Paddock 1</td>
<td>Paddock 2</td>
</tr>
<tr>
<td><strong>Total (L/ha)</strong></td>
<td>8.98</td>
<td>48.05</td>
</tr>
<tr>
<td>Pre-em Spraying</td>
<td>0.12</td>
<td>0.35</td>
</tr>
<tr>
<td>Post-em Spraying</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>Spreading</td>
<td>0.09</td>
<td>0.14</td>
</tr>
<tr>
<td>Cultivation</td>
<td>0.00</td>
<td>26.32</td>
</tr>
<tr>
<td>No-Till</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>One cultivation</td>
<td>0.00</td>
<td>7.65</td>
</tr>
<tr>
<td>Deep ripping</td>
<td>0.00</td>
<td>18.66</td>
</tr>
<tr>
<td>Seeding</td>
<td>1.15</td>
<td>5.47</td>
</tr>
<tr>
<td>Disc</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Tine</td>
<td>1.15</td>
<td>5.47</td>
</tr>
<tr>
<td>Hay Production</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Swathing &amp; harvesting</td>
<td>--</td>
<td>13.59</td>
</tr>
<tr>
<td>Harvesting</td>
<td>5.48</td>
<td>--</td>
</tr>
<tr>
<td>Crop/Sheep monitoring</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>Transport (off farm)</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td><strong>Total Fuel Use Per</strong></td>
<td>13,477</td>
<td>24,026</td>
</tr>
<tr>
<td>*<em>Paddock (total(L/ha)<em>area)</em></em></td>
<td>$16,576</td>
<td>$29,552</td>
</tr>
<tr>
<td><strong>Cost Per Paddock ($)</strong></td>
<td>33,691</td>
<td>60,066</td>
</tr>
<tr>
<td><strong>Carbon Emissions (kg)</strong></td>
<td>Total Fuel Use (L) 45,862</td>
<td>Total Fuel Cost $56,411</td>
</tr>
</tbody>
</table>

Figure 2. A snapshot of the ‘Fuel Comparison’ worksheet which provides the user with the estimated fuel use for each management option and paddock for both the crop and pasture phases and the total fuel use, cost and carbon emission.
Poor soil water storage and soil constraints are common in WA cropping soils

Stephen Davies, Jim Dixon, Dennis Van Gool and Alison Slade, Department of Agriculture and Food, Western Australia
Bob Gilkes, School of Earth and Geographical Sciences, University of Western Australia

KEY MESSAGES

Western Australia’s soils are highly weathered and consequently have or are prone to developing numerous physical and chemical constraints that limit root growth and plant available water resulting in reduced productivity. An understanding of the constraints present in the soil and their impact on plant available water holding capacity is essential for more efficient agronomic management.

AIMS

• Increase understanding of subsoil constraints in WA soils including prevalence of specific constraints and their association with soil types and landscapes.
• Increase awareness of subsoil constraints to enable grower recognition and management.

METHOD

From late 2004 to 2006 the ‘Managing Hostile Subsoils Western Australia’ research project has examined more than 120 soil profiles mostly with grower groups belonging to the Local Farmer Group Network and Grower Group Alliance. Soil pits were excavated and the soil profile assessed for the presence of physical and chemical constraints. Soil pH and EC were measured in the field in a 1:5 soil:water extract. Soil texture, structure, and degree of compaction, gravel content and at some sites dispersion were assessed in the field using Australian Soil and Land Survey guidelines (McDonald and Isbell 1990). For some sites samples were collected and analysed for various soil properties including the exchangeable sodium percentage and soil boron concentration. Plant available water capacity (AWC) of the soil was estimated from the texture, structure and observed rooting depth (Moore et al. 1998). Soils have been classified according to the Department of Agriculture and Food, Western Australia (DAFWA) Soil Groups of WA nomenclature (Schoknecht 2005) in a number of cases some of the individual soil groups have been combined to simplify presentation and discussion of the results. For example, the brown, red and yellow sandy earths have been combined into a single sandy earth group for presentation and discussion (Figure 1; Table 1). Where applicable the severity of constraints has been ranked according to the DAFWA Land Evaluation Standards for Land Resource Mapping guidelines (Van Gool et al. 2005). Given that the soil pits were examined in collaboration with Local Farmer Group Network grower groups it was possible for us to record grower perspectives and responses regarding the subsoil constraints they were being shown. This was done using a combination of taking notes of the interaction occurring during the soil pit workshop, workshop evaluation questions and with follow-up questionnaires.

RESULTS

Only 7% of the profiles examined were deemed to be completely free from physical and chemical subsoil constraints. Many of the soils (56%) had multiple constraints such as combinations of acidity and hardpans or alkalinity, salinity and poor subsoil structure, for example.

Plant available water holding capacity

Low to very low plant available soil water capacity (AWC < 70 mm) was the most common constraint, occurring in 53% of the profiles examined (Figure 1). There are various reasons for low AWC. Sandy textured soils, high gravel content, poor subsoil structure, shallow soils, physical hardpans or chemical constraints that restrict root growth all limit AWC. For this reason the gravel soils and sandy duplex soils tended to have poor AWC (Figure 1). Those sandy duplex soils with higher AWC had better structured subsoil clay that allowed reasonable root penetration and access to more stored water. The capacity to improve plant available water capacity in soils depends on what is causing the problem.
Some intrinsic soil properties such as coarse texture, gravel content and shallow soil depth cannot realistically be altered so crops and pastures need to be managed accordingly. High gravel contents, reducing soil volume and available water were common, affecting one third of the profiles examined (Figure 1). Other constraints that reduce water availability through restricted root growth and rooting depth including hard pans, acidic layers and in some cases poor subsoil structure can be ameliorated increasing plant available water. The sandy and loamy earths tended to have higher AWC due to a combination of increasing clay content with depth, increasing the water holding capacity of the soil and good rooting depth, with the observed rooting depth mostly being > 80 cm (data not shown).

![Estimated plant available water contents for a range of soil types based on texture, structure and crop rooting depth. Rating based on the standards defined by Van Gool et al. 2005.](image)

**Physical constraints**

27% of the soil profiles examined had poor subsoil structure with two-thirds of these being the sandy and loamy duplex soils (Table 1). However, a substantial proportion of the duplex soils had reasonably well-structured subsoils. In fact 23% of the shallow loamy duplex soils did not have any obvious subsoil constraint (Table 1) with well structured subsoils and observed rooting depths of 75 cm or more (data not shown). Massive subsoils can sometimes be disrupted using deep ripping, although the depth to which this can be economically done is limited. Research in WA has clearly shown that not all poorly structured subsoils respond positively to this type of amelioration and there is often a need to stabilise and consolidate this improved soil structure at the time of ripping using ameliorants such as gypsum and organic matter. Nearly three quarters of the sandy earth soils...
examined were compacted (Table 1). Compaction affected one-third of the deep sands and was reasonably common in the deep loamy duplexes and loamy earths. In the sandy earths compaction is commonly removed by deep ripping, often with considerable benefit (Davies et al. 2006).

Table 1. Number of pits assessed and affected by specified subsoil constraints or unconstrained for a range of soil types

<table>
<thead>
<tr>
<th>Soil group</th>
<th>No. of pits</th>
<th>High Gravel</th>
<th>Compaction</th>
<th>Poor structure</th>
<th>Acidity</th>
<th>Alkalinity</th>
<th>Salinity</th>
<th>Dispersive</th>
<th>Boron toxicity</th>
<th>Waterlogging</th>
<th>Rock &lt; 50 cm</th>
<th>Unconstrained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow gravel</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duplex sandy gravel</td>
<td>11</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep sandy gravel</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loamy gravel</td>
<td>14</td>
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<td>Calcareous loamy earth</td>
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<tr>
<td>Non-cracking clay</td>
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<td>8</td>
<td>1</td>
<td>2</td>
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</tbody>
</table>

**Chemical constraints**

Subsoil acidity was the most common chemical constraint affecting about 90% the deep sand and sandy earth soil profiles examined and nearly one-third of the all soil profiles examined (Table 1). Half of the loamy earths and deep sandy gravels were affected, by subsoil acidity and over one-third of the deep sandy duplex profiles (Table 1). Strong subsoil alkalinity was present in 27% of the soils examined, occurring mainly in the sandy and loamy duplex, loamy earth and clay soils. High subsoil salt levels were also a common constraint affecting 24% of the soil profiles and these were almost always associated with the strongly alkaline subsoils (Table 1) and sometimes with dispersive subsoils. Almost all of the saline subsoils were not associated with rising watertables (secondary salinisation) but rather were inherently high concentrations of salt in the root zone. The most common soil groups affected by root zone salinity were the calcareous loamy earths, clays and shallow sandy or loamy duplexes (Table 1). The extent of root zone salinity and impact on crop yields for soils and conditions of the WA wheatbelt is not known and is being assessed. Management is likely to involve modified agronomic practices mostly involving the use of salt tolerant crops and pastures on soils where there may be no surface expression of salinity together with surface gypsum application.

**Grower perspectives**

Over 500 farmers and 100 agribusiness personnel have attended the workshops across the State. The level of knowledge about subsoil constraints was varied. Over 60% of participants had been to soil pit workshops before and the majority were aware of subsoil constraints such as acidity and compaction. However many were unaware of how common subsoil constraints were and in particular
that you could get combinations of constraints which resulted in amelioration being complicated. Nearly all farmers at the workshops regularly tested soil with 95% only testing the topsoil. The majority of the workshops looked at both ‘high yielding’ and ‘low yielding’ soils selected by the farmers visited. The surprises were that many ‘good’ soils were found to have constraints present or were on the verge of developing induced constraints such as acidity. Many farmers felt the workshops were worthwhile and had learnt something new. Some of the farmers where constraints were found have started to look at management options such as liming and changing varieties.

CONCLUSION

While this survey of soil profiles is not representative of the extent of these constraints or soil types in the entire wheatbelt it does highlight the diversity and frequent occurrence of subsoil constraints in the WA wheatbelt. It also indicates which constraints are commonly associated with which soil types. It is important for growers and advisers to be able to understand and describe a soil accurately and then be aware of which constraints are most likely to be present and how to identify them. In particular, we have revealed that high salt levels in the root zone and low plant-available soil water storage are common constraints that are not generally recognised and managed appropriately. Examining and describing the soil and identifying subsoil constraints provides growers with a greater capacity to manage their crops and pastures appropriately, to correct problems, improve productivity and identify the most suitable land use options.

REFERENCES


KEY WORDS

subsoil, constraints, available water capacity, acidity, alkalinity, salinity, compaction, soil structure

ACKNOWLEDGMENTS

Thanks to all the growers and grower groups who supported this work and provided sites and Paul Carmody and the Local Farmer Group Network for supporting the initiative. The assistance and work of Dan Evans and Tania Liaghati (formerly UWA) and David Gartner and Ted Griffin (DAFWA) is gratefully acknowledged. Funding for this research was provided by the Grains Research and Development Corporation.

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Paper reviewed by: Jeremy Lemon
Developing potential adaptations to climate change for the low rainfall farming system using the economic analysis tool, STEP

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KEY MESSAGES

- The current low rainfall farming system may be unsustainable due to the predicted impacts of climate change on crop yields.
- Higher wheat prices and more favourable terms of trade may extend the life of the low rainfall farm.
- STEP allows alternative systems to be compared. Production thresholds that maintain the financial viability of the farm can also be identified.

AIMS

There is significant uncertainty over the impact of climate change on farm businesses. Knowledge of the nature of the impacts of climate change will facilitate planning, strategic decision-making and policy processes at a farm, regional, State and national level. Our study uses the STEP (Simulated Transitional Economic Planning) tool to: (i) examine the consequences of possible climate change effects on the productivity and profitability of the Northern Agricultural Region’s low rainfall farming system; and (ii) test the financial viability of two potential adaptations to climate change.

METHOD

The low rainfall farm – current system

A farm was constructed in STEP to represent an average farm business in the low rainfall zone (< 325 mm) of the north-eastern wheat-belt. Soil types were based on data from the Pindar-Tardun catchment (Clarke, 1995). The mixed enterprise farm comprised 60% cropping and 40% volunteer pasture, which supported a self replacing merino flock of 2042 DSE. The lambing rate was 85% for mature ewes and 75% for maiden ewes. The wool yield was 5 kg per head and 5.5 kg per head for ewes and wethers respectively. The wool price was $4.50/kg (greasy) and animals were culled at seven years.

The cropping and livestock rotations reflected the current state of local farming systems (Sandison, 2002) with yields and variable costs based on a survey of local farmers and yields being long-term averages for each soil type. Other financial data were obtained from Bankwest Benchmarks and DAFWA Gross Margins Guides. To simulate the cost-price squeeze, costs were increased at 3% per annum and returns increased at 2% per annum. A discount rate of 8% was applied to the cumulative financial position to yield the net present value (NPV) of the farm’s land use strategy. The long-term crop yields were increased by 0.5% per annum to simulate technological advances in management and breeding.

Impact of climate change

Two climate change scenarios were generated using the CSIRO-developed program ‘OzClim’. OzClim generated projected monthly rainfall and temperatures at 5-yearly intervals from 2005 to 2055 based on the (i) CSIRO Mk II or (ii) Hadley Centre (HADCM2 and HADCM3) climate models. Both climate scenarios were based on the SRES A2 emissions scenario (IPCC, 2001), which describes a medium to high level of projected greenhouse gas (GHG) emissions under a set of defined demographic and technological advances. Both scenarios were also run with a high sensitivity of climate change to GHG emissions.

Both scenarios projected an increase in minimum and maximum temperatures and a decrease in annual and growing season rainfall. The trend of climate change over the 50-year period was approximately linear.
Land use capability data and climate information were then combined with a modified French and Schultz equation (Van Gool and Vernon, 2005) to produce predicted potential crop yields. Both scenarios predicted declining yields at an average annual decline of 1.2% and 1.5% per annum for the CSIRO Mk II and Hadley scenarios respectively.

The impact of reduced yields from climate change in the north-eastern low rainfall farming system was analysed over the 50 years using the STEP model. STEP is an Excel-based spreadsheet that uses simulation to link whole farm annual financial budgets over a series of years. Its main output is the annual surplus/deficit of each year being analysed. The annual surplus/deficit is calculated as gross farm income minus expenditure (which includes 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 different climate scenarios. The role and value of adaptation strategies can also be considered in STEP.

The STEP analyses of the current low rainfall farming systems consider two possible climate change scenarios and consider average climate conditions associated with those scenarios.

**Testing adaptations to climate change using STEP**

STEP was used to test the financial viability of two adaptation strategies:

(i) Opportunistic cropping when seasonal conditions favoured above-average yields. In this system, cropping the best soil types and achieving above-average yields in 2:10 and 3:10 years was investigated.

(ii) An alliance with pastoral regions for trade cattle in combination with oil mallee alleys for carbon sequestration and opportunistic cropping. This strategy involved grazing trade cattle from pastoral regions over winter/spring, opportunistic cropping on the best soils in 1:5 years and planting oil mallee belts on the deepest soils for carbon sequestration. This system was tested with a sensitivity to three wheat prices ($165/t, $204/t and $254/t) and two weight gains per head of cattle (120 kg and 180 kg) under conditions of declining, neutral and increasing terms of trade. Two carbon prices ($10/t and $50/t CO₂ equivalent) were also tested for each wheat price scenario. Cattle were stocked at an average of 3 DSE/ha.

**RESULTS**

**Effect of climate change on the current system**

The farm, as modelled, became financially unviable under both the CSIRO Mk II and Hadley climate scenarios (Figure 1) in which annual yields declined at 1.2% and 1.5% per annum, respectively. For these scenarios, average annual deficits were consistently generated over the 50 years. In contrast, the current farming system under no projected climate change maintained an annual surplus, mainly due to the annual improvements in yield (0.5% per annum), even under declining terms of trade. The ‘no yield decline’ scenario was included as a best case scenario where yield improvements from new technology balanced out the yield decline from climate change. While the ‘no yield decline’ scenario showed an initial annual surplus, the farm’s financial position eventually went into deficit after 20 years due to the impact of declining terms of trade.

In the future, long-term average wheat prices could increase and the trend of declining terms of trade could slow or even reverse. The CSIRO Mk II climate scenario was tested for sensitivity to higher wheat prices and neutral or increasing terms of trade. Both higher wheat prices and more favourable...
terms of trade extended the financial life of the farm and increased profitability (Figure 2). For farm-gate wheat prices of $204/t and $254/t, the effect of continual declining yield (1.2% per annum) combined with declining terms of trade eventually forced the farm into cumulative deficit. Even with neutral terms of trade the farm’s financial position declined over time for the $204/t wheat scenario. Only increasing terms of trade, or a $254/t wheat price combined with neutral terms of trade, allowed the farm to maintain a positive financial position.

Figure 2. Sensitivity of the low rainfall farm’s annual surplus/deficit under the CSIRO MkII climate scenario to wheat price (a) $204/t farm-gate (b) $254/t farm-gate, and to declining, neutral and increasing terms of trade (T of T).

**Testing adaptations to climate change using STEP**

The opportunistic cropping scenario (2:10 and 3:10 years) was tested by comparing the average annual surplus or deficit of the farm over a 30 year period (in net present value terms) at two wheat prices ($204/t and $254/t farm-gate) and under declining, neutral and increasing terms of trade (Table 1). The farm was financially viable over a 30-year period if above-average crop yields were achieved in 3:10 years with the wheat price at $254/t farm-gate, or at $204/t farm-gate combined with increasing terms of trade. Where high wheat yields were possible in only 2:10 years, the farm was not financially viable at either wheat price.

<table>
<thead>
<tr>
<th>Frequency of high yields</th>
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<th>3:10 years</th>
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</thead>
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<tr>
<td>Wheat price* $/t</td>
<td>T of T ↓</td>
<td>T of T Neutral</td>
</tr>
<tr>
<td>$204</td>
<td>-$60,000</td>
<td>-$45,000</td>
</tr>
<tr>
<td>$254</td>
<td>-$36,000</td>
<td>-$21,000</td>
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Surpluses are shown in **bold**, deficits in *italics*. * Farm-gate price.

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<tr>
<th>Cattle weight gain/head</th>
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<th>180 kg</th>
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<td>Carbon returns $/t CO₂ eq</td>
<td>T of T ↓</td>
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<tr>
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<tr>
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<td>-$13,000</td>
</tr>
<tr>
<td>$50</td>
<td>$2,000</td>
<td>$20,000</td>
</tr>
</tbody>
</table>

Note: Cattle at 3 DSE/ha for 4-6 months. Pasture costs $22/ha. Surpluses are shown in **bold**, deficits in *italics*. * Farm-gate price.
The system of trade cattle in combination with oil mallee alleys for carbon sequestration and opportunistic cropping was also tested. Sensitivity of the farm’s financial position to wheat price, live weight gain of cattle, the future trend in terms of trade and carbon returns from oil mallees over 30 years is shown in Table 2.

Weight gain per head is a particularly strong driver of profit in the system. In general, at a stocking rate of 3 DSE/ha, cattle must achieve a weight gain of 180 kg/head for the farm to remain viable unless higher wheat prices can be achieved with neutral or increasing terms of trade. At the higher wheat price of $254/t, only 120 kg/head weight gain is needed, provided the terms of trade are at least neutral. The price of carbon returns has only a small influence on the profitability of the system as the oil mallees comprise only 6% of the farm area.

CONCLUSION
The predicted impact of climate change on crop yields could make the current low rainfall farming system financially unsustainable within a few decades.

The STEP tool was used to assess the financial viability of two alternatives to the current farming system. The option of opportunistic cropping has the potential to be a high risk alternative. It relies on accurate forecasting and the correct interpretation of the season, as the cropping income must be high enough to cover costs and compensate for the lack of income in intervening years. Profitability of the system requires a fine balance between an adequate frequency of cropping years, success in achieving above-average yields, securing a high wheat price and receiving favourable terms of trade.

The other option of a mixed enterprise system, involving cattle trading and growing of oil mallees, has additional risk mostly associated with (i) supply of the trade cattle and (ii) achieving the required weight gain. The pastoral cattle alliance must be flexible enough to handle the reduced demand for cattle in a cropping year. However, a mixed enterprise may be a better alternative for spreading risk. STEP analysis of the combined trade cattle/oil mallee/opportunistic cropping system resulted in identification of some of the drivers of the system and threshold values which need to be achieved to make the system successful. However, analysis of environmental and other impacts need further consideration.

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. Further exploration of alternatives for the low rainfall farm and analyses of their financial viability is needed. Such analyses will facilitate the determining of appropriate policy and research agendas for the region.

REFERENCES


KEY WORDS
climate change, low rainfall, STEP, farming system, financial viability, adaptation

ACKNOWLEDGMENTS
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Paper reviewed by: Rob Grima and Ross Kingwell

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What soil limitations affect the profitability of claying on non-wetting sandplain soils?

David Hall¹, Jeremy Lemon¹, Harvey Jones¹, Yvette Oliver² and Tania Butler¹
¹Department of Agriculture and Food, Western Australia, Esperance
²CSIRO Div Sustainable Ecology, Perth

KEY MESSAGES

• Claying non-wetting sandplain soils which have multiple limitations is profitable even in soils whose production efficiencies (actual/potential yields) are as low as 0.5.

• Inadequate incorporation of clay applied at high rates (greater than 200 t clay subsoil/ha) is often the ‘Achilles Heel’ of claying operations. Poor incorporation results in surface sealing causing low water infiltration, poor seedling emergence, root growth and crop yields.

• A minority of deep sands with low nutrient and water holding capacity can have such low production bases that claying will not be a profitable option.

• Claying to achieve 4-6% clay in the organically stained topsoil layer is sufficient to overcome non wetting. The tonnage of clay required to do this will depend on the clay per cent of the subsoil material applied. Accordingly, there is no universal application rate.

INTRODUCTION

Water repellence is a major cause of reduced crop yields on sandplain soils in WA. While considerable research has been conducted in the use of furrow sowing, surfactants and biological degradation of waxes, clay application is the only treatment which provides an instantaneous and permanent solution to water repellence in sands (Carter and Hetherington 1997, Cann 2003). As a consequence the practice of claying has been widely adopted particularly on the south coast sandplain. In the majority of cases claying has had a beneficial effect on crop yields due to improved crop emergence, weed control, erosion control and crop nutrition. However, there are instances where claying has not resulted in yield increases or the yield increases have barely been able to justify the expense of claying. Given the cost of claying is approximately $500-700/ha, it is as important to know which soil properties will influence the success of the claying operation. The circumstances where claying has been sub-economic are discussed in this paper.

METHOD

Long term claying and deep tillage trial (Dalyup)

A trial to investigate clay rates and incorporation depths was established in 1998 by WANTFA 40 km west of Esperance. The soil is classified as a grey deep sandy duplex (Fleming series) and is rated as severely non wetting (MED > 3). The trial consisted of five clay rates (0, 50, 100, 200 and 300 t clay subsoil/ha) and two incorporation depths (shallow 0-7 and deep 0-15 cm) replicated three times in a randomised block design. The topsoil clay percentages for the 0, 200 and 300 t/ha treatments were 0.5, 4 and 7% respectively. Prior to the 2005 cropping season the shallow incorporation treatments were deep ripped to 45 cm using an ‘Agroplow’ with tynes spaced at 50 cm intervals. Crop growth and grain yields, soil strength (cone index) and soil chemical properties (pH, Organic Carbon, Cation Exchange, N, P, K, S) were measured in each treatment. The profitability of the treatments were assessed using discounted cash flows (7% interest rate) from inception to the completion of the experiment in 2007.

Investigations where clayed paddocks have not resulted in yield increases (Neridup)

Two paddocks on different properties where claying was perceived by the farmer to have failed were investigated. Both paddocks were located less than 30 km north east of Esperance within the Neridup catchment on deep sands (> 1 m). The paddocks had been clayed during the wet summers of 1999 and 2000 by the same contractor using carry grader equipment. At Site 1 only half the paddock had been clayed enabling a comparison to be made between the clayed and unclayed areas. At Site 2, clay had been applied to the whole paddock at a nominal rate of 300+ t clay subsoil/ha. Soil pits were
excavated within low and higher producing areas of the clayed paddock. Crop growth and grain yields, water storage, soil strength (cone index) and soil chemical properties (pH, Organic Carbon, Cation Exchange, N,P,K,S) were measured within each area. Soil pits were excavated at each site and root depth measured.

At both the Dalyup and Neridup sites water limited potential yields were estimated using APSIM and/or PyCal. This was done to assess how close the sites were to their growth and yield potential and determine the size of the gap between actual and potential yields.

RESULTS

Claying on marginal sandplain soils

Higher clay rates (200, 300 t/ha) at the Dalyup site significantly increased crop yields by 65% (range 40-90%) over the four years 2004-2007 (Figure 1). There were no significant differences in any years between the 200 and 300 t/ha clay rates. Ripping to 45 cm further increased yields by 18% (range 15-20%) for the 2005-2007 seasons. The improved yields are attributed to increased plant emergence and nutrient supply, in particular potassium. This is consistent with previous research findings (Carter and Hetherington 1997).

Analysis of the Dalyup soils show that non-wetting, although a key limitation, is one of many soil limitations to crop production. Soil properties which affect nutrient availability, retention and supply including cation exchange (1-2 cmol+/100 g), organic carbon (0.8-0.9%), plant available water (60 mm/m) and soil pHCaCl₂ 4.1-5.1) are inherently low at this site. Furthermore soil strength (Cone Index at field capacity) exceeds 4 MPa at depths greater than 0.4 m. Restrictions to root growth were evident in 2006 given that lupins growing over a fibre optic cable, laid to a depth of 1 m in 1995, had double the growth compared to neighbouring untreated areas.
During the first five years of the experiment the discounted net returns (Figure 2) for the clayed treatments were not as profitable as the control treatment (0 t clay subsoil/ha). Eight years after applying the clay the 200 and 300 t/ha treatments were found to be more profitable than the control. Cumulative net returns for the high clay treatments were $100-150/ha more profitable than the control. The benefit:cost ratios for the 50, 100, 200 and 300 t/ha treatments were 0.45, 0.79, 1.42 and 1.24 respectively after eight years.

**Figure 2.** Cumulative discounted returns for the clay treatments relative to the control. Dalyup 1999-2007.

**Claying issues – Site 1 (Incomplete clay incorporation)**

Poor clay incorporation has been implicated as a cause of yield reductions associated with claying on several properties on the south coast sandplain. At one site within the Neridup catchment, canola yields in 2007 were 2 t/ha in the unclayed section compared to 1.3 t/ha within the clayed. Yield potential for the site was 2.5 t/ha. Hence, the production efficiencies for the clayed and unclayed sites were 0.5 and 0.8 respectively.

The bulk density at the surface of the clayed site was considerably higher than the unclayed area (Figure 3a). As a result of the higher bulk density, soil water infiltration would appear to be lower resulting in soil water storage in the clayed sites being substantially lower than those on the unclayed site (Figure 3b). Due to the lower soil water content soil strength was higher (Figure 3c). Canola root growth was restricted to the top 15-20 cm in the clayed area compared to 85 cm in the unclayed. Soil water, bulk density and root growth data suggests that rainfall was restricted from infiltrating through the clay surface layer. The lack of root growth is consistent with farmer observations over several years that the clayed areas ‘hayed off’ earlier than the unclayed.

**Figure 3.** (a) Bulk density. (b) Volumetric soil water contents; and (c) Corresponding soil strength (Cone Index) values for the clayed and unclayed sites. December 2007.

**Claying issues – Site 2 (Low nutrient and water retention)**

At the second clayed site most of the paddock yielded less than half the water limited yield potential for the 2005-2007 cropping seasons. ‘Good’ and ‘Poor’ areas of the paddock, as identified from yield maps, achieved production efficiencies (actual/potential yields) of approximately 0.7 and 0.2 respectively for the three years. The whole paddock production efficiency in 2007 was 0.3. The farmer’s conclusion is that claying has not been profitable at this site.
Preliminary soil testing of ‘Good’ and ‘Poor’ areas (Table 1) implicate low; Organic Carbon levels (< 0.6% OC), plant available water (< 40 mm/m), root depths (< 20 cm) and high surface density (> 1.5 g/cm³) as the main causes of reduced crop production. In both the ‘Good and ‘Poor’ areas soil pH$_{\text{CaCl}_2}$ is low (range 4.1-4.4) with exchangeable aluminium$_{\text{CaCl}_2}$ levels ranging from 2-7 ppm.

Table 1. Soil properties including organic carbon (OC), cation exchange capacity (CEC), surface (0-5 cm) bulk density (BD), plant available water (PAW) and root depth for ‘Good and ‘Poor’ production areas. All values were measured in April 2007 apart from root depth which was measured in December 2007

<table>
<thead>
<tr>
<th>Site</th>
<th>OC %</th>
<th>CEC me/100 g</th>
<th>BD Mg m⁻³</th>
<th>PAW mm/m</th>
<th>Root depth cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>0.95</td>
<td>2.28</td>
<td>1.34</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>Poor</td>
<td>0.5</td>
<td>1.26</td>
<td>1.5</td>
<td>36</td>
<td>15</td>
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</table>

CONCLUSIONS

Considerable increases in crop yields have been achieved on sandplain soils from claying, however where there are multiple soil limitations to crop growth the resultant yields can be considerably lower than the rainfall limited yield potential. This study has shown that claying remains a profitable option for severely non-wetting soils which have multiple limitations and which are achieving approximately 50% of their yield potential. In this instance, the period of time required to become profitable was five years while the increase in profitability was $150-200/ha eight years after claying. Where crops achieve less than 50% of their yield potential there will be a point where claying is no longer viable. Deep acid sands which have low nutrient and water holding capacity fall into this category. Inadequate incorporation of clay, particularly when applied at high rates (> 200 t clay subsoil/ha) can lead to surface sealing, poor water infiltration and storage and stunted root growth. In this and other studies the optimal clay rate to mitigate non-wetting was 4-6% clay within the organically stained topsoil layer. As the clay per cent of the material applied can vary from 20-70% clay the tonnage of clay subsoil needs to be altered accordingly to prevent too much or too little clay being applied.

KEY WORDS

soil management, non-wetting, claying, economics, sandplain, clay rates

ACKNOWLEDGMENTS

This project was funded by GRDC (DAW93) and the LWRDC/GRDC Healthy Soil Project. We would like to thank the farmers involved in this project for providing their most challenging paddocks for this research.

Project No.: GRDC DAW93
Paper reviewed by: Jeremy Lemon
Farming systems adapting to a variable climate: Two case studies

Kari-Lee Falconer, Department of Agriculture and Food, Western Australia, Moora

KEY MESSAGES
The management and effective utilisation of soil moisture can be a risk management focus in both the mixed Crop and livestock and Crop farming systems.

AIMS
To capture examples of growers in the low rainfall Northern Agricultural Region of WA using alternative risk management strategies to manage seasonal variability.

METHOD
Two farmers in the low rainfall area north of Dalwallinu were interviewed at the completion of harvest in 2007. Their approach to managing production risks during a drought was studied. Two different farming systems were examined; a mixed crop and livestock system and a predominantly crop system. Both farmers have made recent changes to their farming systems. The key management strategies used to manage production risk are highlighted for each of the different farming systems.

RESULTS

System 1 – The flexible farming system – no set rotations with crop and livestock

This low rainfall farming system with no set paddock rotations has been designed through farmer experience to capitalise on late summer and early autumn rains. This provides flexibility for both the cropping and sheep enterprises to better manage the seasons. Flexibility in the farming system has been developed through a pasture management strategy which takes advantage of summer thunderstorms providing rain to produce early sheep feed. With the advent of an early May break of season the pasture management strategy provides an opportunity to increase the crop and wheat program area which is the key profit driver of the system.

Why it changed?
The property’s historical rainfall records showed the farmer that good summer rains provided stored subsoil moisture and this resulted in good growing seasons in most years. In 2000 the property received 97 mm of rain in January which was followed by another 193 mm of rain in March. With the opportunity of the early rains, 1600 ha of pasture was sown in March that year resulting in productive pastures on the property with the Cadiz serradella averaging 1 t/ha of harvestable seed. The break of season was late in mid-June in 2000. Previous observations of summer moisture followed by a late break were that it provided a surplus of summer weeds which drained moisture, resulting in little value to following winter crops. However, this type of season start could be utilised for better stock feed by sowing pastures.

Key features of the new farming system
Flexibility in the farming system is achieved by dry sowing pasture mixes at the end of March each year and maximising the potential use of early rainfall. Early rains allow these pastures to establish faster than volunteer annuals providing valuable stock feed in the traditional autumn feed gap. The oats and Cadiz pasture mixes are sown at different ratios between paddocks with a high ratio of oats providing stock access to quick early feed. The stocking rates on the pasture paddocks during this traditional autumn feed gap are then increased above expected normal grazing pressures. In seasons with summer rains and early May breaks this strategy provides the opportunity for more paddocks to be cropped to wheat than normal.

It is the heavier soil types which cover a third of the property that are added to the cropping program in these types of season starts which require at least average rains to provide significant profit. The key to this system is the availability and early establishment of good pastures in favourable seasons. The cropping program is dependant on early rains and has a sowing decision trigger point on 24 May.
developed from the farms historical rainfall records dating back to 1929. Beyond the trigger point and without stored soil moisture the production risk is managed by dropping these soil types from the cropping program leaving only the lighter soil types to be cropped. The production risk for the livestock enterprise is also reduced by increasing the number of pasture paddocks available and lowering the property’s effective winter grazing pressure.

**The new system in action**

In 2006 the farm received about 50 mm in mid January through thunderstorms and then rainfall again in early April. This provided enough moisture to germinate the dry sown pastures. The pasture system worked very well in 2006 with sown pasture offering approximately nine times greater grazing value than the annual volunteers. This significantly reduced the supplementary feeding requirements and associated costs.

Extra bonuses of sowing legume pastures on early Autumn rains also increases the amount of residual nitrogen produced and the ability to split lambing times on the property to capture market opportunities. In 2000 the nitrogen benefit of the Cadiz pasture planted was calculated at about 200 kg/ha nitrogen which can set up paddocks for a number of seasons, although this can be significantly less in drier seasons.

**The future**

What has worked particularly well on the property over in the last five seasons has been the split mating and autumn lambing made available with the new opportunity of early season feed. The farmer plans to continue developing this flexible farming system and playing the season as it comes.

“If we get these wet summers you really need to actually do something. I think by being flexible it should be more productive… we just have to play every year as it comes.”

**Case Study 2 – Utilising moisture conservation technology in the cropping program**

This low rainfall cropping system is designed to conserve both summer rainfall and moisture during the season. It uses no till and nutrient management to conserve moisture to continue cropping through dry seasons. Chemical fallows are a key component of the system together with a sowing strategy to decrease early biomass and competition to conserve moisture in crops. In 2007 the whole cropping program which included wheat, barley, lupins and oats was dry sown relying on the property’s moisture conservation program.

**Why it changed?**

The development in the farming system has been gradual and deliberate since the initial discovery of the benefits of a no-tillage system over 10 years ago. Another change to the farming system began after observing the benefits in improved soil structure and water infiltration when stock were removed from a number of paddocks. Over four to five years the exclusion of livestock from paddocks was implemented across the property which virtually became livestock free.

**Key features of the new farming system**

With the combined introduction of a no-tillage system and the removal of livestock the property’s soil structure improved. During this period liming was also an important component to the development of the system as it provided crop roots with access to stored subsoil moisture by reducing acidic subsoil constraints and the main property now has 10 year liming history.

The major focus of the farming system is the storage and retention of moisture in the soil and with up to 70% of the arable land in crop this begins in the fallow phase of the rotation. Moisture is conserved in the soil by spraying paddocks soon after seeding to prevent a large biomass growth of weeds which would use valuable stores of water. The benefits of the chemical fallows were seen on farm in 2006 when a neighbouring wheat on wheat paddock yielded 0.9 t/ha less than the fallowed paddock. Chemical fallows however will not prevent wind erosion events and so a cover crop of Saia oats has recently been introduced to the system.

Oats were chosen as the cover crop because of their ability to produce a large biomass early in the season converting moisture into dry matter more efficiently. Cover crops are dry sown early in April and then sprayed out by July so that August-September rainfall can be conserved. The farmer’s
theory is that with enough biomass, cover crops will lower the ground temperatures and save further moisture loss by lowering evaporation. If evaporation is reduced by lower soil temperatures then only a small amount of moisture will evaporate from the surface leaving more moisture closer to the surface which could help with crop establishment at seeding.

To conserve moisture during the cropping phase the crops are sown with knife points. Wheat seeding rates have been reduced from 70 kg/ha to 40 kg/ha with the aim to decrease early biomass and lessen plant competition for moisture (Blackwell et al. Crop Updates 2006). Early biomass growth of cereal crops and excess moisture use is also managed by deferring nitrogen applications until four weeks after seeding. Only a minimal amount of nitrogen is applied at seeding to discourage excess biomass growth in the crops providing the soil nitrogen levels are sufficient.

There is a mix of soil types on the main property but predominantly sandy loam with gravel beneath. The northern block farm is mainly wodjil soil but has a mixture of good and bad soil types.

Did the farming system pay off in 2007?
In financial terms the gamble to dry sow the whole cropping program did not pay off in 2007. The northern property yielded between 0.1-0.2 t/ha while the southern property yielded 0.6 t/ha. To a large degree financial failure was also a reflection on the extra investment in land improvements made on the newer northern property during the year. The soils on the northern property were very compacted and so a cropping program with cultivation, lime and fertiliser was deemed necessary to continue repairing the soil structure and improve the lands soil water storage capacity. The improvements would be made again if the 2007 year was repeated.

“Everything is going for the [northern] property at this minute to put a crop in for next year and for that crop to yield well. If the property wasn’t worked [in 2007] and a major thunderstorm activity occurred there would be major water erosion so I am glad I did it.”

The future
The farmer plans to widen row spacing to 300 mm and to move from knife points to discs. With GPS guidance and auto-steer already in use the next step will be to look at variable-rate application for nutrients.

CONCLUSION
Both farms have gone through recent changes to their farming systems in order to be better equipped to manage seasonal variability and make the most of their opportunities in the wet seasons. They have also both focused on the management of soil moisture as the key feature in their risk management programs. The next step in the analysis would be to look at the financial impact of these alternative farming systems compared to district practice. What the case studies do show is that despite a run of dry seasons these low rainfall farmers still have confidence and belief that their farming systems are managing seasonal variability.

KEY WORDS
soil moisture management, low rainfall farming systems, production risk management, seasonal variability

REFERENCES

ACKNOWLEDGMENTS
The two farmers interviewed for these case studies
Project No.: 05N114-01, Northern Agricultural Catchment Council (NACC). National Action Plan.
Paper reviewed by: Rob Grima and Sandra Prosser
Importance of accounting for variation in crop yield potential when making fertiliser decisions

Michael Robertson and Yvette Oliver, CSIRO Sustainable Ecosystems, Floreat

KEY MESSAGES
- Taking account of variation in crop yield potential due to season and soil type when formulating fertiliser rates can increase profit and reduce nutrient excesses.
- Improved estimates of yield potential can increase gross margins by $2-40/ha over ‘farming-for-the-average’, with greater increases on soils with lower PAWC at drier locations.
- The gains to be made by accounting for soil type differences are similar to those that can be made by accounting for seasonal differences, given the difficulty of knowing yield potential with any accuracy at the time a fertiliser decision is typically made. Equal emphasis should be made on both effects when formulating an estimate of yield potential.
- The potential gains described here are worth chasing given rising input costs and greater seasonal variability.

AIMS
With rising fertiliser costs there is a need to be more targeted about the rates of fertiliser application. One way to do this is to pay greater attention to variation in crop needs for nutrients, as influenced by yield potential. Yield potential is the chief determinant of crop nutrient requirements and it varies with season and soil type. Despite this, there is little information available on the gains in profitability that can be made by accounting for the influences of soil type and season on yield potential when making fertiliser decisions. Fertiliser decision support systems (such as NuLogic) attempt to account for yield potential. However, there is little known about the need for an accurate estimate of yield potential, and the relative importance of accounting for the influences of soil type and seasonal conditions. This paper addresses the issue “How important is it to account for yield potential when deciding on fertiliser rates for wheat, versus just using a farming-to-the-average approach?”

METHOD
We used simulated estimates of wheat yield potential generated by APSIM from the last 30 seasons at locations in the central wheatbelt (Kellerberrin) and northern agricultural region (Mingenew), run over a wide range of soil types from each district.

The economically optimum rates of nitrogen (N), phosphate (P) and potash (K) for each simulated yield potential were calculated using standard nutrient response curves after taking into account grain and fertiliser prices. This management strategy effectively assumes ‘perfect knowledge’ of the season and soil type and matches the fertiliser strategy to this season and soil type. This level of season and soil type knowledge is unattainable and this fertiliser strategy was compared to five other more realistic strategies that could be implemented by farmers. These include:

1. Using a long-term district estimate of yield potential, with appropriate weightings for the area of soils in the Kellerberrin and Mingenew cases.
2. Accounting for soil type differences only. This means using a long-term estimate of yield potential for each soil type on their farm, but without accounting for seasonal variation.
3. Accounting for season-to-season differences but ignoring soil type differences. This means using a long-term district-averaged estimate of yield potential and varying this each season.
4. Imprecise estimates of soil and seasonal knowledge. As for scenario 3 but instead of precise estimates of yield potential, use ones that are rounded to the nearest 500 kg/ha.
5. Soil knowledge, categorical seasonal knowledge. As for scenario 3 but instead of precise estimates of yield potential in each season, they were assigned a yield based on the type of season (above, below, average season). In this strategy, P and K were applied at sowing using the long-term seasonal average yield potential for a particular soil, but N was applied later in the season when it was possible to accurately categorise the yield potential into below average, average and above-average yield, because some of the season had already elapsed.
RESULTS AND DISCUSSION

The results, summarised in Table 1, highlight the following points:

1. If one has full knowledge of the crop’s yield potential at the start of the season so that NPK can be applied at the economically-optimum rates, this results in the long-term gains $6-20/ha over the approach of fertilising for the long-term average yield (see row 1 in Table 1). This represents the maximum that can be gained by knowing yield potential.

2. The gains are greater at the drier Kellerberrin situation compared to the wetter and more reliable Mingenew location. The largest gains in accounting for seasonal and soil type influences on yield potential were found on the poorer soils at both locations. This occurs because poorer soils are on the responsive section of the relationship between soil type and yield potential and hence stand to gain from fertiliser management that accounts for their lower yield potential relative to the mean of all soil types in the catchment. Better soil types (> 60 mm PAWC) have similar long-term yield potentials and hence stand to gain less by differentiation of their yield potential.

3. About half of the potential benefit could be attributed to varying N in relation to yield potential and, by inference, half to P and K (compare rows 1 and 2).

4. Less accurate estimates of variation in yield potential due to season (rounded to nearest 500 kg/ha) don’t result in less benefit that accurate ones (compares rows 1 and 5), showing that highly refined estimates of yield do not necessarily deliver greater benefits that less accurate ones.

5. Accounting for seasonal variation was more important than accounting for soil type (compare rows 3 and 4), providing one-half to two-thirds of the benefit of perfect knowledge. However, we all know that forecasting yield potential as a function of season at the time when fertiliser rates are being decided is impossible. Using the categorical forecast of yield potential, the gains are about half of what is potentially possible (compare rows 1 and 6). This places the realisable profit gains from accounting for season onto a similar level with that realisable from accounting for soil type effects.

6. Accounting for soil-type specific effects on yield potential compared to the district average (row 4) and ignoring seasonal variation will deliver benefits only on the poorer soils. For soils with PAWC greater than 60 mm there seems to be little to be gained (< $3/ha) in differentiating between soils in their yield potential.

7. The situations where profit gains are greatest by accounting for yield potential are also those where nutrient excess, and hence potential environmental damage, is likely to be minimised (results not shown).

Table 1. Gains in wheat gross margin ($/ha) due to better fertiliser decisions based on taking account, by varying degrees, the effect on crop yield potential of soil type and seasonal variation. Kellerberrin and Mingenew are compared as representative of low-medium and medium rainfall locations, respectively. Soils are grouped according to their PAWC (mm)

<table>
<thead>
<tr>
<th></th>
<th>Kellerberrin</th>
<th>Mingenew</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soils &lt; 60 mm</td>
<td>Soils &gt; 60 mm</td>
</tr>
<tr>
<td>1 Account for soil type and season ('perfect knowledge').</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>2 Account for soil type and season but adjust N only and not P and K.</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>3 Account for season only and use district average soil type.</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>4 Account for soil type and use long term season average.</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>5 Account for soil type and season to nearest 500 kg/ha.</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>6 Account for soil type and season by its categorisation of below, at or above-average yield.</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>
CONCLUSIONS

With fertiliser costs increasing, it must be used more efficiently as it is usually the single biggest variable cost for most grain growers. Many growers implicitly account for variation in yield potential when making fertiliser decisions. The figures presented in this paper show there are gains to be made where better fertiliser decisions coming from more refined estimates of crop yield potential. Particular attention should be paid in the drier locations of the wheatbelt and on poorer soils as these have most to gain by not using the ‘farming-for-the-average’ approach. The results also highlight that the gains to be made by accounting for soil type differences are similar to those that can be made by accounting for seasonal differences, given the difficulty of knowing yield potential with any accuracy at the time a fertiliser decision is typically made. Equal emphasis should be made on both effects when formulating an estimate of yield potential. Finally, highly refined estimates of yield potential do not provide necessarily better profit gains because of the flatness of the profit-fertiliser response curve.

KEY WORDS

fertiliser, yield potential, soil type, economics, precision agriculture

ACKNOWLEDGMENTS

Peter Stone, Bill Bowden, Roger Lawes, and Fulco Ludwig made valuable contributions to the thinking behind this paper. The work was funded by GRDC and CSIRO.

Project No.: GRDC (CSA0007)
Paper reviewed by: Roger Lawes
Soil acidity is a widespread problem across the Avon River Basin

Stephen Carr¹, Chris Gazey², David York¹ and Joel Andrew¹
¹Precision SoilTech
²Department of Agriculture and Food, Western Australia

KEY MESSAGES

• Ongoing acidification of agricultural soils in Australia is a key limitation to sustainable crop and pasture production.
• In the WA wheatbelt, particularly in the Avon River Basin, soil acidity is a widespread problem with 80% of topsoil samples and 45% of 10-20 cm subsurface soil samples collected in the project falling below the targets of pH(CaCl₂) 5.5 and 4.8 respectively.
• Effective management of soil acidity is enhanced by sampling the soil profile (0-10, 10-20 and 20-30 cm) and testing soil pH on a regular basis (see also Andrew et al. these Proceedings).
• To lift soil pH into the optimal range to maximise farm profits, lime use must increase.

AIMS

Our aims have been to:
• assess the current pH status of soils in the Avon River Basin;
• promote the value of soil testing and monitoring soil pH changes over time;
• promote the use of lime to ameliorate acid soils and treat on-going acidification;
• encourage growers to maintain topsoil pH above 5.5 and subsurface soil above 4.8.

METHOD

Precision SoilTech provides a contract soil sampling service with 11 regionally based contractors across WA. This contract team has sampled in excess of 100,000 sites across WA over the past 10 seasons. To determine the current pH status of soils in the Avon River Basin, data from more than 12,000 soil profiles collected over the past two seasons has been collated and is reported in this paper.

A subsidy provided by the Avon Catchment Council Soil Acidity Project to pay for subsurface soil sample collection and pH measurement was provided to growers using Precision SoilTech contractors to collect topsoil samples for routine fertility measurements. This subsidy was provided to address the key aims of:
• determining the current pH status of sub-surface soils;
• altering grower practice by increasing awareness of the prevalence of low subsurface soil pH;
• verifying the need for higher rates of lime application to ameliorate subsurface acidity.

RESULTS AND DISCUSSION

The subsidised sampling has been well regarded by growers throughout the Avon River Basin. In the sampling season prior to the Avon Catchment Council Soil Acidity Project subsidy (2005), growers in the Avon River Basin using Precision SoilTech had approximately one-third of their topsoil sample sites also sampled for midsoil (10-20 cm) pH, and only 2% sampled for subsoil (20-30 cm) pH (Table 1).

The impact of the subsidy has been striking. In the two years with subsidised subsurface sample collection and pH measurement (the subsidy is continuing this season) three-quarters of all sites from which topsoils were collected had 10-20 cm samples collected and pH measured and almost half of all
sites also had the 20-30 cm depth sampled and pH measured (Table 1). Feedback from many growers suggests they are aware that subsurface acidity is a constraint, and the subsidised sampling enabled them to examine their own soils. This proportion of top, mid and subsoil samples is desirable as it maximises the level of information gained. Not all sites in a paddock require mid and sub soil samples because the pH in these layers is often less variable than it is for topsoil samples.

Table 1. Impact of Avon Catchment Council Soil Acidity Project subsidised subsurface soil sampling on the number of mid and subsoil samples collected since commencement of the project in 2006

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>Pre-project year (2005)</th>
<th>During project to date (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topsoil (0-10 cm)</td>
<td>100</td>
<td>100 (12200)</td>
</tr>
<tr>
<td>Midsoil (10-20 cm)</td>
<td>36</td>
<td>75 (9150)</td>
</tr>
<tr>
<td>Subsoil (20-30 cm)</td>
<td>2</td>
<td>40 (4870)</td>
</tr>
</tbody>
</table>

Topsoil acidity is widespread in the Avon River Basin, with 80% of sites sampled in 2006 and 2007 below the target of 5.5. The severity of subsurface acidity is also significant; over 45% of 10-20 cm subsurface samples in the Avon River Basin are also below the target pH 4.8. The widespread soil acidity problem is concerning, and implies inadequate lime is being applied. We are confident our data is an accurate representation of the current situation because our sample size (> 12,000 sites) is large, the frequency distribution of the soil pH measured is typical and normally distributed (Figure 1) and samples have been widely distributed across the Avon River Basin (Figure 2).

Figure 1. Soil pH distribution of topsoil (0-10 cm), midsoil (10-20 cm) and subsoil (20-30 cm) for samples collected in 2006 and 2007 as part of the Avon Catchment Council Soil Acidity Project soil sampling subsidy.
Given the extent and severity of soil acidity identified in this project, we suggest that many soils will require the immediate application of 2 t/ha of lime to lift the soil pH into the target range. This rate is based on comprehensive field data from Department of Agriculture and Food, Western Australia lime trials over the past 25 years. Although higher than the 1 t/ha recommended during the mid 1990s Time to Lime campaign, it is necessary given the acidification that has occurred since the ‘Time to Lime’ campaign. In much of the WA wheatbelt lime is commonly applied at 1 t/ha. The comprehensive survey data collected with the Avon Catchment Council subsidy confirms that this rate is not adequate, and hence there is a continuing decline in soil pH, particularly the subsurface layers. Treating subsurface acidity first requires adequate lime to increase the topsoil pH to above 5.5, and then further application of lime to move down and treat the subsurface layers. Subsequent pH testing after three to four years will also be necessary to monitor progress.
CONCLUSION

Soil acidity is a widespread problem throughout the Avon River Basin. There is a very high proportion of soils with both topsoil (pH > 5.5) and subsurface soil (pH > 4.8) well below the targets defined for optimal production and farm profit. Monitoring soil pH down the soil profile is the key to any liming program. Understanding subsurface soil pH enables better targeting of ongoing liming requirements.

Lime use needs to increase dramatically to achieve target soil pH. Whilst many growers in the Avon River Basin are applying lime, the rate and frequency of application are not adequate to counter ongoing acidification. Recent agronomic advances, the increased use of fertiliser nitrogen and the poor buffering capacity of WA soils are resulting in accelerated acidification.

The key challenge into the future is to encourage growers to continue sampling to depth and monitor pH every 3 to 4 years in order to adjust and improve liming programs.

KEY WORDS
subsurface acidity, pH measurement, monitoring soil condition, lime use

ACKNOWLEDGMENTS

Funding for this program has been provided by the Avon Catchment Council with investment from the Western Australian and Australian Governments through the National Action Plan for Salinity and Water Quality and from Precision SoilTech who developed the sampling methodology.

Project No.: SI002 04A1-08 Avon Catchment Council Soil Acidity Project
Paper reviewed by: Wayne Pluske, Nutrient Management Systems
The use of soil testing kits and ion-selective electrodes for the analysis of plant available nutrients in Western Australian Soils

Michael Simeoni and Bob Gilkes
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KEY MESSAGES
• Simple soil testing kits have little or no potential for use in testing nutrient levels in Western Australian soils.
• Ion selective electrodes, used in combination with the correct extraction procedures, offer potential as rapid, easy methods for analysing plant available nitrogen and potassium.

AIMS
Representative soil sampling and analysis are important in understanding variations in fertiliser requirements at a paddock scale. However, farmers generally submit a limited number of soil samples for analysis since more intensive soil testing regimes are limited by cost. Simple, economical alternatives to laboratory analysis to enable rapid testing of soils are available but their accuracy and reliability on Western Australian soils has yet to be tested.

In this project, we assessed the potential of commercially available soil test kits and nitrate and potassium ion selective electrodes (ISEs) as rapid soil testing methods that farmers/consultants could use to accurately determine plant available nitrogen (PAN), phosphorus (PAP) and potassium (PAK) in soil.

METHODS
For this trial seven soil test kits (details in Table 1) were assessed for PAN, PAP and PAK. All tests are based on a visual comparison of a coloured extract to a chart to determine soil nutrient concentration. In addition two ISEs, manufactured by Horiba were chosen, one for nitrate and one for potassium. The ISEs were selected because of compact design and simplicity of use. No phosphate ISEs are currently available.

Table 1. Details of the soil tests methods trialled

<table>
<thead>
<tr>
<th>Soil test kits</th>
<th>Ion selective electrodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accugrow Soil Test Strips (ETS, Hach)</td>
<td>Cardy nitrate ion selective electrode (Horiba)</td>
</tr>
<tr>
<td>Hach Test Strips (Hach)</td>
<td>Cardy potassium ion selective electrode (Horiba)</td>
</tr>
<tr>
<td>Hanna Test Kit, HI3896 (Hanna Instruments)</td>
<td></td>
</tr>
<tr>
<td>Lamotte Soil Kit Model EM (Lamotte Company)</td>
<td></td>
</tr>
<tr>
<td>Merck Test Strips (Merck)</td>
<td></td>
</tr>
<tr>
<td>Rapitest Soil Test Kit, (Leaf Luster)</td>
<td></td>
</tr>
<tr>
<td>Westminster Soil Test Kit (West Meters Ltd, UK)</td>
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</tr>
</tbody>
</table>

Forty four soils from across the Western Australian wheatbelt were selected for the trial. The soil test kits were performed in accordance to the manufacturer’s instructions. Test methods for the ion selective electrodes were derived through the screening of a range of extractants, soil to extractant ratios and extractant times to determine the optimum conditions for use. Based on these trials, an
optimal extraction method for the nitrate and potassium ion selective electrodes was determined. In both cases this involved the extract of soil at a soil:extractant ratio of one to two for a period of one minute, followed by about five minutes settling time before analysis. The selected extractant for nitrate was a 0.1 M solution of sodium acetate and acetic acid (pH 4.6), whilst for potassium a 1.5 M BaCl₂ extractant was selected. The results for all rapid tests were compared to the analysis of the soils using the recognised Australian standard methods performed either commercially or in-house.

RESULTS AND DISCUSSION

Soil testing kits

The soil test kits were simple to use and with costs ranging per test of between $0.50 and $1.80, inexpensive by comparison to laboratory analysis. For each soil test kit the accuracy was determined by converting the laboratory results into equivalent test kit colour, and then comparing that colour to the results of the trials. If the colours were the same the test kit was considered accurate. If the test kit result was above or below the colour designated by the laboratory result, then it was deemed an overestimate or underestimate accordingly. A summary of these results is provided in Table 2. The Accugrow, Merck and Westminster test kit strips showed some potential for determining PAN, whilst Lamotte and Hanna performed adequately in a comparison of PAP to Colwell and Olsen laboratory analyses. None of the kits would be considered useful for determining PAK in Western Australian soils as they are quite insensitive.

Table 2. Accuracy of test kits for N, P, K in soils expressed as a percentage of the 44 soils analysed

<table>
<thead>
<tr>
<th></th>
<th>Accugrow</th>
<th>Hach</th>
<th>Hanna</th>
<th>Lamotte</th>
<th>Merck</th>
<th>Rapitest</th>
<th>Westminster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant available Nitrogen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accurate</td>
<td>80</td>
<td>53</td>
<td>53</td>
<td>20</td>
<td>60</td>
<td>53</td>
<td>73</td>
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<tr>
<td>Overestimated</td>
<td>13</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>27</td>
<td>47</td>
<td>13</td>
</tr>
<tr>
<td>Underestimated</td>
<td>7</td>
<td>47</td>
<td>40</td>
<td>80</td>
<td>13</td>
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Overall none of the soil test kits proved adequate for analysis of all three nutrients for following reasons:

- People interpreted colours differently making consistent interpretation of results difficult to achieve.
- The cloudiness or colour of the soil extract often affected interpretation.
- The stepwise nature of colour charts (one must choose one colour or another), means that there are only a limited numbers of soil nutrient levels to choose. Often there are only three colours to choose from which again reduced the precision of the tests.
- A number of the test kits were not designed to test for the low nutrient levels that are common in Western Australian soils particularly for K.
Numerous attempts to improve the soil test kit results by using different extractants or changing soil to extractant ratios did little to improve overall results.

**Ion selective electrodes**
The ion selective electrodes retail for less than $600 and require only a very simple calibration to prepare them for use.

A comparison of the PAN in the soils (NO$_3$-N) as determined by laboratory methods and ISE results (Figure 1) showed adequate sensitivity and a good relationship between the two methods ($R^2 = 0.83$). The plant available nitrogen content of soils selected for this trial was low (less than 25 mg/kg NO$_3$-N) and based on the data collected it should be possible to determine plant available nitrogen using ISE with an error of ± 3 mg/kg. Critical concentrations of nitrogen for optimum growth of wheat as summarised by Peverill *et al.* (2005) range from 20-45 mg/kg NO$_3$-N, therefore the nitrate ISE should provide farmers with a good indication of PAN.

Elevated chloride concentrations will affect nitrate readings, and whilst the addition of silver acetate to the extract alleviated the problem to some extent, nitrate results from areas of high salinity need to be treated with caution.

![Figure 1. Comparison of ISE and Laboratory results for NO$_3$-N in Western Australian soils.](image1)

Using the BaCl$_2$ extractant, a strong relationship was observed between ISE and laboratory K as shown in Figure 2 ($R^2 = 0.93$) in soils with available K ranging from 20-400 mg/kg K. Whilst the amounts of K removed by the two extractants were different, the application of a constant correction factor to ISE values should enable the determination PAK with an error of about ± 28 mg/kg K in soil. However the critical K concentration for the optimum growth of wheat, defining deficient and marginal soil is 60 mg/kg or less (Peverill *et al.* 2005), limiting the utility of the instrument at the lower end of the soil K range. Nevertheless the potassium ISEI appears to be a promising technique for the determination of PAK in Western Australian soils. The potassium electrodes do not experience the interference problems associated with the nitrate ISE.

![Figure 2. Comparison of ISE and Laboratory results for available K in Western Australian soils.](image2)
CONCLUSION

Whilst inexpensive and simple to operate, the colour indicator soil test kits overall proved inadequate for soil testing. Attempts to improve the kits by altering extractants or soil to extractant ratios met with little success.

In contrast, both nitrate and potassium ion selective electrodes combined with modified extraction techniques have considerable potential to determine plant available nitrogen and potassium in Western Australian soils. They are fast, relatively easy to operate economical and if used correctly should provide reliable use over a long period.

These instruments should be considered as an augmentation rather than an alternative to laboratory analysis. In the correct combination they can offer farmers could estimate in-paddock variation in soil fertility enabling precision fertiliser application.

Work on assessing rapid soil testing techniques for phosphorus is continuing.

KEY WORDS
soil test kits, ion selective electrode, nitrogen, potassium

ACKNOWLEDGMENTS
Authors wish to acknowledge Australian Scientific for the loan of the ion selective electrodes and CSBP for the supply of soil samples and data. This project is funded by GRDC; Project Number UWA00089.

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Paper reviewed by: Chris Gazey
Redlegged earth mite resistance and integrated strategies for their control in Western Australia

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KEY MESSAGES
Populations of redlegged earth mites, Halotydeus destructor from at two known sites, Esperance and Cranbrook, have been found to have major resistance to widely used synthetic pyrethroid insecticides. These alarming discoveries bring into question the future effectiveness of management options against this widespread pest and the current dependence on insecticides.

In order to preserve the benefits of current inexpensive insecticides and to manage crop and pasture pests in a sustainable manner, lessons should be learnt from other industries where previous pest resistance has occurred. These involve an integrated approach where natural and cultural factors which limit pest populations are used and only supplemented, where necessary, with insecticides as a final option.

BACKGROUND
The redlegged earth mite, Halotydeus destructor (Acari: Pentaleidae) is one of the most important and widely distributed pests in broad-acre farming systems in southern Australia. These mites are particularly damaging at the establishment phase of crops and pastures. In years with a late ‘break of season’ or with late sown crops and pastures, seedlings may emerge in the presence of large populations of mites. This can result in severely reduced plant density or total seedling mortality, necessitating re-sowing in some cases. Canola seedlings are particularly at risk of damage, whereas lupins and other pulse crops are more tolerant. Cereals and grasses are able to tolerate considerable feeding damage.

Substantial benefits to pasture production and seed yield from control of redlegged earth mites has been observed. Measurements taken in set stocked pastures showed an average increase of 2.1 t DM/ha (range of 0.2-4.0 t DM/ha) (Michael et al. 1997). Redlegged earth mites also reduce clover seed production by more than 70% in some sites and seasons, but have no effects in others.

Farmer reliance on insecticides has been steadily increasing over recent decades with the wider adoption of minimum and no-till farming systems and the lower cost of chemicals. Farmer attitude to pest management is strongly influenced by previous experience. Pest control is usually seen as only a small component of any farming system, particularly when management systems have previously provided low cost control. This situation can quickly change when pest management practices or chemical failure result in unacceptable levels of crop or pasture damage. Attitudes to risk from pest damage also vary enormously. Some farmers are willing to make a decision not to spray crops or continue monitoring in the presence of moderate numbers of mites. Others have an aversion to risk and will spray with minimal mite damage levels. Moreover, many farmers would prefer to simultaneously control all invertebrate pests that threaten their crops. These factors have important consequences on sustainable insecticide usage and designing integrated control strategies.

Many pests have the capacity to develop resistance to chemicals. Selection of resistant strains can occur within a few generations, depending on the population’s genetic makeup and its exposure to the chemical. Put simply, the more frequently a confined population is exposed to a chemical, the higher the selection pressure and the quicker resistance is likely to develop.

RESISTANCE DISCOVERIES
The first demonstrated case of chemical resistance in redlegged earth mites was reported in 2006 (Umina 2007). An Esperance farmer found that he was not able to control an infestation of redlegged earth mites in his seedling canola crop. Four applications of registered rates of synthetic pyrethroids failed to control the mites in a canola paddock that subsequently suffered extensive damage and considerable yield loss. A further case of known insecticide resistance near Cranbrook was confirmed in 2007 and a possible third case of resistance is suspected from initial testing of mites from Piesseville.
Samples of the mites from Esperance and Cranbrook were tested at the Centre for Environmental Stress and Adaptation Research (CESAR) at the University of Melbourne. Toxicology bioassays were conducted on the mites and compared with mites from susceptible ‘control’ populations. Very high levels of resistance to two synthetic pyrethroids, bifenthrin and alpha-cypermethrin, were found in the Esperance and Cranbrook redlegged earth mite populations.

A resistance factor of greater than 240,000 fold against bifenthrin and almost 60,000 fold for alpha-cypermethrin was found in the Esperance population when compared to susceptible mites. Importantly this strong resistance was shown to be heritable, persisting after several generations of laboratory culturing. Fortunately the mites remained susceptible to the organophosphate group of chemicals such as dimethoate and omethoate.

**IMPLICATIONS**

Currently, chemicals are the major management option used for the control of redlegged earth mites. These are frequently applied to manage a number of invertebrate pests with farmers sometimes applying four or five pesticide sprays in a single season. A common approach is to apply ‘insurance sprays’ to cover anticipated pests, especially as a combined tank mix whilst applying herbicides or other sprays. These prophylactic sprays are sometimes applied without any paddock inspections to justify the actual presence of pests.

It’s quite probable that chemical resistant redlegged earth mite populations are present in more than the current two known localities in Western Australia or elsewhere across southern Australia, especially in paddocks that have a history of repeated chemical applications with synthetic pyrethroids. In recent years the increased usage and reliance on low cost insecticides has accelerated the selection pressure placed on pest populations and has led to the current resistant populations.

**INTEGRATED APPROACH TO MANAGING PEST PROBLEMS**

In order to preserve the benefits of current inexpensive insecticides and manage crops and pastures in a sustainable manner, lessons should be learnt from horticultural and other industries where pest resistance has occurred. These involve an integrated approach where natural and cultural factors which limit pest populations are used and only supplemented where necessary with insecticides as a final option. To successfully carry out integrated pest management the following issues need to be understood and taken into consideration:

1) **Correct identification of mite species**

There are a number of pest earth mites that can easily be misidentified due to their small size. Bryobia (clover) mite, balaustium mite and blue oat mite are commonly found in crops and pastures and misidentification can easily occur unless they are closely examined under a magnifying glass.

The biology of the earth mites differs and importantly they respond differently to various insecticides and rates. Balaustium and bryobia mites have a much higher tolerance to synthetic pyrethroids insecticides than redlegged earth mites. Failure in control mites may be assumed to be from insecticide resistance but could in fact be a misidentification of species.

Circumstantial evidence by some farmers in Western Australia suggest that some mite species may have increased in importance as a consequence of an increased frequency of use and higher application rates of insecticides against redlegged earth mites. Balaustium mites were considered primarily a predatory mite species and were not confirmed as a crop pest until 1997. It could be argued that increased insecticide selection pressure on redlegged earth mite populations has created a vacant niche that has allowed for the increase of these other mite species. The removal of one species favouring the increase of another has been demonstrated where lucerne flea and redlegged earth mite co-habit pastures.

2) **Monitoring**

Monitoring of redlegged earth mite populations to determine control threshold levels for on-farm pest management decisions can be a difficult. The small size of the mites and their varying behaviour and mobility make visual assessments of numbers difficult. Weather conditions such as temperature, cloud cover and time of day can mean that mites on one occasion are easily seen feeding on leaves whilst on another they are predominately on the soil surface and camouflaged against a darker background.
The difficulty in accurately assessing numbers has lead to visual damage symptoms on leaves being used as a more accurate indicator of damage potential.

Key times for monitoring pests are:

- Autumn inspections following ‘break of season’ rains and before sowing. This is an important time to understand what pests are present and to decide if insecticides are needed and if so to target only those that are present with the correct chemicals and dose rates.

- During seedling emergence and early plant establishment. Moderate to low numbers of mites may cause some plant mortality and visual silvering and leaf distortion which is concerning to farmers but may not be of economic importance. Trial results (Michael and Micic unpublished) have indicated that under moderate redlegged earth mite numbers no measurable yield loss has been found. It is likely that the degree of any yield loss depends on the level of plant density remaining after mite feeding damage, the compensating ability of the remaining plants and length of season. The impact of mite populations is further complicated when additional crop stresses (drought, waterlogging, disease, etc.) are present and limiting the plants’ ability to compensate for mite feeding damage. Despite some monitoring difficulties, a thorough inspection by farmers can often safely avoid the use of insecticides where pest levels are low.

- During spring when mite numbers are usually increasing to high levels and before they commence laying their over-summering eggs which can carry-over populations into the following autumn. Use of strategically timed insecticide (Timerite®) or grazing of pastures may be required.

3) Cultural control options

Intensive spring grazing of pastures to feed on offer (FOO) levels, generally below 2 t/ha, will greatly reduce pest numbers and their carry-over potential between seasons. Much of the spring production in set stocked pastures is wasted, with only 10-40% of feed estimated to be utilised, and this allows mite populations to increase (Michael et al. 1997). Removal of the surplus production by increasing grazing has reduced mite populations from 46,000/m² to 27/m² following a 4-fold increase in grazing days (number of sheep X days grazing). After heavy spring grazing susceptible crops can be established in the following autumn without the need for insecticide treatments.

Herbicide (or full cultivation) fallow periods where no green material exists in paddocks for at least a week prior to sowing crops will greatly assist in starving out mites and reducing their impact. Some paddocks can have a higher or lower risk of earth mite damage depending on the previous crop rotations. The risk is generally highest if paddocks have been in long term pasture (with high levels of broad-leafed plants) where mite populations have been uncontrolled. Lower risk paddocks that generally do not require mite control are often those which follow a cereal or chickpea (weed free) crop where conditions are less favourable for mite increase.

Planting a border of wheat or oats can protect canola from mite invasion from neighbouring high risk mite infested paddocks, while a border of lupins can act as a trap crop. Effective borders need to be more than 10 m wide based on dispersal rates of mites.

4) Insecticide options

The routine spraying of all pasture paddocks in spring using Timerite® dates to prevent a build-up of mites is likely to be unsustainable. Rather it is recommended that farmers should only select paddocks for spring spraying, based on FOO levels, future grazing management options, seed production requirements and intended paddock use next autumn.

Use of insecticide seed treatments (e.g. dimethoate and imidacloprid) for crops and new pastures with moderate pest pressure is preferable to spraying whole paddocks as it directs smaller quantities of pesticide to where it is needed rather than over-spraying beneficial predators.

Where spraying is required the use of ‘soft’ chemical options should be considered. For example when spraying to prevent aphid feeding damage in spring the use of pirimicarb insecticides will provide good control of the aphids whilst leaving the beneficial predators and parasites unharmed.

Rotating chemical groups where possible, for example between synthetic pyrethroid and organophosphates between and within seasons will help to reduce resistance build-up.
Unfortunately due to low insecticide costs and time constraints some farmers in recent years have used blanket high rates of chemicals across all paddocks as insurance sprays. This practice will only increase the selection pressure for invertebrate pest resistance development and should be avoided.

When farmers can identify variations in pest population densities by using monitoring techniques then the option of patch spraying identified risk areas such as along a fence line, rather than whole paddock is preferable.

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

**5) Biological control**
In Australia, there are effective predators present which specifically target lucerne flea, redlegged earth mite and blue oat mite. The French anystis mite *Anystis wallacei* is an effective predator of redlegged earth mite, blue oat mite and lucerne flea but is limited in its distribution. The pasture snout mite *Bdellodes lapidaria* is widespread in many WA pastures and helps to suppress lucerne flea numbers. These predators have most impact under continuous pasture situations. Their numbers are significantly reduced by grazing pastures to low feed on offer levels and repeated crop rotations. Because the predators spread very slowly (about 70 m per year) they only become effective when they are collected and re-distributed on farms and allowed to increase over a number of years.

**6) Host plant resistance against pests**
Most annual and perennial pasture grasses (e.g. Kikuyu) have a high level of tolerance to pests and spraying of established pastures is rarely required. Contrastingly, legumes are generally much more susceptible to earth mite and lucerne flea damage. Hundreds of introduced subterranean clover species have been screened for seedling resistance. The commercial release of a small number of cultivars with reduced susceptibility to *H. destructor* is anticipated. One alternative pasture legume species, *Trifolium glanduliferum* cv. Prima has already been released in part because it has strong resistance to redlegged earth mites. Potential for some other crop and pasture species is being investigated.

**ACKNOWLEDGMENTS**
The collaboration and expertise of Paul Umina and the Centre for Environmental Stress and Adaptation Research (CESAR) at the University of Melbourne is gratefully acknowledged.

The discovery of the redlegged earth mite resistance has been greatly assisted by State collaborative networks established under the National Invertebrate Pest Initiative (NIPI), supported through the Grains Research and Development Corporation (GRDC).

**REFERENCES**


Paper reviewed by: Geoff Strickland
The economics of treating soil pH (liming)

Chris Gazey¹, Steve Davies², Dave Gartner¹ and Adam Clune¹, Department of Agriculture and Food, Western Australia, ¹Northam, ²Geraldton

KEY MESSAGES

- Maintaining optimal pH is necessary if farm productivity is to be maintained.
- Soil acidity, in particular subsurface acidity, is widespread and a significant constraint threatening production and flexibility in the farming system.
- Increases in land value and potential gross margins through increased grain prices change the economics of ameliorating or preventing constraints to production.

AIMS

To raise awareness of factors which affect the economic viability of managing soil acidity with lime.

METHOD

The Avon Catchment Council Soil Acidity project has conducted an extensive monitoring program of soil profiles in the Avon River Basin (see Carr et al. and Andrew et al., these proceedings) which clearly demonstrate that the soil pH profiles for much of the area do not meet the Avon Catchment Council soil pHCa targets of 5.5 and 4.8 for topsoil and subsurface respectively.

The methodology to demonstrate the value of applying lime is simple, if the increased returns from liming are greater than the costs incurred then it is an economical practice. However, the uptake of liming is currently less than required to reach the targets for sustainable management of acidity. Clearly, there are many more factors which influence the liming decision. As each situation is specific to the individual and their circumstances at the time, the combination of factors involved are infinite. The following discussion outlines the factors which need to be considered when developing a liming program and a case study demonstrates the significance of early liming to avoid losses in production.

Returns from liming and results from both individual and aggregated trials have been published in previous Crop Update series (see Davies et al. 2006). The average increase in cereal production across hundreds of trial years is 8-12% (depending on the rate of lime applied), so an average grain yield increase of 10% is not unreasonable. It could also be considered conservative in some cases as grain yield responses can be 30-50% or more depending on the situation, location, crop species and season.

RESULTS AND DISCUSSION

An outline of factors to consider when assessing the economic viability of managing soil acidity by the application of lime:

Value of produce

- Grain price – are grain prices likely to remain good?
- Gross margin of the paddock.
  - What are the potential yields from the crops which can be grown in a well managed paddock where pH is non-limiting compared with one where low pH constrains both yield and choice of crops/pastures in the rotation?
  - What is the ‘lime’ cost of the farming system? (Time to Re-Lime Series #5)
- Value of the asset – in particular land price. How much should I be prepared to spend on maintaining or improving the value of the land?
Cost effectiveness of lime

Many factors affect the cost effectiveness of lime. Essentially it is the total cost to raise the pH by a desired amount.

- **Neutralising Value (NV)** – This value indicates the ability of lime to neutralise acidity. The active ingredient of lime is the carbonate ($\text{CO}_3^{2-}$) and pure calcium carbonate is given a value of 100%. Therefore, the higher the NV the more active ingredient available to increase the soil pH (decrease acid).

- **Particle size (Fineness)** – The finer the product the greater the surface area and the faster it will react in the soil to neutralise acidity. Particle size distribution is based on the percentage of the lime sample in each size range after it has passed through five different sizes of sieving screens during the testing process. Particles less than 0.5 mm in size neutralise soil acid most quickly, while larger particles have a neutralising effect over a longer period (Time to Re-Lime Series #9).


- **Freight cost** – Transport costs are a significant component of the total cost of liming. Look for back-loading rates and other opportunities to reduce costs (Time to Re-Lime Series #4). Calculate the total cost per tonne of neutralising value using a calculator such as the one on the soil quality website at [http://www.soilquality.org.au/calculator](http://www.soilquality.org.au/calculator).

Speed of response

- The pH of the soil profile (as well as soil type and farming system) determines the amount of lime required to raise the pH to the desired level. Surface applied lime usually takes between four to seven years to treat acidity in the subsurface layers. The amount of acid at pH 4.4 is 2.5 times as much as there is at pH 4.8 (Time to Re-Lime Series #2).

- Increases in grain yield or pasture production as a result of liming are an indication that productivity has been lost. The pH targets set by the Avon Catchment Council are designed to avoid losses due to soil acidity for most crops and pastures and to prevent acidification of the subsoil.

- The choice of recovery liming to return soil pH to appropriate levels or maintenance liming to avoid production losses is up to the individual; knowledge of the soil pH profile through monitoring (Time to Re-Lime Series #11) is an important part of that choice.

CASE STUDY

Maintaining a suitable soil pH profile through surface application of 2 t/ha of limesand from Lancelin (neutralising value 89%) in 1996 at Bindi Bindi resulted in a cumulative net increased income of $106/ha from three wheat crops (1996, 1998, 2004), using 2005 wheat prices and input costs and distributing the cost of the lime over 10 years at 8% interest. 1997 was a pasture year and after the wheat crop in 1998 no further measurements were made on the trial until strong visual responses were observed in a wheat crop in 2004. In 2005 pasture biomass, measured in September, was 70% higher (2.9 t/ha) on the plots where 2 t/ha lime had been applied previously compared with the unlimed control plots (1.7 t pasture biomass/ha). A second pasture was grown in preference to cropping in 2006, due to late start to season. In 2007, 12 years after the initial application of lime, wheat grain yield was increased by 10% (270 kg/ha) compared to the plots which hadn’t been limed. In today’s prices (ASW base rate of $414/t at 15/01/08) this equates to an extra $107 gross income/ha, giving a cumulative increase of more than $200/ha over the 12 years from four cereal crops. Pasture responses were observed but are not included in the analysis. The cost of applying 2 t/ha of lime in 1996 was estimated to be about $44/ha compared with about $75/ha at current prices.

The soil pH for the limed plots (2 t/ha lime in 1996) is now back to the pH levels of 1996 before liming, after having been above the topsoil target pH for many years, indicating that the applied lime has been completely used. Additional surface and deep placed applications of lime applied in 2005 (details not reported in this paper) are expected to continue to maintain the soil pH and yield in the future.
CONCLUSION

Growers need to assess their circumstances and long-term goals for soil management. There will always be a more pressing short-term action. However, because there is no ‘quick-fix’ solution to soil amelioration, a longer-term view is required. If action is repeatedly delayed, not only will the problem continue to worsen, the cost of amelioration will continue to increase while the capacity to pay for those increased costs will decrease.

KEY WORDS

soil pH, lime, quality, soil acidity, economics

ACKNOWLEDGMENTS

Funding for this program has been provided by the Avon Catchment Council with investment from the Western Australian and Australian Governments through the National Action Plan for Salinity and Water Quality and from Precision SoilTech who developed the sampling methodology.

Project No.: SI002 04A1-08 Avon Catchment Council Soil Acidity Project
UWA00081 GRDC Managing Hostile Subsoils WA

Paper reviewed by: Wayne Pluske, Nutrient Management Systems

Time to Re-Lime series

Extension publications produced as part of the Avon Catchment Council Soil Acidity project, first appearing in the FarmWeekly Rural Newspaper from August 2007 to April 2008:

Time to Re-Lime Series #2. Acidity and Lime
Time to Re-Lime Series #4. Spring liming a good option for pasture
Time to Re-Lime Series #5. Causes of soil acidity
Time to Re-Lime Series #8. Lime industry Code of Practice
Time to Re-Lime Series #9. Lime Quality
Time to Re-Lime Series #10. Lime WA Inc. limewa.com.au
Time to Re-Lime Series #11. Monitoring your soil pH
Health benefits – A key future differentiator for high value grains

Matthew Morell, Theme Leader, CSIRO Food Futures Flagship

The traditional differentiators of grain quality have been price and end use quality, and considerable progress has been made in identifying the genetics required to continuously improve the yield, disease resistance and grain compositional performance of our major grain crops. However, in an international marketplace where Australia competes with producer nations with price/production advantages (derived from factors such as low input costs or substantial government subsidies), Australia needs to maintain a profile as a consistent supplier of high quality grain products that meet end user requirements.

A major trend in the international food market is a consumer driven demand for products that deliver health and wellness outcomes, without compromising on taste or convenience. Grain products such as wheat have suffered as a result of fads such as the Atkins and similar high protein/low carbohydrate diets which resulted in significant shifts away from wheat in countries such as the US. In Australia, the past five years have seen dramatic shifts in consumer preference, illustrated by the market share for white bread falling from 70% in 2003 to 50% in 2007, driven by an increase in sales in wholemeal and whole grain breads.

The CSIRO Food Futures Flagship grains program has identified the development of grains capable of delivering human health benefits as a major plank of our strategy for increasing the future profitability of the Australian grains industry. The program recognises that such attributes must be packaged with traditional aspects of cereal quality such as processing performance and end use organoleptic properties, so the human health program is closely integrated with research on traditional cereal quality.

Three broad areas of research are being undertaken, in carbohydrates, lipids and protein quality. The carbohydrate program focuses on the development of grains with reduced digestibility in human foods. Such products are valued because they can deliver two general classes of health benefit. Firstly, reduced digestibility results in a reduced rate of digestion in the small intestine, leading to a lower rate of glucose uptake in the blood stream, most frequently measured as a decrease in the Glycaemic Index. This outcome is positive for those managing Type II diabetes, those at risk of developing metabolic syndrome, and for people such as endurance athletes wanting a slow sustained supply of energy. The second key parameter is called resistant starch (RS) and is defined as the starch and its digestion products that survives small intestinal digestion and reaches the large bowel. In the large bowel, fermentation of RS results in a number of beneficial effects, including the production of butyrate, a chemical associated with reduction in the incidence and severity of colo-rectal cancer. Several mechanisms have been identified to deliver these outcomes, including ‘high amylose starches’ and increased non-starch polysaccharides and examples of grains developed with substantiated improved performance (high amylose wheat, BarleyMax) will be discussed.

A second major area of research is in Omega-3 oils. Long chain Omega-3 oils are associated with a wide range of health benefits including cardiovascular health, cognition and infant development. In this project, we have isolated the genes from microalgae that synthesis the long chain omega-3 delivering the most important health benefits (known as EPA and DHA) and transferred these genes to oilseed plants.

The third area of research relates to celiacs disease. Gluten proteins are known to trigger celiacs disease in some individuals with particular genetic predispositions to the disease. Dramatic enhancements of health and quality of life are associated in these individuals with total avoidance of wheat, barley, oats and rye. In this project, we have identified a mechanism for developing barley for brewing that delivers beers with gluten levels below tolerance limits.

Each of these examples reinforces the promising future for the development of a new generation of grains delivering substantiated health benefits. Australia is well placed because of its grain and nutrition science base to develop and deliver such products. Australia has secured significant IP positions in a number of these technologies, raising the prospects that Australian farmers will be ideally placed to realise benefits from the implementation of this technology.
Carbon in Australian cropping soils – We need to be realistic

Alan Umbers (M Rur Sc), GRDC/DAFF Sustainable Industries Initiative Project

KEY MESSAGES
Carbon in Australian cropping soils is dynamic and cyclical. It is possible to increase soil carbon by increasing inputs of organic matter. However, growers should also be aware that in producing grain, greenhouse gases are emitted, with these mostly exceeding any sequestration in soil. Improvements in farming systems have improved and can continue to offer improvements in greenhouse gas sequestration, however, the balance of additions and emissions need to be considered. Soil type and level of production can significantly influence the amounts possible to be added to soil.

Farming systems including no-till and stubble retention offer benefits, though the use of nitrogen fertiliser and agricultural chemicals carry greenhouse gas ‘costs’, that in any assessment will have to be counted.

It should also be remembered that in drought years emissions will be potentially higher, and additions very much lower or non-existent.

Grain producers should look with great caution at any forecasts that there is much money to be made out of carbon trading, since, in simple terms they will probably remain net emitters of greenhouse gasses, even if these have fallen greatly in recent years.

AIMS
The aim of this analysis of the potential for soil carbon sequestration and the implications for any future carbon trading scheme were seen as necessary to attempt to bring realism to the debate, to consider the actuality of carbon dynamics in grain production and to encourage growers and other to consider the total carbon cycle in farming, that is both emissions and sequestration potential.

The emergence of carbon trading schemes also brought a need to examine the potentials these bring to grain producers, and to highlight the considerations farmers may need to be aware of.

METHOD
This paper is based on an analysis of several greenhouse gas calculators available pertinent to grain production systems. It considers the real life implications of today’s farming systems as applied using these calculators.

Further, a consideration for how these results may impact in an environmental containing carbon trading schemes was applied to draw conclusions about what farmers may need to consider under such schemes.

RESULTS

Background
Australian rainfed cropping soils are generally low in carbon, with the usual measure of Organic Carbon frequently at levels of around 1%. In many of the more sandy loam soils (for example of Western Australia or the Mallee areas or the eastern cropping belt) well under this is seen.

It would be foolish to suggest that previous to being cleared and farmed such soils were very high in organic carbon, with much of Australia’s remnant ‘virgin’ soil in the cropping areas at only 1.5% to 2%. Any suggestion that farmers can increase soil carbon to levels of 3% or greater neglects to understand that soil carbon is part of the carbon cycle, and heavily dependant on plant growth, soil microbial
activity and seasonal conditions. It would be more or less impossible to see soils being able to have organic carbon levels increased by cropping or farming practices at anything other than slow rates, and reaching an equilibrium point.

**Carbon and the farming system**

Farmers involved in producing grain are generally net emitters of greenhouse gasses by simple virtue of the inputs used, for example fuel and fertiliser. The farming of soil to produce grain often includes some form of soil disturbance, at least at planting, and in some cases additional tillages are still used. These operations and inputs result in greenhouse gas emissions, comprising both carbon dioxide (CO₂) and nitrous oxide (N₂O), the latter a potent greenhouse gas.

The amount of tillage used has decreased dramatically in the last 20 or so years with the adoption of no-till practices, and the retention of crop stubbles, and have brought a resultant reduction in fuel use. In addition, these practices have the potential to reduce the emission of greenhouse gasses from soils (by virtue of less tillage), and also to add some carbon to soils by the reduction in disturbance and oxidation or plant matter, for example root systems. However, the amounts possible to be 'added' to soil even given these more conservative systems are limited. Researchers, for example Prof. Peter Grace at the University of Technology in Queensland, attest to this limited ability for grain producers, even using the most conservative tillage and fertilise systems to 'add' much more than 100-200 kg/ha of carbon to soil per year.

Carbon can only be added to soil under such farming systems by growing more biomass in the soil, and either slowing it’s release by micro-organisms by reducing tillages and retaining crop remains. The problem for grain producers is that in the process of producing grain crops, greenhouse gasses are emitted, and the amounts emitted farm outweigh any carbon ‘added’ to soil.

**Use of carbon models**

Several models have been developed in recent years, in Australia, that estimate the emissions and potential amounts added to soil in the cropping industries. These include:

- The Grains Environment Datatool (GEDT) by the Centre of Excellence in Cleaner Production at Curtin University of Technology in WA by Professor Rene van Berkel. This spreadsheet based tool gives some guidance about emissions from various farming systems and crop production inputs.
- Another spreadsheet based tool produced by the National Greenhouse Gas Initiative, a joint project between the GRDC, Victorian DPI, University of Melbourne, CSIRO, the Department of Agriculture and Food in WA.
- SOCRATES (Soil Organic Carbon Reserves and Transformation in agro-Ecological Systems). This simulation model was developed by the CRC for Soil and Land Management, at CSIRO Land and Water, Adelaide.

Whilst all of these tools urge caution in the interpretation of their outputs, they can give some useful guidance as to levels of both emissions and sequestration of greenhouse gasses in Australian cropping soils.

Farmers and interested observers need to remember that in any future carbon trading scheme, BOTH emissions and sequestration will be used in calculating any level of participation. In the Australian Grains Industry any reasonable estimate will show a large net emission, rather than any significant sequestration. The figures show the following evidence for this:

Estimates from the models:

**Carbon sequestration**

Using SOCRATES, and typical crop rotations and inputs, in typical cropping areas of Australia, estimates of carbon sequestration range up to 0.01% in organic carbon per year. In typical Australian cropping soils this equates to around 100 kg/ha per year. Importantly this level of increase levels out after 10-20 years to reach a new slightly higher equilibrium.
So, if 100kg/ha of carbon can be sequestered this equates to 2 million tonnes over the 20 million or so hectares of crop grown in Australia.

**Greenhouse gas emissions**

The three models offer slightly different estimates of potential emissions from a cropping operation, ranging from approximately 300 kg/ha to 1500 kg/ha per year. Even if one takes a rough estimate of 800 kg/ha, this greatly outweighs the amount sequestered, by 700 kg/ha over a growing season.

**Long term results**

Few long term farming systems trials have measured greenhouse gas emissions and sequestrations, though some have tracked soil organic carbon levels.

One example, though one not necessarily applicable to Western Australian circumstances, is from a 33 year tillage experiment at Hermitage in southern Queensland (Wang et al. 2004).

When examining results from different systems (no-till vs conventional tillage, stubble retained vs burnt and nitrogen fertiliser vs no nitrogen), both carbon additions to soil and emissions from these systems were evaluated.

The analyses revealed that significant C sequestration in soil was achieved only under the No-Till + No Fertiliser + Stubble Retained treatment (9.2 t CO₂ ha⁻¹) over the 33 years of the experiment.

Total on-farm emissions from diesel combustion, urea hydrolysis, stubble and fertiliser N, and stubble burning ranged from 5.7 to 13.1 t CO₂-e ha⁻¹ under the zero N fertiliser treatments and from 21.9 to 28.6 t CO₂-e ha⁻¹ under the + nitrogen fertiliser treatments. Again these are over the 33 years of the experiment.

Off-farm emissions associated with the manufacture and transport of diesel fuel, farm machinery, N fertiliser, and herbicide were in the range of 1.9 to 2.8 t CO₂-e ha⁻¹ under the zero N fertiliser treatments and 10.5 to 11.4 t CO₂-e ha⁻¹ under the + N Fertiliser treatments.

Of the total emissions, on-farm N₂O flux contributed from 16% to 51% under various treatments. N-related emissions, including CO₂ release from urea hydrolysis, manufacture, and transport as well N₂O fluxes, contributed to the total emissions by between 17% and 86% depending on the treatment.

The authors suggest that to maximise the greenhouse mitigation potential whilst sustaining crop productivity, future farming strategies should aim to improve N use efficiency.

However, the results form this analysis (even given it is from northern Australia) indicate that under present farming systems, greenhouse gas emissions will likely outweigh sequestration.

**CONCLUSION**

If, in this example, 800 kg/ha is emitted from a cropping program, then over 20 million hectares, this gives 16 million tonnes of emissions.

Simple arithmetic shows that the grains industry will be a net emitter of greenhouse gasses, to the tune of approximately 700 or so kg of emissions per hectare, or 14 million tonnes over the whole Australian crop.

On a hectare basis, it is likely that many cropping farms will be net emitters of greenhouse gasses, up to 700 kg/ha, and potentially more, per year.

If, under a carbon trading system carbon is valued at (say) $20 per tonne, then rather than farmers making a return from sequestering carbon, they may end up with being asked to pay around $14 per hectare, and potentially more.

The good news is that the continued development of many aspects of current farming practices, including reduction in tillage, retention of crop residues and more careful and tailored use of N will assist in maximising carbon sequestration and minimise emissions. Even if these developments do
not total to net carbon sequestration, and the possibility of income from carbon trading, farmers can be confident they are doing their bit to reduce emissions at least.

KEY WORDS

carbon sequestration, emissions, carbon trading, soil carbon

REFERENCE

W.J. Wang, A.R.C. Dalal and C. Mitchell (2004). ‘Importance of N-related greenhouse gas emissions in a cropping system under contrasting farming practices.’ CRC for Greenhouse Accounting and NR&M, 80 Meiers Road, Indooroopilly, Brisbane, Qld 4068, Australia.

ACKNOWLEDGMENTS

Project No.: DAFF / GRDC Sustainable industries Initiative Project
Paper reviewed by: Prof. Peter Grace, QUT Queensland
AGWEST® Bartolo bladder clover (*Trifolium spumosum*) – a low cost annual pasture legume for the wheat/sheep zone

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

**KEY MESSAGES**

AGWEST® Bartolo is a new annual pasture legume that has impressed farmers and seed producers through its consistently high forage and seed production and this variety should increase the stability of legume pastures grown in rotation with cereal crops.

AGWEST® Bartolo can be grown successfully across mildly acid to alkaline sandy-loam and loam soils (pH 5 to 8 CaCl₂) and is suited to regions with 325 to 500 mm annual rainfall. High seed yields in excess of 1 t/ha that can be direct harvested by grain harvesters makes bladder clover a lower cost alternative to subterranean clover and annual medic in many situations.

AGWEST® Bartolo is hardseeded with over 50% of the seed remaining hard after one summer and has good protection against false breaks of season. The levels of hard seed suggest a potential use of bladder clover in both, self-regenerating ley systems or short-term phase farming systems.

**INTRODUCTION**

The main constraints to the introduction or (re-introduction) of pasture legumes in ley farming systems is generally a combination of seed availability, cost of establishment and probability of success. In addition, the key to the ongoing success and accumulated benefits of annual pasture legumes is the capacity to develop a persistent seed bank. Seed banks can be severely diminished by factors such as overgrazing, un-seasonal rainfall (false breaks), intensified cropping or weed control measures in both the crop and pasture phases.

AGWEST® Bartolo bladder clover was commercialised primarily because of a set of seed characteristics that can help address some of these constraints to production and make pasture legumes more attractive for adoption by wheat-belt farmers. AGWEST® Bartolo bladder clover was originally collected in Cyprus and developed by the DAFWA Pasture Science group through the National Annual Pasture Legume Improvement Program during the period 1997 to 2007.

**KEY AGRONOMIC FEATURES**

*Herbage and seed production*

AGWEST® Bartolo is a semi-erect, mid maturing cultivar, flowering approximately 105 days after emergence in Perth. It is adapted to soils of mildly acid to alkaline reaction (pH 5 to 8 CaCl₂) and to a range of textures provided it is reasonably fertile and not saline or subject to long periods of waterlogging. The quantity of forage produced by AGWEST® Bartolo is generally equivalent or better than current pasture options. Peak dry matter yields in small un-grazed experimental swards have ranged between 4 and 7 t/ha (Table 1). Seed yields have been exceptionally high in both small scale un-grazed experimental swards (Table 1), in seed production crops (1.1 t/ha clean seed after combine harvesting) and under continuous grazing. Under the dry seasonal conditions of 2006 (140 mm for the entire growing season), AGWEST® Bartolo swards at Northam measured 100 kg/ha of residual seed after continuous grazing compared to 50 kg/ha in Dalkeith subterranean clover swards. Seed is easily harvested using conventional grain harvesting machinery.

*Nutritive value*

The feeding value of AGWEST® Bartolo was compared to subterranean clover (cv. Dalkeith) in 2006 at Northam using 14 month old Merino wethers. Both clovers had the same relative feeding value under the conditions of the experiment. At late flowering (October), the in-vitro digestibility of bladder clover was around 82% with 22% crude protein, these values decreased with senescence. There
were no differences in liveweight change or wool growth between sheep grazing bladder or subterranean clovers. There were no differences in meat eating quality (tenderness, juiciness, odour, residual mouth feel or flavour) or fatness. Levels of formononetin (0.015%) and genistein (0.002%) were lower than in subterranean clover cv. Dalkeith and are unlikely to cause a phyto-oestrogen effect in grazing animals.

Table 1. Dry matter production (DM), seed yield (SY) and regeneration of AGWEST® Bartolo and several annual pasture legumes over three years (standard errors in brackets) at Cunderdin in Western Australia. The swards were prevented from setting seed in 1999

<table>
<thead>
<tr>
<th>Legume species</th>
<th>DM Sep. '98 (t/ha)</th>
<th>SY Nov. '98 (t/ha)</th>
<th>Regeneration Apr. '99 (plant/m²)</th>
<th>Regeneration Jun. '99 (plant/m²)</th>
<th>Regeneration Feb. '00 (plant/m²)</th>
<th>Regeneration May '00 (plant/m²)</th>
<th>DM Sep. '00 (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. spumosum AGWEST® Bartolo</td>
<td>5.2 (0.2)</td>
<td>1.2 (0.2)</td>
<td>163 (19)</td>
<td>771 (144)</td>
<td>125 (44)</td>
<td>553 (265)</td>
<td>6.7 (0.3)</td>
</tr>
<tr>
<td>M. polymorpha Santiago</td>
<td>5.8 (0.5)</td>
<td>0.5 (0.3)</td>
<td>300 (53)</td>
<td>579 (151)</td>
<td>172 (54)</td>
<td>272 (126)</td>
<td>4.9 (0.5)</td>
</tr>
<tr>
<td>M. littoralis Herald</td>
<td>6.3 (0.4)</td>
<td>0.4 (0.1)</td>
<td>2933 (472)</td>
<td>1946 (490)</td>
<td>297 (81)</td>
<td>406 (64)</td>
<td>5.1 (0.4)</td>
</tr>
<tr>
<td>B. pelecinus Casbah</td>
<td>4.3 (0.3)</td>
<td>0.5 (0.1)</td>
<td>0</td>
<td>500 (196)</td>
<td>419 (161)</td>
<td>333 (47)</td>
<td>5.5 (0.7)</td>
</tr>
<tr>
<td>T. glanduliferum Prima</td>
<td>4.9 (0.5)</td>
<td>0.4 (0.1)</td>
<td>3550 (593)</td>
<td>2325 (344)</td>
<td>0</td>
<td>53 (14)</td>
<td>2.2 (0.9)</td>
</tr>
<tr>
<td>T. subterraneum Dalkeith</td>
<td>4.0 (0.05)</td>
<td>0.2 (0.0)</td>
<td>3225 (503)</td>
<td>2475 (135)</td>
<td>233 (32)</td>
<td>219 (22)</td>
<td>3.7 (0.5)</td>
</tr>
<tr>
<td>T. michelianum Frontier</td>
<td>5.1 (0.4)</td>
<td>0.2 (0.0)</td>
<td>967 (270)</td>
<td>1942 (509)</td>
<td>0</td>
<td>56 (36)</td>
<td>0</td>
</tr>
</tbody>
</table>

Regeneration and hardseed

AGWEST® Bartolo regenerates well in both continuous pasture and after rotational cropping. The pattern of seedling emergence also shows considerable resilience against un-seasonal rainfall. After a significant rain event at Mingenew in April 1999, nearly 200 seedling/m² emerged on the bladder clover plots (Table 2). Two months later (normal break) a fresh emergence of an additional 2150 plants/m² occurred. In contrast, the greater proportion of T. subterraneum seed germinated on the earlier rain event (621 plants/m²), much of which died after insufficient follow up rain.

Table 2. Regeneration of AGWEST® Bartolo, Prima gland clover and Dalkeith subterranean clover (standard errors in brackets) in 1999 at Mingenew in Western Australia

<table>
<thead>
<tr>
<th>Legume species</th>
<th>Regeneration (plant/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 April 1999</td>
</tr>
<tr>
<td>T. spumosum AGWEST® Bartolo</td>
<td>196 (68)</td>
</tr>
<tr>
<td>T. glanduliferum Prima</td>
<td>74 (27)</td>
</tr>
<tr>
<td>T. subterraneum Dalkeith</td>
<td>621 (74)</td>
</tr>
</tbody>
</table>

The hard seed content and seed softening pattern in AGWEST® Bartolo is highly desirable to cope with un-seasonal rainfall and to provide long term legume stability in pastures (Table 3). The final level of hard seed after one summer of seed softening (about 55%) together with regeneration data from the field suggests that AGWEST® Bartolo has adequate hard seed levels to survive a crop rotation but is also suitable for use in a phase farming system (short pasture phases of one to three years and requiring resowing when needed). Seed softening was measured using free seed exposed on the soil surface so levels of softening are likely to be higher than that occurring in a normal field situation.

Crop Updates is a partnership between the Department of Agriculture and Food, Western Australia and the Grains Research & Development Corporation

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Table 3. Individual seed weight (mg), and seed softening (% hard seed) of AGWEST® Bartolo and a range of annual pasture legumes in the field over one summer at Perth, Western Australia (initial test January 1999, final test 1 July 1999)

<table>
<thead>
<tr>
<th>Legume species</th>
<th>Seed weight (mg)</th>
<th>Hard seed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGWEST® Bartolo</td>
<td>2.6</td>
<td>97 (0.5)</td>
</tr>
<tr>
<td>Santiago</td>
<td>3.6</td>
<td>98 (0.1)</td>
</tr>
<tr>
<td>Herald</td>
<td>2.3</td>
<td>95 (3.6)</td>
</tr>
<tr>
<td>Casbah</td>
<td>1.2</td>
<td>99 (0.2)</td>
</tr>
<tr>
<td>Prima</td>
<td>0.7</td>
<td>98 (0.4)</td>
</tr>
<tr>
<td>Dalkeith</td>
<td>6.7</td>
<td>88 (5.0)</td>
</tr>
<tr>
<td>Frontier</td>
<td>0.7</td>
<td>86 (7.7)</td>
</tr>
</tbody>
</table>

Herbicide reaction

AGWEST® Bartolo is sensitive to many of the more common broadleaf herbicides including Bromoxynil, Spinnaker® and Raptor®. Broadstrike® appears reasonably safe and Tigrex® may offer an intermediate weed control option. Further research is required to develop complete pasture manipulation options.

Disease and insect tolerance

Testing has indicated little or no sensitivity to clover scorch disease (Kabatiella caulivora). Occasional infections of pseudopeziza leafspot (Pseudopeziza trifolii) have been observed in high rainfall areas. Sensitivity to common viruses is similar to subterranean clover. Field observation and glasshouse screening indicates a low to moderate sensitivity to red-legged earth mite. Damage is generally less severe than with annual medics or subterranean clover. It is susceptible to attack from aphid and lucerne flea and control will be required for heavy infestations. Establishing plants can be effected by the common brown pasture looper. It is not severely affected by native budworm.

Rhizobial requirements

Inoculation with Group C (strain WSM 1325) is highly recommended.

Seed production, handling and processing

Seed of AGWEST® Bartolo can be easily harvested with conventional multi-crop harvesters. Best results are achieved using an open front with a tined reel and crop lifting fingers (Index of harvestability around 75%). Bladder clover drum settings are similar to those used for wheat but with a reduced wind speed. The small round seeds are easily handled with augers and elevators and can be cleaned with basic seed processing equipment. The seeds are very physically hard and therefore aggressive scarification is required to achieve high levels of germination. One and half hectares of AGWEST® Bartolo Breeders seed was sown at Northam (WA) in May 2005 at 10 kg/ha with 300 kg/ha of 3:1 super-potash fertiliser. In total this crop yielded 1.7 tonnes of clean Basic seed. We expect that harvest yields of around 500 kg/ha will be easily achieved in medium rainfall wheatbelt regions in most seasons. Certified seed will be produced under a Trademark license scheme.

CONCLUSION

Bladder clover is expected to be widely adopted across many soil types and farming systems throughout the wheatbelt, where traditional pasture legumes such as subterranean clover and annual medics are not performing adequately. Ease of seed production should result in ready availability of seed and provide farmers with new opportunities to build up their pasture legume base. In pasture crop rotations the stability of the legume pasture should be improved and resowing or topping-up of seed banks should be more economical.

KEY WORDS

annual pasture legume, hard seed, seed production, clover, forage quality
REFERENCES

ACKNOWLEDGMENTS
AGWEST® Bartolo was developed and field tested within the National Annual Pasture Legume Improvement Program supported by Grain Research & Development Corporation (GRDC) and Australian Wool Innovation (AWI). The Centre for Legumes in Mediterranean Agriculture (CLIMA) at UWA hosted the project and also provided financial support. CSIRO Livestock Industries assisted with the comprehensive grazing experiment at Northam.

Project No.: GRDC UWA 360
Paper reviewed by: Ron Yates (DAFWA)
Maximising the value of point based soil sampling: Monitoring trends in soil pH through time

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¹Precision SoilTech
²Department of Agriculture and Food, Western Australia

KEY MESSAGES
Growers establishing on-farm soil monitoring programs can examine the impact of acidity amelioration treatments and make more informed management decisions. Growers are able to use soil testing results to assess temporal soil nutrient and chemical property (i.e. pH) trends over time. To accurately monitor trends, appropriate sampling methodology and accurate recording of site location and data is necessary. Soil acidification occurs throughout the soil profile, significant advantages can be gained from soil monitoring to a depth of 0.3 m or greater.

AIMS
To encourage growers to increase the value of current and future soil sampling by providing information that will enable soil pH monitoring programs to be established at the paddock and farm scale. We also aim to demonstrate the value of subsurface soil testing and will show examples to show how deep soil testing can improve the accuracy of liming recommendations.

METHOD
Point based, time series determination of soil pH changes can be used to assess the rate a soil is acidifying and the efficiency of amelioration treatments. To monitor soil pH change, the following points are important to consider.

Sampling sites should:
• be established prior to sampling and accurately represent the soil type variability within the paddock. Soil types that dominate the paddock should contain proportionally more sites than smaller areas of soil or those which are atypical;
• not be located in areas that typically have abnormal nutrient levels such as headlands, sheep camps, around water troughs and gateways;
• be sampled to a depth of 0.3 m or greater at intervals of 0.1 m (i.e. 0-10 cm, 10-20 cm and 20-30 cm). Contamination between soil intervals should be minimised;
• be sampled in summer when the soil is dry as it is more likely that soil conditions will be similar from year to year;
• be sampled in a consistent manner each time of sampling (pogo, exhaust tube, contractor);
• have the GPS coordinates recorded in the datum GDA94 and use a GPS device with an error of less than two metres with these coordinates being used for the next time of sampling;
• be sampled every three to four years to assess the impact of management and amelioration.

Soil samples should:
• be taken from the complete depth of the profile interval (i.e. from 0-10 cm) as the sample will not be representative if only a portion of the profile interval is sampled (e.g. 0-7 cm) is collected;
• be collected in a standardised, consistent manner each time of sampling. The recommended sampling method is to take 10-15 soil cores, bulked, mixed and sub-sampled. These cores should come from between and within the seeding furrow, in proportions determined by row width and row precision (GPS guidance);
• be sent to the same analytical laboratory at each time of sampling. The laboratory should have Australian Soil and Plant Analysis Council Inc. (ASPAC) accreditation. All pH analysis should be conducted and reported in 1:5 CaCl₂.
**Precision SoilTech soil monitoring methods**

Precision SoilTech use a standard sampling machine and method of collection to minimise sample variability at each time of collection. Ten soil cores are collected from each site (approximately 8 m x 4 m) to a depth of 0.3 m at 0.1 m depth intervals. Eight soil cores are taken between the row and 2 from within the row. A Rinex H-Box GPS guidance computer is used to log each sample site with sub metre (GPS) or sub 10 cm (DGPS) accuracy.

**RESULTS**

Grower initiated soil monitoring programs exist on a number of mixed production properties in the WA Wheatbelt. Precision SoilTech are contracted to collect the samples from the same location over time. The red dots in Figure 1 represent soil sampling locations that have been sampled up to four times over a nine year period. Examining soil pH changes over this time has identified increases following a comprehensive liming program. Topsoil pH's have increased from below 5.0 to above 5.5 and subsurface layers increased from below pH 4.5 to above 5.0. Monitoring of long term lime trials has identified decrease in topsoil and subsurface soil pH's of a similar magnitude over the same timeframe (Gazey et al. these Proceedings).

![Figure 1. Aerial image showing soil variability and position of sampling sites. An aerial image can be helpful for identifying soil types and areas to be avoided (headlands, etc.).](image)

The Avon Catchment Council’s Soil Acidity project has shown the importance of sampling the subsurface soil to determine extent of soil acidity (see Carr et al., these Proceedings). Soil pH profile information can be used by growers and agronomists to tailor agronomic and amelioration programs for each paddock or farm. The added value of knowing subsurface soil pH in determining the appropriate rate of lime to be applied at any given location in the paddock is shown in Table 1.
Table 1. An example of a liming recommendation highlighting how knowledge of subsurface pH influences the amount of lime prescribed. Soil acidity at depth requires greater amounts of lime to increase pH. Knowing the soil pH at depth will allow for more efficient use of lime.

<table>
<thead>
<tr>
<th>Paddock</th>
<th>Site</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Soil type</th>
<th>Topsoil pH</th>
<th>Midsoil pH</th>
<th>Subsoil pH</th>
<th>Recommended t/ha over 10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONE 1</td>
<td>-31.776833</td>
<td>117.828083</td>
<td>S</td>
<td>5.5</td>
<td>1~3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ONE 2</td>
<td>-31.772783</td>
<td>117.829967</td>
<td>S</td>
<td>5.5</td>
<td>5.0</td>
<td>1~2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ONE 3</td>
<td>-31.770233</td>
<td>117.826550</td>
<td>S</td>
<td>5.5</td>
<td>5.0</td>
<td>5.0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ONE 4</td>
<td>-31.787383</td>
<td>117.813950</td>
<td>S</td>
<td>5.5</td>
<td>5.0</td>
<td>4.0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>ONE 5</td>
<td>-31.775900</td>
<td>117.823383</td>
<td>S</td>
<td>5.5</td>
<td>4.5</td>
<td></td>
<td>1~3</td>
<td></td>
</tr>
<tr>
<td>ONE 6</td>
<td>-31.775367</td>
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<td>S</td>
<td>5.5</td>
<td>4.5</td>
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<td>ONE 7</td>
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<td>-31.784383</td>
<td>117.823050</td>
<td>S</td>
<td>5.5</td>
<td>4.2</td>
<td></td>
<td>2~4</td>
<td></td>
</tr>
<tr>
<td>ONE 9</td>
<td>-31.784400</td>
<td>117.819817</td>
<td>S</td>
<td>5.5</td>
<td>4.2</td>
<td>5.0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>ONE 10</td>
<td>-31.788367</td>
<td>117.820583</td>
<td>S</td>
<td>5.5</td>
<td>4.2</td>
<td>4.2</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSION

Growers and agronomists can determine the extent of topsoil and subsurface soil acidity and implement suitable amelioration programs. Soil pH monitoring can be used to assess the impact of management, both positive and negative. This monitoring can be used to modify the existing amelioration program to maximise the benefits from managing soil acidity.

KEY WORDS

soil pH, monitoring, subsurface

ACKNOWLEDGMENTS

Funding for this program has been provided by the Avon Catchment Council with investment from the Western Australian and Australian Governments through the National Action Plan for Salinity and Water Quality.

Project No.: S1002 04A1-08 Avon Catchment Council Soil Acidity Project

Paper reviewed by: Wayne Pluske, Nutrient Management Systems
Improved crop root growth and productivity with deep ripping and deep-placed lime

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²School of Earth and Geographical Sciences University of Western Australia
*Presenting author

KEY MESSAGES
Root abundance, root growth, biomass and yield of wheat are substantially improved when acidic subsoils are partially ameliorated with seams of deep placed lime.

AIMS
- Assess the effectiveness of deep placed lime for amelioration of acidic subsoils and benefits to crop growth and productivity in farmer managed paddocks.
- Measure crop root growth in acidic subsoils partially ameliorated with seams of deep placed lime in farmer managed paddocks.

METHOD
The short and long-term benefits of deep-placed lime on crop root growth and productivity was assessed in farmer’s paddocks at Kellerberrin and Bodallin. Treatments at both sites included an untreated control, deep ripping at 15 cm and 30 cm without lime and deep ripping at 15 cm and 30 cm while incorporating lime at 500 kg/ha (Kellerberrin) or 2 t/ha (Bodallin). Both sites were ripped with the same deep ripping implement with a tine spacing of 20 cm. Impacts of the ripping and liming treatments on soil strength and root growth were also examined. Both sites were sown across the treated plots with the rest of the paddock by the host-growers.

Short-term benefits of deep placed lime (Kellerberrin)
Soil strength was measured in situ with a hand-held penetrometer (Mecmesin compact force gauge 200N) using a 5 x 5 cm grid placed on a vertical soil pit face cut across the rip lines. Strength was measured to a depth of 40 cm. Soil at the site consists of 10 cm of granular dark brownish yellow loamy sand over yellowish brown sandy loam and sandy clay loam to a depth of 60 cm. Soil samples were collected from the pit face for measurements of soil pH, extractable Al and soil moisture. Wheat root abundance was scored in situ on the soil pit face using the method of McDonald and Isbell (1990).

Long-term benefits of deep placed lime (Bodallin)
Longer-term benefits of deep ripping and liming were assessed at an experimental site at south Bodallin that was established in 2001 (Davies et al. 2006). The soil at the site consists of a yellowish brown sand to 15 cm over a massive yellow clayey sand to a depth of 70 cm. In 2004 the plots were split with half of each plot receiving surface lime. Wheat was sown at the site on 20 May 2006. On 5 July 2006, 46 days after sowing during mid-tillering, soil cores were taken in and out of lime treated and untreated rip lines and split into 10 cm increments. Cores were sub sampled for soil pH and roots washed out, root presence or absence in each core was recorded. Washed and cleaned roots were scanned and root length determined using WINRHIZO scanning and root image analysis software. In early September 2006 soil penetration resistance was measured vertically from the surface to a depth of 40 cm using a RIMIK CP40 cone penetrometer.

RESULTS
Short-term benefits of deep placed lime (Kellerberrin)
The soil at Kellerberrin was strongly acidic. The subsoil prior to ripping and lime treatments had pH (CaCl₂) values of 4.1 at 10-30 cm which are below the recommended target pH₉₅ of 5.5 or above.
Exchangeable aluminium levels are also high ranging from 5-24 mg/kg and are well above the recommended level of 4 mg/kg (data not shown).

![Spatial strength maps (a,b,c), laboratory pH (1:5 water) maps (d,e,f), gravimetric water content (g,h,i) and tabulated plant root growth (j,k,l) for Kellerberrin ripping and liming trial.](image)

**Figure 1.** Spatial strength maps (a,b,c), laboratory pH (1:5 water) maps (d,e,f), gravimetric water content (g,h,i) and tabulated plant root growth (j,k,l) for Kellerberrin ripping and liming trial.

Ripping of similarly textured and structured acidic soils at depths of 15 and 30 cm plus the incorporation of lime (500 kg/ha) during ripping improved wheat root growth (Figure 1). Spatial plots of strength show the depth of disturbed soil increases from 10 cm in the no-rip no-lime treatment (Figure 1a), to 15 cm in the rip no-lime treatment (Figure 1b), and 15 to 20 cm in the rip plus lime treatment (Figure 1c). A horizontal abrupt increase in soil strength is present in the no-rip treatment (Figure 1A). Soil strength is lower (21-60 N) at 30 to 40 cm in this treatment corresponding to higher moisture content in the sub-soil. A discontinuous band of higher strength (81-100 N) approximately 10 cm in thickness is present in all treatments but the depth to this layer increases after ripping. In the no-rip no-lime treatment (Figure 1a) it was present at 15-20 cm, while in the ripped treatments (Figure 1b,c) it was present at 20-30 cm.
A comparison of the no-rip and no-lime treatment (Figure 1d) with the rip plus lime treatment (Figure 1f) shows the latter has increased soil pHw by approximately 2 pHw units at 10 cm and 1 pHw unit at 30 cm. Ripping and lime incorporation produced an even increase in pH across the profile.

Roots were more abundant in the lime treated subsoil (Figure 1l). They were common (10-25 roots per 0.01 m²) at 10-20 cm and ranged from few (1-10 roots per 0.01 m²) to common at 20-40 cm. In the no-rip no-lime treatments (Figure 1j) and ripped no-lime treatments (Figure 1k) root abundance was predominantly few or nil for subsoil from 10-40 cm. The increase in wheat root abundance at 90 days may be a result of the increased depth of soil disturbance (ripping) plus the incorporation of lime. A long-term benefit in sandy-quartz rich textured soil obtained by applying lime may be the improved ability of roots to colonise and maintain the disturbance caused by ripping.

**Long-term benefits of deep placed lime (Bodallin)**

The untreated soil at the site was strongly acid with a pHCa of 4.3 or less throughout the profile (Figure 2a). Deep ripping had no effect on the soil pH. Addition of surface lime in 2004 to either ripped only or control plots increased the topsoil pHCa above 4.5, still well below the topsoil target pHCa of 5.5 and the pHCa of the subsoil remained below 4.5. The best pHCa profile was obtained with combination of both deep placement and surface liming with a surface soil pHCa of 5.6 and the subsoil pHCa of 5.0 or more (Figure 2a). The penetration resistance of the subsoil measured using a cone penetrometer was high (Figure 2b). Penetration resistance for the soil below 10 cm was > 1500 kPa regardless of treatment. Surprisingly benefits from deep ripping the soil five years previously were still evident even though the paddock is sown and harvested with grower machinery without controlled traffic. Soil penetration resistance was lower for the deep ripped soil from 10-22 cm depth in the profile which corresponded to the depth of ripping in 2001 (Figure 2b). Incorporation of lime into the subsoil while ripping further reduced the penetration resistance compared with the control or deep ripped only soil (Figure 2b). Lower penetration resistance of the subsoil that had received deep placed lime was observed from 10-30 cm, extending well below the original ripping depth.

![Figure 2](image-url)

**Figure 2.** (a) Soil pHCa measured from soil cores collected 46 days after sowing (DAS), during tillering and (b) soil penetration resistance measured using a cone penetrometer 110 DAS. Bars represent the standard error of the mean for a transect measured in 3 replicate plots.

Increased soil pHCa and lower soil strength was reflected in improved crop shoot and root growth. The frequency of root occurrence in the soil cores taken during mid tillering (46 DAS) gave a clear indication of the abundance of roots in the subsoil (Table 1). Half the subsoil cores collected from 20-30 cm contained roots when the soil had been ripped only, compared to 96% for the cores.
containing roots where the soil had been ripped and lime incorporated to a depth of 30 cm. Deep incorporated lime doubled wheat root length density (RLD) at 20-30 cm compared with ripping only (Figure 3). Two-thirds of the 30-40 cm samples contained roots where lime had been deep placed compared with less than 45% of the samples from any of the other treatments (Table 1). Additional surface lime applied in 2004 did not increase root abundance or RLD in the subsoil. In the surface 10 cm of soil the RLD (data not shown) ranged from 3.3 cm/cm³ in the control plots to 4.3 cm/cm³ in the ripped with deep placed lime plots with an additional increase to 5.1 cm/cm³ with the application of surface lime to the deep placed lime treatment.

Table 1. Root abundance as assessed by the proportion of soil core samples that contained wheat roots, collected 46 days after sowing

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Soil sample depth</th>
<th>0-10 cm</th>
<th>10-20 cm</th>
<th>20-30 cm</th>
<th>30-40 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control: not ripped, no lime</td>
<td></td>
<td>100</td>
<td>100</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>Control + 2 t surface lime/ha in 2004</td>
<td></td>
<td>100</td>
<td>92</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Deep ripped</td>
<td></td>
<td>100</td>
<td>83</td>
<td>50</td>
<td>17</td>
</tr>
<tr>
<td>Deep ripped + 2 t surface lime/ha in 2004</td>
<td></td>
<td>100</td>
<td>92</td>
<td>67</td>
<td>25</td>
</tr>
<tr>
<td>Deep ripped and deep placed lime</td>
<td></td>
<td>100</td>
<td>96</td>
<td>96</td>
<td>67</td>
</tr>
<tr>
<td>Deep ripped and deep placed lime + 2 t surface lime/ha in 2004</td>
<td></td>
<td>100</td>
<td>100</td>
<td>92</td>
<td>75</td>
</tr>
</tbody>
</table>

Figure 3. Relationship between root length density and soil depth. The proportion of roots in soils cores from 20 to 30 cm was doubled by the incorporation of lime compared to ripping only.

Improved root growth for the deep placed lime treatment correspond with a > 20% increase in total shoot dry weight and grain weight of harvest index hand cuts compared to the deep ripped only treatment (Table 2). Increased yield for the deep placed lime treatment was largely due to there being more grains per head (Table 2). While there was a trend toward more heads for the deep placed lime treatment this was not significant. The addition of surface lime in 2004 increased the biomass and grain yield by about 18-20% on average, independent of the 2001 treatment, and in this case surface lime increased head numbers by 12% (Table 2).

Like the harvest index cuts there was no significant interaction between the 2001 and 2004 treatments for the machine harvest grain yield (data not shown). Main treatment effects were significant ($P < 0.05$). The 2001 deep ripping with deep placed lime treatment produced a 24% higher yield (1.73 t/ha cf. 1.39 t/ha) than the deep ripped only treatment (data not shown). Surface lime, applied at a rate of 2 t/ha in 2004 increased grain yields by an average of 12% (1.58 t/ha cf. 1.41 t/ha).
Table 2. Shoot and grain dry weight and yield components of harvest index hand cuts taken at harvest, 21 November 2006. There was no significant interaction between the 2001 and 2004 treatments for any of the parameters measured so main effects of the 2001 and 2004 treatments are shown separately.

<table>
<thead>
<tr>
<th></th>
<th>Shoot weight (kg/ha)</th>
<th>Grain weight (kg/ha)</th>
<th>Harvest Index</th>
<th>1000 grain weight (g)</th>
<th>No. heads/ m²</th>
<th>No. grains/ head</th>
<th>No. grains/ m²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2001 Treatment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>3527</td>
<td>1683</td>
<td>0.47</td>
<td>34</td>
<td>251</td>
<td>19</td>
<td>4880</td>
</tr>
<tr>
<td>Deep ripped</td>
<td>3868</td>
<td>1825</td>
<td>0.47</td>
<td>34</td>
<td>264</td>
<td>20</td>
<td>5428</td>
</tr>
<tr>
<td>Deep ripped and deep placed lime</td>
<td>4759</td>
<td>2269</td>
<td>0.48</td>
<td>35</td>
<td>284</td>
<td>23</td>
<td>6415</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>674</td>
<td>318</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>2</td>
<td>870</td>
</tr>
<tr>
<td><strong>2004 Treatment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nil surface lime</td>
<td>3694</td>
<td>1748</td>
<td>0.47</td>
<td>34</td>
<td>254</td>
<td>20</td>
<td>5075</td>
</tr>
<tr>
<td>2 t/ha surface lime</td>
<td>4370</td>
<td>2106</td>
<td>0.48</td>
<td>34</td>
<td>284</td>
<td>21</td>
<td>6138</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>426</td>
<td>201</td>
<td>ns</td>
<td>ns</td>
<td>18</td>
<td>ns</td>
<td>550</td>
</tr>
</tbody>
</table>

CONCLUSION

Treatment of acid sandy earth subsoils with deep placed lime improves crop root growth in the subsoil. At Bodallin, in the sixth year after the deep placed lime treatments had been applied, the improved crop root growth corresponded with improved shoot biomass and grain yield. Surface lime applied two years previously at the Bodallin site also resulted in substantial increases in grain yield indicating the responsiveness of the site to lime. The benefits of deep placed lime at the Bodallin trial have been shown to last at least seven years with significant yield increases in each cropping year (Davies et al. 2006).

REFERENCES


KEY WORDS
subsurface acidity, liming, deep ripping, deep placed lime, root length density, root abundance

ACKNOWLEDGMENTS

Thanks to Kit Leake (Kellerberrin) and Gerry and Kelvin Kent (Bodallin) for provision of experimental sites on their properties and for their support and enthusiasm. Thanks to Breanne Best (DAFWA, Northam) for technical assistance. Funding for this research is provided by the Grains Research and Development Corporation and the Avon Catchment Council with investment from the Western Australian and Australian Governments through the National Action Plan for Salinity and Water Quality.

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Paper reviewed by: Prof Bob Gilkes
The role of pastures in hosting Root Lesion Nematode (RLN, *Pratylenchus neglectus*)

Vivien Vanstone, Ali Bhatti and Ming Pei You, Department of Agriculture and Food, Western Australia, South Perth

**KEY MESSAGES**

- Pastures vary in their susceptibility to RLN.
- Under some pastures, RLN levels could increase and become damaging to subsequent cereals.
- Serradella and sulla cultivars are resistant to *Pratylenchus neglectus*.
- Biserrulla and most clover cultivars are susceptible.

**BACKGROUND AND AIMS**

Rotation using poor or non-host crops is the key to effective and sustainable nematode management. However, all RLN species have wide host ranges. The effect of pastures on nematode populations in cereal cropping rotations is unclear. *P. neglectus* is the predominant RLN species in Western Australian cropping areas, so the effect of pastures on the population of this pest was assessed to determine the potential influence on subsequent cereal crops.

Tests were conducted to determine the ability of a range of pastures to host the RLN, *P. neglectus*.

**METHOD**

Pastures (25 cultivars representing 17 species, Table 1) were grown in the glasshouse and ten replicates of each inoculated with 2,000 *P. neglectus* from laboratory culture. The total number of nematodes in the root system of each plant was determined ten weeks after inoculation (Figure 1).

Pasture cultivars were classified as susceptible or resistant to *P. neglectus* based on statistical comparison with the susceptible and resistant controls, Machete wheat and Tanjil lupin, respectively.

**RESULTS**

The pastures tested varied in their ability to host *P. neglectus* (Figure 1, Table 1).

- *P. neglectus* did not multiply on the serradella and sulla cultivars tested. These were therefore classified as resistant.
- Rose clover (cv. Hykon) and purple clover (cv. Electra) were moderately susceptible.
- Biserrulla, all other clovers and medic were susceptible, resulting in significant increase in the nematode population during the growing period of the plants.
Figure 1. *Pratylenchus neglectus* levels extracted from 25 pasture cultivars 10 weeks after inoculation. Machete wheat susceptible (S); Tanjil lupin resistant (R).

Table 1. Reaction of pasture cultivars to *Pratylenchus neglectus*

R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; VS = very susceptible

<table>
<thead>
<tr>
<th>Cultivar/Species</th>
<th>Species</th>
<th>Reaction to P. neglectus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanjil lupin</td>
<td>Lupinus angustifolius</td>
<td>R</td>
</tr>
<tr>
<td>Charano yellow serradella</td>
<td>Ornithopus compressus</td>
<td>R</td>
</tr>
<tr>
<td>Flamenco sula</td>
<td>Hedysarum coronarium</td>
<td>R</td>
</tr>
<tr>
<td>Yelbini yellow serradella</td>
<td>Ornithopus compressus</td>
<td>R</td>
</tr>
<tr>
<td>Margurita French serradella</td>
<td>Ornithopus sativus</td>
<td>R</td>
</tr>
<tr>
<td>Cadiz French serradella</td>
<td>Ornithopus sativus</td>
<td>MR</td>
</tr>
<tr>
<td>Santorini yellow serradella</td>
<td>Ornithopus compressus</td>
<td>MR</td>
</tr>
<tr>
<td>Erica French serradella</td>
<td>Ornithopus sativus</td>
<td>MR</td>
</tr>
<tr>
<td>Hykon rose clover</td>
<td>Trifolium hirtum</td>
<td>MS</td>
</tr>
<tr>
<td>Electra purple clover</td>
<td>Trifolium purpurreum</td>
<td>MS</td>
</tr>
<tr>
<td>Sceptre lucerne</td>
<td>Medicago sativa</td>
<td>MS</td>
</tr>
<tr>
<td>Mauro biserrula</td>
<td>Biserrula pelecinus</td>
<td>S</td>
</tr>
<tr>
<td>Casbah biserrula</td>
<td>Biserrula pelecinus</td>
<td>S</td>
</tr>
<tr>
<td>Caprera crimson clover</td>
<td>Trifolium incamatum</td>
<td>S</td>
</tr>
<tr>
<td>Cefalu arrowleaf clover</td>
<td>Trifolium vesiculosis</td>
<td>S</td>
</tr>
<tr>
<td>Sothis eastern star clover</td>
<td>Trifolium dasyurum</td>
<td>S</td>
</tr>
<tr>
<td>CF27 bladder clover</td>
<td>Trifolium spumosum</td>
<td>S</td>
</tr>
<tr>
<td>2002ESP4 biserrula</td>
<td>Biserrula pelecinus</td>
<td>S</td>
</tr>
<tr>
<td>Coolamon sub. clover</td>
<td>Trifolium subterraneum</td>
<td>S</td>
</tr>
<tr>
<td>Machete wheat</td>
<td>Triticum aestivum</td>
<td>S</td>
</tr>
<tr>
<td>Nitro Plus Persian clover</td>
<td>Trifolium resupinatum</td>
<td>S</td>
</tr>
<tr>
<td>Frontier balansa clover</td>
<td>Trifolium michelianum</td>
<td>S</td>
</tr>
<tr>
<td>Dalkeith sub. clover</td>
<td>Trifolium subterraneum</td>
<td>S</td>
</tr>
<tr>
<td>Caliph barrel medic</td>
<td>Medicago trucatula</td>
<td>S</td>
</tr>
<tr>
<td>Urana sub. clover</td>
<td>Trifolium subterraneum</td>
<td>S</td>
</tr>
<tr>
<td>Santiago burr medic</td>
<td>Medicago polymorpha</td>
<td>VS</td>
</tr>
<tr>
<td>Prima gland clover</td>
<td>Trifolium glanduliferum</td>
<td>VS</td>
</tr>
</tbody>
</table>
CONCLUSION

In cropping paddocks where *P. neglectus* is present, growing serradella or sulla will not lead to increase in the nematode population. Thus the effect of RLN on subsequent cereal crops will be reduced.

Conversely, biserrulla and some clovers can support high populations of *P. neglectus* that could become damaging to cereals and other crops.

Effect on RLN levels will depend on the pasture species.

Since species of RLN other than *P. neglectus* occur in Western Australian cropping areas, additional tests are required to determine the effect of pastures on these other nematodes.

KEY WORDS

nematode, pasture, rotation

ACKNOWLEDGMENTS

DAFWA Pasture Management staff provided seed for testing and advice on growing pastures: Clinton Revell, Phil Nichols, Angelo Loi, Kevin Foster.

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Paper reviewed by: Bill MacLeod
To rip or not to rip. When does it pay?

Imma Farre, Bill Bowden and Stephen Davies
Department of Agriculture and Food, Western Australia

KEY MESSAGES
On average removing subsoil constraints, such as traffic pans, gives positive grain yield responses, however, negative responses to ripping have been observed on some soils in some seasons. Sand plain soils are more responsive to subsoil constraint amelioration but the frequency of negative responses to amelioration is greater when only a mild constraint is removed. Negative responses on heavy soils are less likely but the size of the responses is also smaller making it only worthwhile removing the most severe constraints. Knowing the frequency and size of positive and negative responses to amelioration of subsoil constraints will allow farmers to determine whether it is worthwhile taking the risk to overcome the constraints.

AIMS
Subsoil constraints to root growth can cause water and nutrient limitations to grain yields in our environment. The impact of subsoil constraints on crop growth and grain yield varies markedly with season, location and soil type. Both positive and negative grain yield responses to subsoil amelioration practices such as deep ripping and subsoil liming have been observed. To determine if amelioration of such constraints is a paying proposition, growers need to know the size and frequency of positive and negative grain yield, and dollar, responses to removing them.

It is impossible to collect enough direct, field trial information to handle the interactions of soil type and season on such responses. However, the validated crop simulation model APSIM-Wheat (version 4.1) can be run for a range of soil types, seasons and locations and so allow us to map the regions according to the chances of getting a response to amelioration. In the preliminary study reported here we specifically investigated the effect on wheat production, of reducing root growth rates in the 20-40 cm depth layer for four different severities of soil constraint at two locations and on two contrasting soil types.

METHOD
APSIM-Wheat (v. 4.1) simulates daily values of root growth, biomass and grain yield based on information on daily weather, soil type and crop management.

Simulations were run for Mingenew in the medium rainfall zone (mean April to October rain 350 mm) and Mullewa in the low rainfall zone (mean April to October rain 270 mm). Two soil types present in the wheatbelt of WA, a loamy sand (sand plain) and a duplex (heavy) soil were chosen. Simulations were performed for the 50 year period of 1957-2006. Soil was assumed to be dry at 1 January each year. Sowing time was controlled by a rainfall driven sowing rule, allowing sowing to occur on the first sowing opportunity between 25 April and 31 July.

These runs were devised to improve our understanding of the nature of the season by soil type by location responses to degrees of an unspecified root growth constraint between 20 and 40 cm deep in the profile. Roots had no constraints to growth above and below those depths – i.e. the constraint was a ‘pan’ or ‘choke’ of varying degrees of severity. In the model, this is done by changing the soil hospitality factor to simulate unconstrained, mild, moderate and severe levels of root constraints respectively. The severe level effectively stops roots penetrating more than 23 cm into the soil. The other levels allow roots to penetrate to different depths for different constraints, depending on season.

RESULTS AND DISCUSSION

Yields
The results showed that removing any of the levels of constraint gave increases in the average yield across 50 years (Table 1).
Table 1. Average wheat yields (kg/ha) at different levels of a constraint to root growth in the 20-40 cm layer, for heavy and sand plain soil types at Mullewa and Mingenew

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil type</th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mullewa heavy</td>
<td>1675</td>
<td>1613</td>
<td>1379</td>
<td>1104</td>
<td></td>
</tr>
<tr>
<td>Mullewa sand plain</td>
<td>2515</td>
<td>2242</td>
<td>1008</td>
<td>573</td>
<td></td>
</tr>
<tr>
<td>Mingenew heavy</td>
<td>2469</td>
<td>2299</td>
<td>1870</td>
<td>1557</td>
<td></td>
</tr>
<tr>
<td>Mingenew sand plain</td>
<td>3375</td>
<td>2703</td>
<td>1279</td>
<td>771</td>
<td></td>
</tr>
</tbody>
</table>

It is interesting to note the average yields which are possible when roots are constrained to only about 230 mm of soil depth (severe constraint; Tables 1 and 2). On the heavy soil, some seasons allow yields of up to 2.5 t/ha with only 23 cm soil depth while on the sand plain soil, this limit is only about half that (Figure 1), reflecting the relative storage of water in the two soil types. When there is no constraint to root growth this soil type effect is reversed.

Table 2. Average root depths (mm) at different levels of a constraint to root growth in the 20-40 cm layer, for heavy and sand plain soil types at Mullewa and Mingenew

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil type</th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mullewa heavy</td>
<td>908</td>
<td>843</td>
<td>699</td>
<td>233</td>
<td></td>
</tr>
<tr>
<td>Mullewa sand plain</td>
<td>1666</td>
<td>1554</td>
<td>874</td>
<td>231</td>
<td></td>
</tr>
<tr>
<td>Mingenew heavy</td>
<td>1023</td>
<td>957</td>
<td>699</td>
<td>233</td>
<td></td>
</tr>
<tr>
<td>Mingenew sand plain</td>
<td>1833</td>
<td>1700</td>
<td>971</td>
<td>235</td>
<td></td>
</tr>
</tbody>
</table>

At the unconstrained and mild levels of constraint, root depth varied markedly with season but averaged 900 mm on the heavy soil and about 1700 mm on the sandplain soils (Table 2). At the moderate level of constraint these came back to about 650 mm and 900 mm respectively. At the severe level, no roots went beyond about 240 mm in any season (Table 2). Average root depths were of the order of 100-150 mm deeper at Mingenew than Mullewa – probably reflecting differences in average wetting depths.

The removal of the low level of constraint gave negative grain yield responses in a number of years (points above the 1:1 line in Figure 1), indicating that in some years, a level of root constraint was beneficial. Practices like ripping a hardpan often gave negative responses even though in the long term the net effect was positive (Table 1). Invariably the negative responses were related to better early growth of the unconstrained crop leading to the squandering of water such that there were inadequate supplies to fill the grain later in the season.
The results showed differences between rainfall locations, soil types and season types. The removal of mild soil constraints gave a negative yield response in about half of the years in Mullewa and in one quarter of the years in Mingenew (points above the 1:1 line in Figure 1 or 100 minus the values in Table 3). In terms of soil types, responses were far greater on sand plain soils than on heavy soils. The negative responses to amelioration were more frequent on sand plain soils than on heavy soils (Table 3; Figure 1). There was also an important effect of season type. Dry years or years with annual rainfall below median were four times more likely to have negative responses to amelioration than wet years (Table 3). The negative responses to the removal of constraints were more likely in low rainfall locations, on sand plain soils and dry years. Conversely, the frequency of positive responses to amelioration was higher in wetter years and at the wetter locations (Table 3). Heavy soils had more frequent positive responses than sand plain soils.

Table 3. Proportion of years (%) with a POSITIVE yield response to removing a MILD subsoil constraint, for all seasons, dry (below median rainfall) and wet (above median rainfall) for heavy and sand plain soils at Mullewa and Mingenew

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil type</th>
<th>All seasons</th>
<th>Dry seasons</th>
<th>Wet seasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mullewa</td>
<td>Heavy</td>
<td>53</td>
<td>33</td>
<td>71</td>
</tr>
<tr>
<td>Mullewa</td>
<td>Sand plain</td>
<td>47</td>
<td>33</td>
<td>58</td>
</tr>
<tr>
<td>Mingenew</td>
<td>Heavy</td>
<td>73</td>
<td>50</td>
<td>96</td>
</tr>
<tr>
<td>Mingenew</td>
<td>Sand plain</td>
<td>69</td>
<td>50</td>
<td>88</td>
</tr>
</tbody>
</table>

Economics

In order to determine if it is economically viable to remove the subsoil constraint, we need to know the magnitude of the positive or negative yield responses to removing the constraint (above). We then need to calculate costs of ameliorating the constraint and the price of the grain. For this exercise (Table 4, Figure 2) we have assumed a cost of (unspecified) amelioration of $40/ha and a return of $250/t for the grain. We have NOT taken future returns (i.e. residual value of amelioration) into account.
The need to be able to define the severity of the constraint is obvious (Figure 2). On heavy soils, the chances of getting significant, paying, short term, responses to amelioration of a mild constraint are small. On sand plain soils, it is obvious that that you will get paying responses to ameliorating moderate and severe levels of constraint in almost all seasons at both locations. At the mild level of constraint you very often get negative returns from amelioration. There is nothing like a destroyed promise of good returns (early crop growth is good in these situations) to turn a grower away from what is a long term, on average, paying proposition!

The marked variation of profitability of amelioration with season (as reflected in the shallowness of the curves in Figure 2) suggests that we might get better returns to amelioration if we could predict/guess the nature of the season to come. An ex-post analysis of these runs (Table 4) shows that positive returns to amelioration on soils of mild constraint are far more likely in wet (and/or high yielding – Figure 1) years than in dry years. The difference in probability of response between seasons diminishes markedly as the severity of the constraint increases.

Table 4. Proportion (%) of years with a positive net return from a removing a MILD subsoil constraint, for all seasons, dry (below median rainfall) and wet (above median rainfall) for heavy and sand plain soils at Mullewa and Mingenew

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil type</th>
<th>All seasons</th>
<th>Dry seasons</th>
<th>Wet seasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mullewa</td>
<td>Heavy</td>
<td>20</td>
<td>8</td>
<td>29</td>
</tr>
<tr>
<td>Mullewa</td>
<td>Sand plain</td>
<td>35</td>
<td>13</td>
<td>54</td>
</tr>
<tr>
<td>Mingenew</td>
<td>Heavy</td>
<td>41</td>
<td>17</td>
<td>63</td>
</tr>
<tr>
<td>Mingenew</td>
<td>Sand plain</td>
<td>63</td>
<td>42</td>
<td>83</td>
</tr>
</tbody>
</table>

Note that compared with Table 3 yield data, the probability of getting positive returns is now higher for the sand plain soil than for the heavy soil – because the levels of response are a lot higher (pay more) on sand plain soils (even though they are less frequent).
CONCLUSION

From the current study it is clear that in most circumstances it is worthwhile removing subsoil constraints on sand plain soils (traffic and acid pans) regardless of their severity at Mingenew. Even in a lower rainfall zone like Mullewa it is well worth ameliorating moderate and severe constraints but for mild constraints there can be a negative effect in a significant number of years. Regardless of soil type or location the more severe the constraint, the bigger is the response to removing it. This fits with current deep ripping practices in the Mingenew area where sand plain soils are often deep ripped before each wheat crop in the rotation.

Amelioration of anything but severe subsoil constraints on heavy soil is probably not worth the effort (less than 500 kg/ha response in most years) until you come into higher rainfall zones. Severe constraints would be those that restrict root growth to such an extent that roots are unable to grow beyond 20-30 cm. In the field, constraints this severe should be quite obvious to direct observation of roots or to the presence of subsoil moisture below 30 cm after crop harvest. Overall, constraints have a far smaller effect on heavy soils than on sand plain soils. The higher water holding capacity of the heavier textured surface soils and the fact that for a given rainfall, the wetting front is far shallower means that a constraint on root growth to depth denies far less resources (water and nitrogen) to crops on heavy soils than on sand plain soils.

These findings have important implications for farmers and the research community. The farmers need to know the frequency and size of positive and negative responses to be able to determine if it is worth trying to overcome the constraints. To this end the GRDC funded WA subsoil constraints project (UWA00081) plans to map the agricultural areas of WA according to some of the above measures of response and chances of response to amelioration of subsoil constraints. The researchers and advisors need to be able to diagnose not only whether there are subsoil constraints but also how severe they are. This may be relatively easy for severe constraint which stops root growth completely but it is much more difficult to distinguish between moderate and mild constraints. The response to removing the constraint can vary markedly with season, location and soil type. Once the risks are defined it may be possible to adjust agronomic management practices (lower seeding rates and/or nutrient inputs, wider rows, etc.) to minimise the risk of a negative responses.

KEY WORDS

subsoil constraints, amelioration, season, sand plain, heavy soils, location

ACKNOWLEDGMENTS

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Project No.: UWA00081
Paper reviewed by: Mike Robertson
Can yield be predicted from remotely sensed data

Henry Smolinski, Jane Speijers and John Bruce, Department of Agriculture and Food, Western Australia

KEY MESSAGES

Remotely sensed data sets together with yield maps can provide land managers with an insight into their paddock variability and overall cropping system efficiency.

All data sets had a relationship with yield for at least one environment (paddock by year combination) however, not one spatial data set could be identified as being best in all environments.

EM and gamma radiometrics are valuable tools that can be used in combination with aerial photography and digital elevation models to delineate land management units and identify environmental constraints. However, soil identification and sampling are still required to validate soil/crop relationships.

AIMS

- Examine the relationships between soil sampling classifications, gamma radiometrics, NDVI (biomass imagery), EM values and elevation.
- To determine whether yield can be predicted from remotely sensed data.

METHOD

Soil survey and field assessment

Traditional soil survey techniques are employed using free survey method at a detailed level (1 site observation/3-10 ha).

Soil observation sites were selected in areas of interest identified from the various spatial data sets and geo-referenced using a standard GPS.

Remotely sensed data

A suite of spatial data was made available through the Corrigin Farm Improvement Group and DAFWA’s spatial data directory for Baker’s, Lee’s and Barrett’s PA paddocks at Corrigin, including:

- digital colour aerial photography enlargements from DAFWA;
- digital elevation models (DEMs) @ 1:5,000 resolution;
- biomass imagery (NDVI) @ 1:10,000; September 2002 and October 2004;
- electromagnetic induction imagery (Geonics EM31 and EM38, 25m transect ground traverse) @ 1:6,000;
- gamma radiometric spectrometry providing ternary imagery and individual potassium (K), thorium (Th), uranium (U) and total emission counts (TC) from 25 m ground traverse @ (1:6,000 resolution);
- crop yield, 2002-2004. Raw binary data obtained from the header was converted to text file format and then imported into Geomedia as a text file.

All radiometric data, EM’s, NDVI, elevations and yield values were kriged using a 25 m search radius to give values at the soil sampling points.

Complete radiometric (U, Th, K and TC), EM and elevation measurements were pre-processed by Geoforce to remove background errors. Yield and NDVI data was available for two years for each paddock. The data set for each measurement was captured at a different resolution with radiometric data being recorded at the lowest resolution (approximately 25 m grid). Elevation was extracted from...
a DEM model at the points at which radiometric data was recorded. High resolution NDVI and yield data was kriged using Vesper to give values at the same points as the radiometric recording points (Whelan et al. 2001).

RESULTS

In Lee's and Barrett's paddocks K was highly correlated with U, Th and TC but the correlation was low in Baker's paddock due to geological complexity. However, the gamma radiometrics was useful in defining distinct geological areas and identifying the major soil groups (pale sandy duplex, gravels, brown loamy duplex).

Elevation was highly correlated with radiometric data in Barrett's paddock, due to its prominent laterite plateau, but had lower correlations at other sites. Although soil point classifications showed some association with radiometric, EM and elevation data on Baker's and Lee's paddocks this was not the case at Barrett's where subsoil acidity is the main limitation.

Case study: Baker's paddock

For Baker's paddock median lupin yield in 2002 was 0.45 (min: 0.01; max: 2.44) and median wheat yield in 2004 was 2.13 (min: 0.33; max: 3.98). There were significant correlations (Table 1) between lupin yield in 2002 and EM measurements and elevation. There is no relationship between lupin yield and NDVI in 2002. There are significant correlations between wheat yield in 2004 and EM measurements, logU, elevation and NDVI in October 2004.

Part of the yield variation can be attributed to the combination of waterlogging and salinity, which are represented by the EM and DEM data sets. The EM imagery and a digital elevation model could be used to delineate the most significant low yielding areas.

Case study: Lee’s paddock

For Lee’s paddock median wheat yield in 2002 was 1.24 (min: 0.10; max: 1.34) and median wheat yield in 2004 was 3.81 (min: 1.20; max: 6.19). There were significant correlations between wheat yield in 2002 and NDVI and elevation. In 2004 all variables had significant correlations with wheat yield.

Most of the yield variation can attributed to two contrasting soil types (loamy gravels and sands) which have different plant available water holding capacity (PAWC). The sands were mainly confined to lower positions in the landscape.

In 2004 (good season), all spatial data sets were useful in identifying yield variation with both gamma radiometrics and EM31-38 imagery indicated textural differences.

Yield data (25 m search radius from sampling points) indicates a 25-30% yield difference between yellow-brown loamy gravels and moderately deep pale sands over gravel.

Case study: Barrett’s paddock

For Barrett's paddock median wheat yield in 2002 was 1.64 (min: 0.01; max: 3.54) and median wheat yield in 2003 was 1.58 (min: 0.06; max: 3.13). There were significant correlations between wheat yield in 2002 and LogTh, LogU, LogTC and NDVI. In 2003 there were significant correlations between canola yield and all variables except elevation and LogK.

Gamma radiometrics imagery was useful in defining broad soil groups and when combined with contour information provided further distinction within the drainage depression. Individual Th and K data distinguished yellow sands from minor areas of pale sand. The negative correlation between EM and yield is not clear as EM values were very low.

Field testing identified subsoil acidity and subsoil compaction as limitations to yield, particularly within the drainage depression and areas of yellow sand, which is clearly indicated by NDVI imagery within the liming trials (south east corner). This emphasises the importance of soil testing for subsoil constraints when analysing yield variation.
Table 1. Correlation with yield. Highlighted values indicate $P < .001$

<table>
<thead>
<tr>
<th>Paddocks</th>
<th>Baker's</th>
<th>Lee's</th>
<th>Barrett's</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI</td>
<td>-0.05</td>
<td>0.49</td>
<td>0.46</td>
</tr>
<tr>
<td>Gamma</td>
<td>0.17</td>
<td>0.22</td>
<td>0.16</td>
</tr>
<tr>
<td>EM</td>
<td>-0.43</td>
<td>-0.27</td>
<td>0.06</td>
</tr>
<tr>
<td>DEM</td>
<td>0.45</td>
<td>0.38</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Visual examination of high resolution NDVI pictures indicate there are effects of seeding, i.e. seeding runs (approx 10 m in width) can be clearly seen in Baker’s and Lee’s paddocks.

In the case of Baker’s paddock 20-30% yield variation between adjacent rows was the result of yield monitor errors brought about by changes in topography (see Figure 1).

DEM’s provided a significant correlation with yield at all sites because of its association with different environmental factors at each site. At Baker’s, yield decline was evident in flow lines and lower slopes that are prone to salinity, waterlogging and frost while at Lee’s, deeper colluvial deposits of pale sand, having low PAWC, mainly occurred on lower slopes.

Lower correlations with yield at Baker’s and Barrett’s probably relate to the influence of several subsoil constraints and climatic conditions (i.e. salinity/waterlogging, frost, subsoil acidity and compaction).

The correlation of radiometric data to yield was overall low in all paddocks with the exception at Lee’s, in 2003, where high Log K values were positively correlated with the more productive gravelly soils ($r = 0.509$).

As radiometric data only identifies soil mineralogy within the upper 30 cm of the soil profile it doesn’t always reflect variations in soil PAWC or indicate subsoil constraints. This was apparent at Bakers where similar radiometric signatures were obtained from pale sandy duplex and sand over gravel soil profiles that had contrasting drainage. Moreover, similar soil types at Lee’s and Barrett’s had the same radiometric signatures but at Barrett’s, soil acidity and compaction restricted yield potential. These examples highlight the importance of selective soil sampling to identify subsoil constraints.

Radiometric maps are a valuable aid in delineating geological zones and soil boundaries and surpass the accuracy that could be achieved from free survey or grid soil survey techniques (from personal survey experience).

EM data was significantly correlated to yield in all paddocks during 2003-2004 seasons and had the best negative correlation with yield at Baker’s where salinity-waterlogging was a limitation within flow lines. In contrast, EM data was positively correlated with yield at Lee’s as the areas of low conductivity were associated with deeper pale sands that have the lowest PAWC values.

CONCLUSION

A combination of spatial data sets is necessary to better understand yield variability. The value of each data sets was shown to vary between paddocks and within paddocks depending on the season and environmental factors. This limits the usefulness of extending any predictions of yield to other paddocks.
High resolution NDVI and yield maps highlighted the variability imposed by cropping management that can result in up to 25% yield variation. Limitations in yield monitoring sensors can introduce a further 20% in variance.

The combination of aerial photography and contours is readily available at minimal cost and is currently used as a standard base with ground-truthing to develop land management zones. The addition of yield maps to these basic data sets will greatly improve the delineation and understanding of yield variability.

High resolution EM and gamma radiometrics can help identify environmental yield constraints and are particularly useful in areas of salinity or strongly contrasting soils however, the high cost of this data will not be warranted in all environments.

KEY WORDS
gamma radiometrics, EM, yield variability

ACKNOWLEDGMENTS
We would like to thank the Corrigin Farmers Improvement Group for the spatial data and their support.

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Paper reviewed by: Jim Dixon, Department of Agriculture and Food, Western Australia
Rotations for profit

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

KEY MESSAGES

Despite having completed four years of a five year rotation there has been very little long term rotation effect on yield. In 2005, large differences in wheat yield were seen resulting from differences in nitrogen fixation in 2004. This observation has not been repeated, with subsequent years not showing decrease in yield associated with continuous cereal cropping relative to a cereal/break crop scenario.

Strong gross margins were achieved for all cropping enterprises in 2007 ranging from $379/ha for lupins to a high of $1104/ha for Wheat. This was due to a combination of good yields and record grain prices. Canola and lupins were the least profitable crops, at $626 and $379/ha respectively, although both performed significantly better than the volunteer pasture, with a gross margin of just $10/ha.

AIM

- 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.

METHOD

The site was 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 growing season mean of 382 mm. Rainfall was 305 mm for the 2007 growing season (May to October). The soil was a loamy sand with a soil pHca ranging from 4.4 to 4.7 at 0-10 cm. Organic carbon ranged from 1.2 to 1.8% at 0-10 cm.

This was the 4th year of a five year rotation. The actual rotations can be seen below in Figure 1.

The trial was laid out in 2004 in a complete randomised block design with nine treatments. This was replicated three times. Plots were 9.8 m wide, 20 m long and sown at 22 cm row spacings. The 2007 treatments were sown with knifepoints into a friable, moist seedbed. The lupins and canola were sown on 3 May. The wheat and barley were sown on 14 June. Lupins (cv. Mandellup) were sown at 90 kg/ha, canola (cv. Bravo) at 4 kg/ha, wheat (cv. Yitpi and EGA 2248) at 80 kg/ha and barley (cv. Vlamingh) at 70 kg/ha. The cereals and lupins were sown at a depth of 4 cm and the canola at 1 cm. Appropriate pre emergent and post emergent herbicides were used. Crop nutrition was provided as soil and tissue testing dictated with basal and topdressed fertilisers. Systemic seed fungicide dressings were used on all cereals, with fungicidal sprays being used on the barley treatments.

Crops were assessed for crop vigour and weed populations at 84 days after sowing (DAS) and disease severity at 153 DAS. Canola and lupins were direct harvested at 194 DAS. Cereals were direct harvested at 222 DAS. Cereal grain was analysed for protein, moisture, screenings, specific weight and yield. Lupin grain was analysed for protein, moisture and yield. Canola seed was analysed for oil content, moisture and yield.

All data was statistically analysed using a confidence interval of 95% unless otherwise specified. Means were compared using Fisher’s Least Significant Difference (lisd) Test.
RESULTS AND DISCUSSION

Crop vigour and weed populations

Crop vigour index (1-9) ranged from 5.3 to 6.7 and weed populations ranged from 11.3 to 17.3 plants per m². There was no difference between treatments for crop vigour (P = 0.46) or weed population (P = 0.85).

Disease

Disease incidence in the cereals was low. No disease problems were reported in the lupins or canola. The powdery mildew severity index (0-100) ranged from 0 to 9.8. The EGA 2248 wheat cultivar was the most susceptible with the Vlamingh barley cultivar being the most tolerant. The cereal on cereal rotations had the lowest scores amongst all treatments. Net Blotch infection in barley was low with less than 3.5% on all leaves. There was no difference (P > 0.40) between barley treatments.

Yield

Grain yields ranged from 1.6 to 3.8 t/ha, with cereals yielding more than either canola or lupins. The only difference to note was the Yitpi wheat cultivar in the vetch/wheat/wheat/wheat treatment (3.8 t/ha) yielding higher than the EGA 2248 wheat cultivar in the continuous wheat rotation (3.0 t/ha). This difference was more likely cultivar related than rotation related. Yields can be seen below in Figure 2.

Grain quality

No differences in grain quality arose from the different rotations with statistically similar protein, moisture, specific weight and screening levels for wheat.

Gross margins

Gross margins for crops in 2007 were generally quite high ranging from $379/ha for lupins through to $1104/ha for wheat. Canola and lupins were the least profitable crops, at $626 and $379/ha respectively, but clearly outperformed volunteer pasture’s gross margin of $10/ha. Gross margins and yields for 2007 can be seen below in Figure 2.
Crop Updates is a partnership between the Department of Agriculture and Food, Western Australia and the Grains Research & Development Corporation.

Figure 2. Yields and gross margins for the different rotations in the Facey Group Rotations for Profit Trial.

Record grain prices played a significant role in the gross margin returns for cropping. Maximum gross margins between years varied significantly despite higher yields being recorded in 2005 ($330/ha) than in 2007 ($1104). Record grain prices and relatively lower sheep returns in 2007 may also adversely skew the long term gross margin for rotation 7. Individual yearly gross margin returns can be seen below in Figure 3, and cumulative gross margins can be seen below in Figure 4.

Figure 3. Yearly gross margin returns from 2004-2007.
CONCLUSIONS

No significant differences in weed density or crop vigour were found between treatments. The use of continuous cereals as opposed to break crop rotations has not led to an increase in leaf diseases or significant differences in yield. The highest yielding treatment was the Vetch/Wheat/Wheat/Wheat rotation. Continuous barley has the highest 4 year gross margin ($1481/ha) whilst Lupin/Wheat/Canola/Wheat ($1444/ha), Vetch/Wheat/Wheat/Wheat ($1346/ha) were quite strong performers also. The traditional role of volunteer pasture within a cropping rotation may have to be questioned as the gross margins over 1, 3 and 4 year periods show a considerable lag between it and continuous cropping enterprises. The use of brown manure crops such as vetch has revealed positive correlations for yield and gross margin. The final year of the rotation trial should lead to a better understanding of the implications of rotation choice on the long term sustainability of farming enterprises in the Wickepin Shire.

KEY WORDS

profit, sustainability, yield, rotation

ACKNOWLEDGEMENTS

Darren Hughes and Peter Rees of Kalyx Agriculture.

Paper reviewed by: Tas Larnach
Rewriting rules for the new cropping economics

David Rees, Consultant, Albany

KEY MESSAGES
Potential profitability of cropping has increased dramatically. This will change the approach to cropping, though will widen the important differences between individual businesses. Without experience at this level of profitability, some economic principles can help with decisions. Some principles suggested are:

- Use past trends as a guide (‘the trend is your friend’).
- Consider changes from all angles – the production response curve, and long term costs and benefits.
- Account for human nature.

BACKGROUND
The recent rise in grain prices has been dramatic, and potentially raises the profitability of cropping to new levels. A chart published by Profarmer (2007) gives a perspective on fluctuations of wheat prices since 1923.

Of course these prices have to be translated into profit, and poor seasons have prevented many WA farmers from enjoying the benefit of these prices. However with an average season, the price rises offer potential for even greater profit than the prices themselves indicate. The example below shows that in response to double the price for wheat, the profit margin increases threefold. It assumes the cost of growing the crop remains unchanged at $200 a tonne.

<table>
<thead>
<tr>
<th></th>
<th>Yield</th>
<th>$/tonne</th>
<th>Gross</th>
<th>Cost/ha</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal wheat</td>
<td>2.0</td>
<td>$200</td>
<td>$400</td>
<td>$200</td>
<td>$200</td>
</tr>
<tr>
<td>Current wheat</td>
<td>2.0</td>
<td>$400</td>
<td>$800</td>
<td>$200</td>
<td>$600</td>
</tr>
</tbody>
</table>

This profit incentive will encourage increased production to levels where there is little experience to guide decisions. Furthermore, the potential profits will facilitate individual goals, and this will accentuate the important differences between farms. Some principles of economics can help with decisions in this new economic environment.

**Principle 1. ‘The trend is your friend’**
Economic trends are the first guide to the direction for WA cropping. Pannell and Kingwell (2004) summarised these trends, and even at that time, concluded that farming returns have matched other investments, which makes the trends outlined in the paper instructive for the improved prospects now faced.
• Individual farms differ widely, so the rules for the new cropping economics will also differ from one farm to the next. It can be inferred that these differences will widen as the new cropping economics allows businesses to capitalise on economies of scale, though this may be at the expense of diversity of enterprises.

• Labour constraints will dominate the new rules, and this will be accelerated by the mining boom. Larger cropping operations use less labour per tonne of grain, and will be advantaged even further with good returns.

• Technology improvements such as plant breeding that have benefited the last two decades of grain farming will be more difficult in the future (e.g. Fisher 2007).

• Significant niche markets for WA grain have not become evident, and at higher prices, margins for premium grain are relatively lower.

• Climate change is now a major driver and will widen the spread between the profitability of well managed crops, and ‘unlucky’ management.

Individual cropping businesses should seek to capitalise on these trends, rather than hope for other opportunities.

**Principle 2. The production response curve**

The fundamental concept of economics is that producers will increase production in response to price of the commodity (whereas consumers will reduce demand as the price rises). However for the individual grain producer, in a single year, the price he will receive (for the same grade of grain) will be the same irrespective of his level of production. This means his decisions should focus on how he goes about producing grain – his supply curve. How should he allocate inputs to produce grain?

Economics assumes that a producer knows how much an input will increase production – the ‘production response curve’. This may not be known with accuracy, but even superficial consideration can help clarify whether increased levels of inputs will clearly increase production.

For most inputs, successful croppers are probably operating near the flat part of the production response curve (e.g. Pannell 2006), but with the new cropping economics, this assumption should be reviewed. It sometimes comes as a surprise that a particular farmer has overlooked an important nutrient input such as a trace element or potassium.

It is disappointing that the production response curve principle is not more widely presented. For example, soil test results would be more meaningful if the production response curves were given. The concept may help people scrutiny the likely range of new claims for special inputs that can now be afforded.

With the new economics, all inputs should be reviewed, and different business will come to different conclusions about levels of input. For instance, for many farmers, finance costs could now be relatively cheap, and rather than increasing inputs per hectare, it may be more effective to purchase or lease more cropping land.

Priorities can be assessed even by considering inputs at the simplest level, grouping assets into categories of land, labour, and capital. At this basic level capital may have been a constraint in the past, such as when farmers were developing new land, but with current economics, labour issues are now a more likely constraint.

**Principle 3. Make decisions at the ‘margin’ not on averages**

The new cropping economics will encourage extra production, not only from extra inputs, but also from extra cropped area. Decisions about extra crop should be made on the basis of the ‘extra’ paddock or the ‘extra’ hectare of crop, not on the basis of cashbook or accountants’ figures – which are totalled across the whole enterprise.

For example, extra grain could be produced by cropping another paddock, and though this may require extra fertiliser (a variable cost), it may not require purchase of extra machinery (a fixed cost). The cost of the machinery in this case should therefore be omitted from the decision.
Another example is that ‘less profitable’ crops such as peas can be worthwhile. The pea crop may be more expensive to grow than a cereal crop and the grain sells for less per hectare, but the crop can be planted later, with existing machinery, and perhaps with no loss of income from another enterprise. There is no ‘opportunity cost’ or penalty on the rest of the cropping program by adding peas to the program.

**Principle 4. Allow for long term costs and benefits**

Inputs such as lime raise another question that is commonly overlooked – the value of the input for future years. It is an investment in the future, and though the current crop may receive some benefit, benefits would be a lot more in future years. It is difficult to show this in traditional cash-flow budgets, and this principle may explain why accountants often have a dismal view of the profitability of agriculture.

Another example is that most growers now consider herbicides as a long term investment. Decisions to spray paddocks are rarely made on the basis of the old ‘economic’ threshold levels, but are now directed at the long term benefit from control of seed banks. On this basis, with more potential long term profit from cropping, it would be worth spraying even at low weed levels.

On the other hand, for drought-affected cropping businesses, with limited cash resources and therefore with short-term priorities, short-cuts on herbicides may be sensible.

**Principle 5. Account for human nature**

The reality is that cropping decisions for a family business may be too complicated even for the basic principles outlined so far. With nothing else to go on, you could do worse than to watch and follow what everyone else is doing. Unlike most other businesses, farmers are fortunate to be able to share business practices with their competitors. Group decisions can be remarkably effective, for example as outlined by James Surowiecki in his book, ‘The Wisdom of Crowds’, with important caveats based on short-comings of human nature.

At its most effective, the group wisdom contributes to appropriate ‘rules of thumb’ to deal with the complexity of cropping decisions. However the old ‘rules of thumb’ could restrict opportunities under the new cropping economics. Likewise, the changes to an individual business that has been the victim of drought will make many of the old rules of thumb obsolete, so while group wisdom can be helpful, ultimately, cropping decisions have to be appropriate to the individual business.

Another relevant aspect of human nature is that people are ‘loss averse’ and more strongly influenced by the chance of losses than the prospect of a success. ‘Fortune favours the brave’. The optimist is less likely to miss such opportunities, and if the optimistic approach happens to be falsely optimistic, research (e.g. Douglas and Jones, 2007) reassures us that people tend to have the psychological resilience to cope if the losses do eventuate. A fundamental requirement for cropping decisions is therefore for it to be ‘your thing in life’ – optimistic for the future, and resilient enough to deal with the inevitable adversity that will come from time to time.

The cropping world is likely to change too rapidly for anyone to have all the answers. However until we develop the experience to be confident in this new environment, the principles such as those outlined above should help with decisions.

**CONCLUSION**

The WA cropping environment has changed dramatically with new price expectations. Without experience of cropping in this environment, it will be some years before new practices are proven. In the meantime, some economic principles provide at least a framework for effective decisions.

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KEY WORDS

economics, crops, decision-making

ACKNOWLEDGMENTS

University of WA support for study towards a master degree in Natural Resource Management.

Paper reviewed by: Allan Herbert, Senior Adviser, Economic Services, Department of Agriculture
and Food, Western Australia
Reducing business risk in Binnu! – A case study
Rob Grima, Department of Agriculture and Food, Western Australia

KEY MESSAGES
- Cropping 90% of the farm created a poor financial position, despite good yields in the ‘90s.
- A new farming system with increased stock focus increased annual profit.
- This new system reduced financial risk.
- Time frame for transition from old to new production system does not affect overall profit.

AIMS
A grower in Binnu wanted to shift his farming enterprise away from cropping dominant to more mixed farming, increasing his stocking rates. He believed this change would reduce financial risk and increase profitability. This analysis compares the annual profit and potential risks of the current known system to the new assumed system. An analysis of preferred transition method is also conducted.

METHOD
The 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 using real farm data from the case study farm to investigate the progressive annual cash flow consequences of changing the enterprise mix. The main output is annual surplus or deficit. The model takes into account the cost price squeeze by increasing costs by 3% per annum and returns by only 2% per annum. A discount rate of 7% was applied to return all annual surplus's to today's value. It should be noted that annual surplus is net of farmers’ wage (management fee or living expense). An annual yield increase of 2% is also included in this analysis. Over the last 20 years this has been the average yield increase for all crops in the State. It is assumed this will continue for all analyses presented here.

The results of the analysis should only be a guide to compare relative differences between the different systems and to explore what are the main profit drivers in each system. Changes in land prices are not included in the system.

The grower supplied soil type zones, along with rotation, production and input cost details for each zone. Average financial data from Bankwest and PlanFarm benchmarks were used to estimate capital and fixed costs. Other assumptions included an average wheat farm gate price of $180/t, $55/head for lambs, $20/head for cast for age ewes and 680¢/kg of clean wool.

Table 1. Soil types and production data in current enterprise

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Poor sand</th>
<th>Good sand</th>
<th>Loam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (ha)</td>
<td>420</td>
<td>1450</td>
<td>440</td>
</tr>
<tr>
<td>(18%)</td>
<td>(63%)</td>
<td>(19%)</td>
<td></td>
</tr>
<tr>
<td>Rotation</td>
<td>WL</td>
<td>WL</td>
<td>WP</td>
</tr>
<tr>
<td>Wheat yield</td>
<td>0.8</td>
<td>1.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Lupin yield</td>
<td>0.8</td>
<td>1.5</td>
<td>-</td>
</tr>
<tr>
<td>Pasture yield</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Fert costs</td>
<td>83</td>
<td>111</td>
<td>87</td>
</tr>
</tbody>
</table>

* Poor sands = 175 ha tagasaste, 105 ha vol past, 140 ha sown oats, good sand = 240 ha sown oats.

^ 200 kg/ha yield loss due to continuous cereal.

Table 2. Economic parameters for the old farm versus the new farm

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Old farm</th>
<th>New farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weak sand</td>
<td>WL</td>
<td>*refer below</td>
</tr>
<tr>
<td>Good sand</td>
<td>WL</td>
<td>WWLWWPoats</td>
</tr>
<tr>
<td>Red loam</td>
<td>WPclover</td>
<td>WW^</td>
</tr>
<tr>
<td>Cropping %</td>
<td>90%</td>
<td>71%</td>
</tr>
<tr>
<td>Pasture area</td>
<td>220 ha</td>
<td>662 ha*</td>
</tr>
<tr>
<td>Breeding ewes</td>
<td>470</td>
<td>2190</td>
</tr>
<tr>
<td>Total DSE</td>
<td>1100</td>
<td>5340</td>
</tr>
<tr>
<td>DSE/ha</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Fodder costs</td>
<td>-</td>
<td>$30,000</td>
</tr>
<tr>
<td>Crop capital costs</td>
<td>$80,500</td>
<td>$70,000</td>
</tr>
<tr>
<td>Stock capital costs</td>
<td>$2,250</td>
<td>$8,900</td>
</tr>
</tbody>
</table>

Crop Updates is a partnership between the Department of Agriculture and Food, Western Australia and the Grains Research & Development Corporation

83
The analyses

1. A financial analysis comparing the old system to the new system using the STEP model, where:

<table>
<thead>
<tr>
<th>Old system</th>
<th>New system</th>
</tr>
</thead>
<tbody>
<tr>
<td>90% crop</td>
<td>70% crop but varies depending on season</td>
</tr>
<tr>
<td>Low stocking rate (5 dse/wgha)</td>
<td>High stocking rate (8 dse/wgha)</td>
</tr>
<tr>
<td>Perennial pasture established on poor sands in belts</td>
<td>Cropping OR grazing can occur between these belts</td>
</tr>
</tbody>
</table>

2. And a comparison of 1 year versus 4 years transition from old system to new.

RESULTS

Old system versus new!

Profit in the old system was negative, with an average annual deficit of -$8,000 (Table 3). Much of this negative result was from failing to achieve break even yields on the weak sands. This soil type makes up a significant part of the farm. A small increase in profit was achieved by simply utilising this land for stock and not crop (data not shown)! A small stock carrying capacity of 3 DSE/wgha with no pasture costs generated a breakeven profit.

The new system generated an average annual surplus of $27,000, so it is clearly more profitable. Looking more closely at each enterprise, both crop and stock gross margins increased in the new system, and crop capital costs were also reduced due to lower cropping area in the new system.

Figure 1: Comparison of Transitions

Transition analysis

The time frame for a transition from the old system to the new system does not affect overall profit. Figure 1 shows the relative impact on annual surplus a one year transition has compared to four years. From 2011 onward the annual surpluses are identical, but there are large differences in the first four years. When transitioning in only one year all establishment costs are spent in the first year, as well as massive stock purchasing costs in the second year to maximise the fodder available. However this scenario has full production from year two onward and therefore has greater returns in years two to four compared to a four year transition. Establishment costs for the longer transition scenario are spread the four years, and no stock buying costs exist as the self replacing flock simply builds up. This means overall costs are lower but stock income is low until the fifth year.
CONCLUSION

When comparing the old production system to the new system, it is clear the new system is more profitable with an average annual profit increase of $35,000. Reduced reliance on cropping, particularly on the weak sands which are highly variable and often provide a negative return, immediately reduces risk. The investment to establish perennial fodder shrubs on this soil type increases income substantially. The major financial and environmental risk with large stock numbers is the autumn feed gap, particularly for those farms with low stubble areas. The latest research suggests perennial shrubs and grasses can be utilised during this period, reducing required hand fed fodder. This mechanism reduces costs and therefore financial risk. It also reduces environmental hazards!

The most recent research data studying stocking rates on perennial fodder suggest a grazing potential of 8 DSE all year round is achievable with small management changes such as rotational grazing and fencing. Wiley and Grima (2007) found that 6 DSE was achievable from these feed types in the 2006 drought year. Some paddocks provided enough feed to sustain 8 DSE all year round. The achieved stocking rate becomes a key profit driver of the new system in this analysis. If the grower achieves only 6 dse/ha then annual profit is reduced to $19,000, and a district average grazing rate of 4 dse/ha will return a negative profit only marginally better than the old system.

This analysis suggests both time frames for transitioning to the new system offer similar benefits. There is probably less risk with a slower transition due to several factors. The first is it allows the grower to maintain his own genetics; dilution of the genetics would occur if ewes were bought in during the rapid transition scenario. Also, the grower will adjust management progressively and learn new or better techniques on a smaller acreage in the first years. Undoubtedly problems would arise and then would be fixed before a large area of land was affected, reducing the risk of possible financial losses.

Reduced risk-financial and production

Managing seasonal risk is possibly the most challenging aspect of primary production. The grower wanted to change the farm design to increase production flexibility. It was this grower’s observation that the old system had less flexibility in coping with seasonality differences. He maintained cropped area at static levels whilst struggling to cope with livestock decisions in dry years. Hence in those years fodder costs usually increased as not only were yields low, but so too was feed from stubbles.

Growers find destocking decisions in dry years extremely difficult. Many claim value in their ‘genetics’ and consequently either don’t destock enough and face costly fodder costs, or destock too late and achieve very low sell prices (supply > demand). Either way, financial costs are incurred. Also, after drought growers wishing to restock face large buyback costs (demand > supply). Hence the sell/buy process can be costly. If a grower can maintain his stock number during this period at low feeding cost (available pasture) can take advantage of the market fluctuations instead of being a victim of them. This clearly reduces risk, and became the focus for this grower. He wanted to alter his response to fluctuating seasons by maintaining stock number and altering crop area according to season type and market signals. This in essence is hoped to reduce financial risk in several ways. This full flexibility was instrumental in considering paddock design. Poor sand paddocks will be sown to fodder shrubs in belts, so as pasture or crops can be used between the belts.

The main costs to this business, apart from once off fodder establishment costs, are crop machinery and variable input costs. Reducing cropped area immediately reduces financial risk IF production income is not compromised. With flexible production options such as the fodder belts, growers can make use of market signals and seasonal information to dedicate land use for either livestock or grain production. The option to utilise some usually cropped land during the dry seasons for feed, or use the poor sand for crop when opportunity arises reduces risk. If the belts prove favourable he will continue to employ a similar tactic on a portion of his better sands. The use of grazing cereal crops is also hoped to be implemented on this farm to further increase stocking potential.

KEY WORDS

pasture, profit, profit drivers, stocking rate, farming system
REFERENCES


Project No.: NLP 053076
Paper reviewed by: Andrew Blake
Does improved ewe management offer grain farmers much extra profit?

John Young, Farming Systems Analysis Service  
Ross Kingwell, Department of Agriculture and Food, Western Australia and UWA  
Chris Oldham, Department of Agriculture and Food, Western Australia

KEY MESSAGES
Even at high grain prices, using target condition scores for ewe management boosts farm profit by up to 6% – through beneficial lifetime impacts on sheep production. The optimum condition score profiles for ewes are robust and are little affected by changing commodity prices, and the relative profitability of the sheep enterprise. The optimal strategy is to aim for a condition score of 2.7 or above at joining then maintain the ewes’ condition through to lambing. However, farmers with crop dominant farming systems may find the profit incentive for adopting target condition scoring of ewes to be inadequate to stimulate a change in their sheep management.

AIMS
To assess the profitability of using target condition scoring for ewe management.

METHOD
The effects of condition score management of ewes was examined using plot scale research during the years 2001 to 2003 at various sites. Statistical analysis of the plot data was followed by paddock scale pilots to test the robustness of the findings from the plot trials. The verified findings were then incorporated into the whole-farm bioeconomic model known as MIDAS (Model of an Integrated Dryland Agricultural System) and a wide-ranging sensitivity analysis was conducted to test the robustness of findings.

The Central Wheatbelt version of MIDAS was selected as the modelling tool because it includes a detailed feed budgeting module that optimises feed management across the whole farm. MIDAS is a computer model used to assess the impact of changes in a farming system. It describes the biological relationships of a representative mixed-enterprise farm and selects the appropriate mix of cropping and sheep to maximise profit. Flock profitability is based on the productivity of each class of stock, commodity prices, and the farm’s carrying capacity. Being an optimisation model, it calculates the optimum stocking rate and optimum use of feed, including level of grain feeding that will maximise profitability while achieving the condition score targets specified for the ewes.

RESULTS
The trial data indicated that managing ewes’ condition scores through their reproductive cycle resulted in:

a. increased lamb survival and weaning percentages;
b. increased progeny fleece weight and decreased fibre diameter of their wool;
c. improved ewe health and survival;
d. increased ewe wool production and tensile strength;
e. improved ewe reproduction.

These trial findings were incorporated in the Central Wheatbelt MIDAS model to show how wholefarm profit is affected.

Fifteen different condition score (CS) profiles were evaluated:

- Three alternative condition scores at joining – 2.7, 3.0 and 3.3.
- Three rates of loss of condition to day 90 – no loss, lose 0.2CS and lose 0.4CS; and
- Four rates of condition change after day 90 – gain 0.4CS, no change, lose 0.2CS’ lose 0.4CS.
The optimum CS profile that includes progeny effects is to aim for a condition score of 2.7 or above at joining then maintain the ewes’ CS through to lambing. At standard prices of commodities, this strategy generates between $2,180 and $5,745 more profit than the optimal CS profile that excludes progeny effects (see Table 1).

If feed grain average historical prices increased 25% (e.g. $278/t for lupins), the stocking rate decreased from 8.5 dse/ha to 7.2 dse/ha. If grain prices increased by 100% then stocking rate decreased further to 6.2 dse/ha. However, the optimum CS profile for either case is robust and the only impact of altering commodity prices or enterprise production relativities is on the joining target. The optimal pattern of ewe condition during pregnancy is unchanged. To achieve these CS targets requires producers to increase their rate of supplementary feeding by about 5% and to alter the allocation of high quality stubbles in summer and autumn.

Table 1. Differences in profitability ($/yr) for the 2000 hectare MIDAS farm when lifetime (progeny) effects are excluded or included. (based on average seasons and prices over the last five years)

<table>
<thead>
<tr>
<th>Optimal condition score pattern for ewes</th>
<th>Excluding lifetime effects</th>
<th>Including lifetime effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Paddock trial findings</td>
<td>Plot trial findings</td>
</tr>
<tr>
<td>Join CS 2.7, maintain to day 90, lose 0.4 to lambing</td>
<td>+$3880</td>
<td>0</td>
</tr>
<tr>
<td>Maintain joining to lambing</td>
<td>0</td>
<td>+$5745</td>
</tr>
<tr>
<td>Percentage of farm profit</td>
<td>4%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Improved ewe nutrition profiles is a profitable change in sheep management. However, the increased profit is small relative to wholefarm profit because the majority of income from farms in the central wheatbelt region of Western Australia is from cropping. There is also some uncertainty about the exact nature of the lifetime impacts as evidenced by the different findings from paddock versus plot-based trials. Further, the change in ewe management requires extra work in grain feeding and rationing the stubbles which may be a disincentive to adoption. It is likely that only farmers with highly sheep dominant farming systems will realistically trial the new system of ewe management as their farm profit is based principally on the profitability of their sheep enterprise.

CONCLUSION

Using target condition scores for ewe management boosts farm profit by up to 6%, even at high grain prices, through beneficial lifetime impacts on sheep production. The optimum condition score profiles for ewes are robust and appear to be little affected by changing commodity prices, and the relative profitability of the sheep enterprise. However, farmers with crop dominant farming systems may find the profit incentives and the extra work involved in monitoring the condition score of ewes to be inadequate to convince them to alter their current management of ewes.

KEY WORDS

sheep management, condition score, central wheatbelt, wholefarm profit

Project No.: Australian Wool Innovation project EC298: Lifetime wool

Paper reviewed by: Allan Herbert
Crop establishment and productivity with improved root zone drainage

Dr Derk Bakker, Research Officer, Department of Agriculture and Food, Western Australia, Albany

KEY MESSAGES

The formation of small drainage furrows and the placement of seed near the edge is a realistic option as a seeding method that will reduce the impact of waterlogging on crop productivity. The trial results continue to show trends in favour of this type of seeding, even in dry years. The disc option for cutting the drainage furrows makes it more attractive from a minimum tillage point of view while some modification to the special ridge-seeding point are still to be tested and tried.

AIMS

To develop and implement a seeding method that would reduce the impact of waterlogging on the crop productivity.

INTRODUCTION

Grains research in the high rainfall zone has consistently and repeatedly highlighted the detrimental effects of waterlogging on grain yield. Raised beds successfully reduce waterlogging and improve grain yield but are difficult to implement due to the permanent nature of the beds which makes them impractical in the pasture phase, the layout of many paddocks, the incompatibility of the beds with many farm operations and requiring large capital investment required.

Research has shown that cereal grain crops are most susceptible to waterlogging between crop emergence and tillering. Traditional seeding techniques always result in the placement of the seed in the furrow made by a leading tyne and/or press wheel, a position most prone to waterlogging see Figure 1.

![Figure 1. Water filled seed furrows at seeding time, North Stirling 2005.](image)

By making small separate dedicated drainage furrows and placing the seed adjacent to those furrows with minimum soil disturbance the seedling is placed in freely drained topsoil during the early stages of development.

The drainage furrows are made during the seeding operation each year and have minimal impact on sheep, trafficability and machinery. The orientation of the drainage furrows is important; furrows up and down the slope greatly enhance shallow drainage whereas furrows on the contour improve moisture retention and storage.

In 2005 (Bakker 2006) and 2006 (Bakker 2007) statistically significant yield increases were obtained with this approach. This paper describes the evolution of this method of seeding with the results obtained in 2007.
METHOD

Seeding treatments were evaluated in small plot trails located in farmers paddocks at Kalgan, Gairdner, Jerramungup and South Stirling. At each location, trials were sown at the break of the season with the same species as the surrounding crop, in areas susceptible to waterlogging.

Trials consisted of a minimum of five replicates with 3 or 4 seeding treatments in a randomised block design. Seeding treatments compared to crop sown with either a narrow point (NP) or a single disc (D) with crop sown adjacent to small furrows, made with either a disc (FD) or modified points (FP). At Kalgan the treatments were: NP, D and FD and sown to triticale, at Gairdner: NP, D and FP sown to barley, at Jerramungup: NP, D and FP sown to wheat and at South Stirling: NP, D, FD and FP sown to barley. All the agronomical inputs were the same as the bulk area.

Furrows were made with discs (FD) or modified points (FP) attached to spring loaded tynes on a small plot seeder. The modified points (FP) created small but well defined triangular shaped furrows with the spoil deposited neatly adjacent to the furrows (Figure 2). The disks used to cut the furrow (FD) were slightly curved, able to cut through a large stubble load effortlessly and reduced the amount of soil shifted compared to the modified points.

In both furrow treatments the seed was placed close to a single disc opener following close behind the furrow forming disk or tine. The disk opener was set to cut soil away from the side of the furrow to a depth just below the original soil level, to minimise toxicity from Trifluralin herbicide. In the case of the FP treatment the disk opener was also followed by a narrow press wheel. See Figure 2 for a schematic layout of the ridge seeding concept, Figure 3 for the actual product while Figure 4 shows the crops growing near the furrows.

The method of placing the seed was similar to the FP. There were two seed rows for each FP or FD.

Figure 2. Schematic rear view of seeding with a furrow point (FP) (left) and with a disc (FD) (right).

Figure 3. Rear view of the plot seeder configured for seeding with furrow point (FP) (left) and with disc (FD) (right). The tyne in front of the disc was used to reduce the work done by the disc.
At two sites (South Stirling + Kalgan) small soil moisture probes of the Time Domain Reflectometry (TDR) type were installed in the soil at 5 cm depth in the drainage furrow, and at 5 and 10 cm depth under and midway the plant rows to measure a possible treatment effect on soil moisture content. Rainfall at the sites was obtained with an automatic rain gauge or measured by the farmer. At the Kalgan site (the most undulating site) two plots in each treatment were equipped with little flumes and automatic water level recorders to measure the amount of runoff from the treatments.

Several weeks after seeding plant germination counts were taken in all the plots, in early October each plot was sampled for biomass by cutting two lengths of 1 metre across the width of the plots and each plot was harvested with a plot header at the end of the season.

RESULTS

Rainfall, crop and germination counts are provided in Table 1. Biomass and grain yield are shown in Table 2.

Table 1. Sites, crops sown, rainfall (actual in 2007 and long term mean) and germination counts.

<table>
<thead>
<tr>
<th>Site</th>
<th>Crop</th>
<th>Rain 2007 (mm)</th>
<th>Long term mean rainfall (mm)</th>
<th>Germination (pl/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NP</td>
</tr>
<tr>
<td>Kalgan</td>
<td>Triticale</td>
<td>430</td>
<td>450</td>
<td>44</td>
</tr>
<tr>
<td>Jerramungup</td>
<td>Wheat</td>
<td>209</td>
<td>263</td>
<td>30a</td>
</tr>
<tr>
<td>Gairdner</td>
<td>Barley</td>
<td>280</td>
<td>330</td>
<td>34a</td>
</tr>
<tr>
<td>South Stirling</td>
<td>Barley</td>
<td>344</td>
<td>398</td>
<td>33</td>
</tr>
</tbody>
</table>

Note: Results with different letters are statistically significant. NA: Not Applicable.

Table 2. Biomass and yield for the ridge seeding trials in 2007. NP: Narrow point, D: Single Disc, FD: Furrows made with discs, FP: Furrows made with points.

<table>
<thead>
<tr>
<th>Site</th>
<th>Biomass (T/ha)</th>
<th>Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NP</td>
<td>D</td>
</tr>
<tr>
<td>Kalgan</td>
<td>16.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Jerramungup</td>
<td>5.1</td>
<td>6.1</td>
</tr>
<tr>
<td>Gairdner</td>
<td>8.6</td>
<td>8.7</td>
</tr>
<tr>
<td>South Stirling</td>
<td>11.1</td>
<td>12.6</td>
</tr>
</tbody>
</table>

Note: Results with different letters are statistically significant. NA: Not Applicable.

The rainfall in 2007 was close to the average growing season rainfall but May and June have been very dry and waterlogging not really an issue. Even at the Kalgan site where the rainfall was the highest and the slope was more than 3%, no runoff was observed from the trial site at any time and the crop did not display any signs of waterlogging. Crop establishment at Kalgan and South Stirling was similar amongst the treatments. At Jerramungup, deeper sowing of the NP treatment reduced plant numbers while at Gairdner shallow sowing of the D and FP in a very dry and slightly water...
repellent top soil reduced the plant numbers. The biomass cuts taken in October all displayed a trend of a slight increase in biomass in the FP and FD treatments which was followed by a similar trend in the yield which was significant only at South Stirling.

The changes in the soil moisture content in the furrow at a depth of 5 cm and in the plant row of the FD treatment and the NP plant row at a depth of 5 cm in relation to the rainfall are presented in Figure 5.

From the traces it is clear that the furrow remained moist for most of the time, followed by the NP with the FD plant row the driest. The soil type in the furrow at the level of the soil moisture probe contained more clay because it was lower in the soil profile than the FD and NP positions which had identical soil types (loamy sand). During the wetter period (August) the trace of the FD was drier than the NP, suggesting that that the introduction of the shallow furrows can reduce the soil moisture content in the plant row at a time that waterlogging is detrimental to crop growth. Further work at this level of detail is required to further confirm this. Of the four sites South Stirling was the most prone to waterlogging because it was located on the edge of a flat swampy area with clay at the surface. The largest rainfall event (mid September) occurred when the crop was well past the tillering stage hence the impact of any possible waterlogging was less severe.

The impact of this type of seeding on the overall yield even though not statistically significant in this year with a dry start, is prospective and requires further exploration. It is possible that the additional soil disturbance of making the furrows released some extra nitrogen even though the use of the narrow points would also disturb the soil enough to also generate some additional mineralisation. It is also possible that the presence of the drier shallow top soil where a lot of the feeder roots are located is significant enough to have some effect on the productivity. These aspects would need to be quantified in a more rigorous study than has been possible to date.

The incorporation of the discs as a means to cut shallow drainage furrows in commercial seeder bars is a realistic option but the use of ridge point would be more difficult. Some modifications to the point are currently being made to incorporate the seeding point with the ridge point so that no separate seeding mechanism is required. This modification will be trialled in 2008.

CONCLUSION
The formation of small drainage furrows and the placement of seed near the edge is a possible option as a seeding method that could reduce the impact of waterlogging on crop productivity. The trial results continue to show a trend in favour of this type of seeding, even in dry years. The disc option for cutting the drainage furrows makes it more attractive from a minimum tillage point of view while some modification to the special seeding-furrow point are still to be tested and tried.
KEY WORDS
waterlogging, ridge seeding

ACKNOWLEDGEMENTS
The help of Grey Poulish (DAFWA Albany) has been greatly appreciated as has been the help of the Steward Smith (MBRS) in harvesting the trials. It has also been appreciated that the landowners: M. Adams, B. Keding, H. Reeves and C. Doncon allowed the trials to be conducted on their properties.

REFERENCES


Paper reviewed by: Dr Wal Anderson
Will wheat production in Western Australia be more risky in the future?
Imma Farre and Ian Foster
Department of Agriculture and Food, Western Australia

KEY MESSAGES
Future climate is likely to be warmer and drier in the wheatbelt of Western Australia. Climate change impacts, without allowing for adaptation strategies, show an increase in the frequency of low yields and a decrease in the frequency of high yielding years for most of the Western Australian wheatbelt.

AIMS
Climate change projections for the mid 21st century for southern WA indicate an increase in temperatures, a decrease in rainfall and higher CO₂ concentrations from current conditions. These changes could have adverse impacts on some agricultural systems, but they may also offer new opportunities (i.e. in areas where the risk of waterlogging may be reduced). The aim of this paper is to quantify the impact of climate change on the risk of wheat production in the wheatbelt of WA. Downscaled climate data from a Global Climate Model (GCM) was used as input into a crop simulation model, in order to evaluate the wheat yields under future climate in a range of representative locations and soil types of the West Australian wheatbelt.

METHOD
Downscaled climate data from the Cubic Conformic Atmospheric Model (CCAM), which is a higher-resolution version of the CSIRO Mk3 GCM, was used as an input into the validated crop simulation model APSIM-Wheat (v. 4.1).

The APSIM-Wheat model was run with current and future daily climate data to simulate grain yield. The wheat model was run with two sets of climate data for 30 year periods: 1) current simulated climate for the period 1975-2004 with current level of CO₂ (350 ppm); and 2) future simulated climate for the period 2035-2064 with expected CO₂ level in the mid 21st century (440 ppm).

The APSIM-Wheat model simulates daily values of root growth, biomass and grain yield based on information on daily weather, soil type and crop management. It calculates the water-limited potential yield of the site, that is, the yield not limited by weeds, pests, and diseases, but limited only by temperature, solar radiation, water, and nitrogen supply at that site.

Simulations were run for 27 locations and two soil types of the WA wheatbelt. The locations were chosen to represent the range of rainfall zones (high, medium and low) and agricultural regions (north, central and south) present in the wheatbelt of WA. Two soil types, a duplex soil and a clay soil, with 86 and 116 mm plant-available water, respectively, were chosen. Waterlogging effects on crop growth and yield were accounted for on the duplex soil. Simulations were performed for periods of 30 years assuming the soil was dry at 1 January each year. Sowing time was controlled by a sowing rule. Every year sowing occurred in the first sowing opportunity between 25 April and 31 July. A long season cultivar was sown if sowing occurred before 20 May, a medium season cultivar was sown between 21 May and 9 June, and a short season cultivar was sown after that date.

These runs were devised to improve our understanding of the nature of the season by soil type by location responses to future climate. Simulations for both current and future periods were run assuming present technology, current varieties and current agronomy packages.

RESULTS
Simulation results showed future yield decline for most of the wheatbelt. Without taking into account the possible effect of changes in technology, varieties and other adaptation strategies, and assuming clay soil at all locations, simulated average yields were lower at most locations (Figure 1). However, future yields could be higher in high rainfall regions and waterlogging prone soils, where the decrease in rainfall would mean a reduction in waterlogging.
Results showed differences between soil types, with heavier clay soils experiencing greater yield penalties in the future, compared with light textured soils. The largest yield decline in the future (Mullewa) was 24% on clay soil and 17% on lighter duplex soil. The largest yield increase (Wandering) was 14% on duplex soil and 7% on clay. Figure 1 shows the average change in wheat yields for the future period compared to the current period based on simulations for 27 locations on a clay soil.

The yield decrease was due to lower rainfall and higher temperatures, which caused shorter growth duration and more water deficit in most locations. Lower rainfall in autumn delayed sowing, which led to a reduction in growth duration, and increased chance of severe water deficit during grain filling. In most locations, the positive effect of increased CO2 levels was more than offset by the negative effect of lower rainfall, delayed sowing and increased temperatures.

The yield increase in some high and medium rainfall locations was due to the positive effect of increased CO2 levels and reduction of waterlogging effects.

Simulations results showed an effect of climate change on yield distribution. Most locations in the low and medium rainfall zones showed an increase in the frequency of years with low or very low yields and a decrease in the frequency of high yielding years, making cropping a more risky business.
than currently in those locations (Figure 2). For example, in Merredin, in the low rainfall zone, and across soil types, we found an increase in the frequency of years with yield under 1 t/ha from two out of 10 years currently to three out of 10 years by mid 21st century. In Wandering, a high rainfall location, and on a waterlogging duplex soil, simulations showed a decrease in the frequency of low yielding years and an increase in the frequency of high yielding years.

![Histograms showing yield distribution](image)

**Figure 2.** Frequency distribution of yields for the period 1975-2004 (current) and 2035-2064 (future) for Merredin (low rainfall), Corrigin (medium rainfall) and Wandering (high rainfall). Simulated yields for a duplex soil.
There were complex interactions between climate change and cropping systems in the simulations. Effects of higher temperatures, elevated CO₂ and decreased rainfall differed between soil types and locations. Table 1 shows the probability of getting a low or a high yield for different soil types and two contrasting locations in the low and in the high rainfall zone. In both locations, the probability of a low yielding year is lower in the clay soil than in the duplex or sand soil. In Merredin, in all soil types, but to a different extent, the probability of low yielding years increases and the probability of high yielding years decreases in the future. In Wandering, the probability of high yielding years increases in the future.

Table 1. Probability (%) of getting certain yield (t/ha) for the period 1975-2004 (current) and 2035-2064 (future) for a clay, duplex and sand soil in Merredin and Wandering

<table>
<thead>
<tr>
<th>Yield (t/ha)</th>
<th>Clay Current</th>
<th>Clay Future</th>
<th>Duplex Current</th>
<th>Duplex Future</th>
<th>Sand Current</th>
<th>Sand Future</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1</td>
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<td>1-2</td>
<td>39</td>
<td>39</td>
<td>44</td>
<td>41</td>
<td>62</td>
<td>59</td>
</tr>
<tr>
<td>&gt; 2</td>
<td>25</td>
<td>19</td>
<td>41</td>
<td>40</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Wandering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2</td>
<td>2</td>
<td>1</td>
<td>14</td>
<td>11</td>
<td>54</td>
<td>29</td>
</tr>
<tr>
<td>2-3</td>
<td>36</td>
<td>22</td>
<td>40</td>
<td>27</td>
<td>37</td>
<td>49</td>
</tr>
<tr>
<td>&gt; 3</td>
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<td>77</td>
<td>46</td>
<td>62</td>
<td>9</td>
<td>22</td>
</tr>
</tbody>
</table>

CONCLUSION

Future climate, without considering changes in technology, varieties and other adaptation strategies, would mean a decline in wheat yields for most of the wheatbelt. However, future yields could be better in high rainfall locations and waterlogging-prone soils.

Heavier soil types are more vulnerable to climate change than light textured soils. The frequency of low yielding years is likely to increase in low and medium rainfall locations. Wheat cropping on low rainfall locations and heavy soils would be more risky than under the current climate.

KEY WORDS

climate model, APSIM-Wheat model, yield

ACKNOWLEDGMENTS

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Project No.: DAW00088
Paper reviewed by: Doug Abrecht
Building farmers’ adaptive capacity to manage seasonal variability and climate change

David Beard, Department of Agriculture and Food, Western Australia

KEY MESSAGES
At the commencement of the AcCLIMATise project, the use of climate risk management (CRM) information and tools by wheatbelt farmers in WA was limited, with most at the initial awareness/interest stage of the adoption pathway. There was also significant scope for improvement in advisor skills.

Over the last two years the project has engaged farmers and farm advisors in a range of activities designed to build their capacity to better manage climate risk. Involvement in the various ‘on-ground’ trial activities has assisted farmers to become better managers of seasonal risk, particularly through integration of all the relevant information needed to make decisions. Improved knowledge and understanding of weather and climate, forward outlooks, and how to interpret them to improve decision making has been a key benefit deriving from farmer and advisor involvement in structured workshop activity. Supporting information in both hard copy and easily accessible web based form has been valued.

Of major importance in the achievement of these outcomes is the utilisation of local DAFWA project officers to work with farmers and farmer groups and drive the various activities at a local level. These activities will need to be maintained beyond the life of the current project if farmer and advisor skills are to continue to build. In addition there is scope to improve the range, depth and geographical coverage of capacity building activities.

AIMS
Farm earnings are two to three more times sensitive to production than they are to price (Carroll 2005) and climate variability is the biggest factor impacting on production. It follows that farmers’ effectiveness in managing climate variability is critical to their profitability and sustainability as farm businesses.

For a landholder, climate change is experienced through changes in climate variability from season to season. Improving the adaptive capacity of landholders to manage the risk implied by seasonal variability therefore improves their capacity to better manage the risks implied by climate change.

In this paper we describe a two year project entitled AcCLIMATise which has set out to:

- benchmark WA grainbelt farmers current knowledge, attitudes, skills, aspirations and practices (KASAP) from a climate risk management perspective;
- develop and deliver an integrated package of information, tools and training targeting farmers CRM needs.

METHOD
To achieve the first objective the project undertook a detailed needs analysis, based largely on two surveys – one of farm advisory personnel, and the second of about 200 wheatbelt farmers (Beard and Short 2007).

Some key conclusions were drawn from this analysis. Many WA wheatbelt farmers were found to be at the early awareness/interest stage of the adoption process of CRM technology. However there were a significant proportion of farmers who were well down the adoption pathway and there was a strong desire by the large majority of farmers to improve their knowledge and understanding of CRM. Finally, while the majority of the advisory profession were leading farmers in terms of their use of climate risk information and tools, there was still a proportion that were not using the technology.
The second objective is being achieved by the implementation of a number of extension activities, originally defined on the basis of the needs of farmers as we originally believed them to be, and subsequently reviewed and refined in light of experience and the results of the needs analysis. Activities have been broadly grouped using categorisations defined in Coutts, Roberts et al. (2005) i.e. information access, programmed learning, technological development, group facilitation/empowerment and consultant/advisor.

**Information access**

- Generation of locally written climate risk information using AgMemo as a primary vehicle.
- The AcCLIMATise Bulletin has been widely distributed in all regions as part of the ‘Farmers accessing climate information’ delivery initiative (see below). A ‘Climate Profile’ designed to provide an easy to read snapshot of the climate at, or close to, each of the farmer sites has also been distributed.
- The DAFWA web site, its contents and links to climate risk information have been reviewed and are being revised to ensure that it meets the needs of its various target audiences, particularly farmers and advisors. This activity is still underway.
- Utilisation/adding value to farmer group websites is being explored and implemented where feasible. A first and leading example of this is the SEPWA website (www.sepwa.org.au/AcCLIMATise).

**Programmed learning**

- A structured workshop series targeted at farmers and farm advisory staff has been developed, piloted and implemented with a total of 11 workshops with the theme ‘Managing seasonal variability – important now, essential in the future’ held across the wheatbelt during July, 2007. A further series of 12 workshops will be held in the March to June period in 2008 which in addition to the wheatbelt will also encompass farmers in the South West.
- To support the workshop series, a complementary workshop handbook has been developed.

**Technological development, group facilitation/empowerment**

The AcCLIMATise project has implemented two initiatives in this category – ‘Farmers assessing CRM information’ (all regions) and ‘On-farm change with seasonal CRM’ (Northern Agricultural Region only). Both provide the opportunity for farmers to trial the use of the tools and information being offered by the project in conjunction with DAFWA project staff, and to move further along the adoption pathway.

Project officers have been in place from early 2006 onwards. Collaborative effort with other researchers at a number of sites has provided real benefits. The results of the trials have been widely publicised to reach other members of the farming community, through a range of different media including AgMemo, the localised ‘Bulletin’, radio interviews, and presentations at farmer group meetings, field days and other farmer events.

**Consultant/advisor**

Private advisory services and DAFWA staff have been targeted through the managing seasonal variability workshops with the aim of ensuring that they are talking knowledgeably and consistently to farmers about climate risk management. Similarly advisory staff have been targeted with the various information products and wherever possible involved in the two technological development initiatives.

**RESULTS**

A formal evaluation of AcCLIMATise activities is currently underway and detailed results are not yet available. However all activities have been reviewed on a continuous basis, project officers have been providing regular reports on their activities and the July 2007 workshop series was also evaluated to provide input into the next series. In combination this enables some insight into the extent to which the project is meeting its objectives and what this might mean for the future.
Farmer participants in the ‘on-ground’ activities have stated that the project and its associated information products have helped them become better managers of seasonal risk, particularly through better integration of all the relevant information needed to make decisions including a better understanding of seasonal outlook information.

However, opinions are divided on whether or not yield forecasting tools are actually useful. Some farmers found it reassuring that the yield forecasts were ‘backing up their own assessments’ of the crop. Others felt that the lack of accuracy in forecasting the season finish, particularly earlier in the season when the majority of the decisions are being made, decreased their confidence in using this information for decision making (Sherriff, Falconer et al. 2008).

Supporting information in both hard copy and easily accessible web based form is important. Farmers appear to have valued the specialised ‘Bulletins’ and supporting AgMemo articles detailing the trial results to date, soil moisture levels, expected outlook, etc. and importantly have found them useful when making management decisions. While web access for climate outlook information appears to be less favoured, it is an important source of weather outlook information and the current revamp of the DAFWA web site aims to ‘leverage’ off this latter need.

The July 2007 series of the ‘managing seasonal variability’ workshop activity attracted about 200 participants comprising about 150 farmers and the balance advisory staff. Workshop participants showed a significant increase in their self assessed knowledge of the three ‘modules’ (weather, climate, climate risk management) gaining an average of 0.8 points on a scale of 1 to 5. On average participants rated the benefit to them of the various modules highly and at about the same level (4 on a scale of 1 to 5).

A majority of participants said that they believed the workshop would help them in their every day management. A number of common themes were apparent including:

- improved knowledge and understanding of weather and climate, weather and climate forecasts, how to interpret them and were to go for information, particularly the web;
- explicit linking of this improved knowledge to improved decision making;
- improved risk management capacity, recognition of the value of a range of tools to assist in decision making and risk management and intent to use those tools.

CONCLUSION

The project has demonstrated the value of working with farmers in a variety of different ways to build their skills and to assist them in better managing climatic variability. Integration of those various methods is important, and dependence on any one extension methodology alone is unlikely to meet with success. However getting the right ‘mix’ of activities, and relative emphases on those activities is a challenge, and realistically can only be achieved through a trial and error approach, recognising the differing needs of farmers and their advisors in different areas of WA.

The importance of having DAFWA project officers working at a local level with both farmers and advisors to promote the use of various tools and decision aids, to provide information on the latest outlooks, how to interpret them and how to utilise them in conjunction with other information is paramount.

The role of advisory staff has emerged as an important factor in building farmers skills, knowledge and understanding of climate risk. In addition there are important synergies to be achieved by involving advisors in capacity building activities rather than just focussing on the farming community alone.

The use of structured workshop activity has proved to be very beneficial but will need to be maintained if farmer and advisor skills are to continue to build. Workshop content needs further development to better meet the needs of different industries for example grazing, and to better reflect both tactical (e.g. seasonal) and strategic (e.g. climate change) decision making needs.

Activity outside of the wheatbelt also needs development, in the south west and in the pastoral areas of WA. Significant work has already been done in establishing the climate information needs of pastoralists in Western Australia (Keogh, Watson et al. 2005), but there have been no specific initiatives implemented to meet that need.
And finally there are potential initiatives that could be developed that would help in improving the range and depth of capacity building activities. Typical examples are the development, publication and promotion of material describing experiences of WA farmers successfully implementing climate risk management – perhaps along the lines of Masters of the Climate (Powell and Blackadder 2000). A recently mooted mentoring system in CRM for younger farmers (N. Hemmings, GSDC pers. comm.) has the potential to engage younger farmers in CRM, and the concept of engaging producers to participate in the production of written CRM information (Keogh, Watson et al. 2005) is also worthy of exploration.

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KEY WORDS

climate risk, farm management, extension

ACKNOWLEDGMENTS

Thanks to all the farmers and advisors who participated in the project, the AcCLIMATise team for their dedication and support, and the various funders of the project including DAFWA.

Project No.: LWA DAW49

Paper reviewed by: Dr Ian Foster
Precision placement increases crop phosphorus uptake under variable rainfall: Simulation studies

Wen Chen¹ ², Richard Bell¹, Bill Bowden², Ross Brennan², Art Diggle² and Reg Lunt²
¹School of Environmental Science, Murdoch University, Western Australia
²Department of Agriculture and Food, Western Australia

KEY MESSAGES
• Placing phosphorus (P) at 8 cm depth consistently produced better crop yield than placing P at the 4 cm, particularly in the dry seasons. There was no further yield benefit when P was placed deeper in the soil profile.
• Alternating wetting up (rain) and drying (soil evaporation) of the soil determined soil P availability to crop uptake and thus crop yield benefits when P was placed at the different soil depths. Soil P availability to crop uptake early in the season was critical to achieving potential yield for wheat.

AIMS
The objective of this paper was to evaluate soil and climatic factors affecting crop P uptake and yield when P was placed at different soil depths using APSIM. Nutrient stratification, particularly soil immobile nutrients such as phosphorus (P), could have a significant impact on availability of nutrients to crops, as soil immobile nutrient availability, root growth and root activity in the surface layer are more vulnerable to drought than those in sub-surface layers. Placing P fertiliser deeper in the soil was demonstrated in the early field studies to improve crop P uptake and yield in a water-limited environment of Western Australia (Jarvis and Bolland 1990). However, soil and climatic factors (and their interactions) driving the benefits of deep P fertiliser placement are not well understood.

METHOD

APSIM soil P module and parameterisation of the APSIM-wheat module

The Agricultural Production Systems Simulator (APSIM) software system simulates cropping systems at the point-scale, accounting for soil chemical, physical and crop physiological growth processes on a daily time step. The model has been developed using a modular software structure so that different modules can be easily linked to adapt to different applications. The soil P module is a representation of the availability of phosphorus in soil. It simulates soil’s ability to supply P to crops and can be linked with crop modules to modify growth processes under P limiting conditions. The principle processes considered in the soil P module are illustrated in Figure 1 (see Probert 2004 for the details). The dominant processes considered by the soil P module are:
• loss of plant availability through time;
• removal by crops;
• addition by crop residues;
• mineralisation/immobilisation of soil organic P.

The routines introduced into the wheat module to restrict growth under P limiting conditions were similar to those used in the nitrogen routines. The APSIM-wheat module was parameterised with the maximum and minimum P concentrations through time, in the different organs of wheat based on literature information. These are then used as the reference to define optimal and minimal P concentrations and to calculate P stress factors to modify wheat crop growth by combining with corresponding water and N stress factors using the law of minimum.

Simulation studies

The simulations were set up using a duplex soil and long-term climatic data (1957-2006) from Merredin, Western Australia to explore the impact of P placement at the different soil depths (4, 8 and 14 cm) on P uptake and yield of wheat. The long-term annual rainfall in Merredin is 323 mm and...
varies greatly between years (ranging from 178 mm to 591 mm). The growing season rainfall (April to October) is 237 mm making up 72% of the annual rainfall and it also varies significantly (140-418 mm).

Figure 1. Schematic representation of the Soil P module showing the principal processes considered in the APSIM (Probert 2004).

The APSIM soil P module was parameterised using a duplex soil. Soil properties used for specifying the simulations are summarised in Table 1. The low labile P was used to ensure that wheat crop would respond, to added fertiliser P, for the P uptake in most seasons. The medium P sorption was used to prevent any P leaching. During the simulations, soil water content and labile P were reset to crop low limit (CLL) and background level (Table 1), respectively on the first day of each year to avoid any carry over effects.

Table 1. Soil properties used for specifying APSIM simulations

<table>
<thead>
<tr>
<th>Soil layer (cm)</th>
<th>SoilWat parameters^1</th>
<th>Soil P parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BD (g cm^-3)</td>
<td>DUL</td>
</tr>
<tr>
<td>0-5</td>
<td>1.72</td>
<td>0.17</td>
</tr>
<tr>
<td>5-10</td>
<td>1.80</td>
<td>0.18</td>
</tr>
<tr>
<td>10-15</td>
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</tr>
<tr>
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<td>0.29</td>
</tr>
</tbody>
</table>

^1 BD is soil bulk density, DUL is drained upper limit, CLL is lower limit of water extraction by wheat, and SWCON is the proportion of water in excess of DUL that drains in one day. The values adopted in the Table are based on the previous modelling studies for a standard duplex soil.

^2 P sorbed at 0.2 mg L^-1 in solution (also referring as O&S value).

RESULTS

Wheat grain yield when P fertiliser was placed at different depths

The P placement at 8 cm depth consistently improved grain yield, particularly when grain yield was < 2500 kg/ha, compared with the placement at 4 cm (Figure 2a). The yield differences between the placements at 8 and 4 cm ranged from 0 to 700 kg/ha and varied significantly between the seasons (Figure 2a), and they were not related to growing season rainfall (Figure 2b). However, the results presented in Figure 2b suggested that the yield benefits of banding P at 8 cm depth were more likely when growing season rainfall was lower than that in the average season. The yield differences
between the placements at 8 cm and 14 cm were small (= < 100 kg/ha) in most years, suggesting no yield benefits when deep banding (14 cm) of P was compared with the current banding practice (5-10 cm).

**Figure 2.** (a) Relationship between wheat yield simulated when P was placed at 8 cm and the yield differences between the placements at 8 cm and 4 or 14 cm, and (b) relationship between the yield differences simulated when P was placed at 8 cm and 4 cm and growing season rainfall.

**P placement effects on dry matter, daily P uptake and soil water dynamics**

The poor correlation between the yield differences and growing season rainfall (Figure 2b) suggested that alternating wetting up (rain) and drying (soil evaporation) through individual rainfall events determined soil P availability to crop uptake and thus yield benefits when P was placed at the different soil depths. This was supported by the follow up detailed simulations (Figure 3). In 1960 and 1970, similar growing season rainfall was received (Figure 2b), but the different daily rainfall distributions led to the very different soil water dynamics (between two years) and thus daily crop P uptake, particularly early in the season, and final biomass when P was placed at 8 and 4 cm depths (Figure 3). The simulations also highlighted the importance of soil P availability to crop uptake early in the season and its impact on P demand and yield potential. Early plant growth is particularly dependent on P because of the needs for rapid cell division and expansion. The primordia for future stems, roots, leaves, flowers and seed are produced very early in plant growth so P deficiency early during the growth of plants can greatly reduce yield potential.

**CONCLUSION**

Placing P at 8 cm depth consistently produce better crop yield than placing at 4 cm, particularly in the dry season. There was no further yield benefit when P was placed deeper in the soil profile. Alternating wetting up (rain) and drying (soil evaporation) of the soil determined soil P availability to crop uptake and thus yield benefits when P was placed at the different soil depths. The simulations also highlighted the importance of soil P availability to crop uptake early in the season and its impact on potential yield. However, for the crops (such as lupins and canola) that were reported to have P demand late in the season, the dry surface soil (due to soil evaporation) could also affect P availability to uptake and thus final grain yield, and this needs to be explored further using APSIM.

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**ACKNOWLEDGMENTS**

We thank Merv Probert, John Hargreaves and Michael Robertson CSIRO Sustainable Ecosystems for their help in APSIM and Senthold Asseng CSIRO Plant Industry for providing WA soil parameters.

**Project No.:** UWA 00084

**Paper reviewed by:** Geoff Anderson
Figure 3. Wheat dry matter accumulation (kg/ha), daily P uptake (kg/ha/day) from the soil layer where fertiliser P was banded, and soil water content in the fertilised soil layer (0-5 cm, 5-10 cm, 10-15 cm) when P was banded at the three different depths (4, 8 and 14 cm respectively) on a duplex soil in 1960 and 1970.
What is the role of grain legumes on red soil farms?

Rob Grima, Department of Agriculture and Food, Western Australia

KEY MESSAGES

- Lupins grown strategically in rotation reduce annual profit when compared to other cropping options.
- Some evidence suggesting the development of understanding particular seasons for tactical implementation may lift profit substantially.

AIMS

To identify what role grain legumes play on a predominantly red loamy soil farm in the northern agricultural region (NAR) of Western Australia.

METHOD

An NLP funded project titled ‘economic assessment of sustainable farming systems’ developed several model farms for the medium rainfall zone in the NAR. The analysis was economically based using the STEP program, developed by DAFWA (detailed by Peek and Abrahams, 2005). Each model farm broadly represented the distinct rainfall and soil type differences within the region, with one such farm based entirely on red loamy soils. The standard farm included all production income and costs, as well as capital expenditure, overheads and drawings. Data pertaining to these figures was gathered from several representative farmers as well as Bankwest and PlanFarm benchmark data, and was peered by industry representatives and growers.

The model farm totalled 3500 hectares and consisted of two separate soil types: high production and moderate production. Several scenarios were developed reflecting the range of potential enterprise mixes, i.e. the proportion of crop to stock. The rotations for each scenario were also developed in consultation with local growers. Lupins were not considered as part of the ‘standard’ rotation for any scenario! These rotations and their annual profit can be seen in Table 1. Table 2 shows the annual profit achieved for each scenario when lupins are included into the rotation on the high production loams only. It was assumed that the rotational benefits from a lupin crop are a 250 kg/ha yield increase, a 1.5% protein increase, and a 40 kg/ha urea reduction to the following cereal crop (Martin Harries, pers. comm.). There was also a minor reduction in stock fodder requirements.

RESULTS

Table 1 shows the annual profit for all scenarios when utilising the ‘standard’ rotations. Clearly scenarios 2 and 3 offer the greatest return on this farm, however all scenarios are profitable.

<table>
<thead>
<tr>
<th>Scenario rotations and annual profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario</td>
</tr>
<tr>
<td>Crop %</td>
</tr>
<tr>
<td>High production rotation</td>
</tr>
<tr>
<td>Moderate production rotation</td>
</tr>
<tr>
<td>Total breeding ewe number</td>
</tr>
<tr>
<td>Annual profit</td>
</tr>
</tbody>
</table>

Table 2 shows the lupin yield sensitivity analysis and its influence on profit for most scenarios. A survey of the last eight years trial data indicates lupin yields average around 1 t/ha on red soils, with a range from 0.2-3.0 t/ha. This compares with a sandy soil average of 1.9 t/ha! The representative growers suggested their annual lupin yield average to be slightly lower at 0.9 t/ha, with a similar range.

The yields required by lupins to achieve a similar profit to ‘standard’ rotations is greater than the long term average, but not greater than recorded seasonal yields. This suggests that lupins would provide significant economic benefit in at least some seasons! As cropping % increased, the required lupin...
yield is reduced. This is because the benefits to following wheat crops are spread over a larger area. Hence at lower cropping % there is less total benefit, increasing the reliance on a cash surplus from the lupin crop itself.

Table 2. The sensitivity of different potential lupin yields on annual profit

<table>
<thead>
<tr>
<th>Crop %</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard profit – No lupins</td>
<td>$27,000</td>
<td>$138,000</td>
<td>$106,000</td>
<td>$68,000</td>
</tr>
<tr>
<td>Rotation – With lupin</td>
<td>LWB</td>
<td>LWB</td>
<td>PvLW</td>
<td>PvPvLW</td>
</tr>
<tr>
<td>0.9</td>
<td>$4,000</td>
<td>$96,000</td>
<td>$41,000</td>
<td>$14,000</td>
</tr>
<tr>
<td>1.1</td>
<td>$22,000</td>
<td>$116,000</td>
<td>$60,000</td>
<td>$28,000</td>
</tr>
<tr>
<td>1.3</td>
<td>$39,000</td>
<td>$136,000</td>
<td>$78,000</td>
<td>$43,000</td>
</tr>
<tr>
<td>1.5</td>
<td>$58,000</td>
<td>$155,000</td>
<td>$97,000</td>
<td>$58,000</td>
</tr>
<tr>
<td>Suggested required yields (t/ha)</td>
<td>1.2</td>
<td>1.3</td>
<td>1.6</td>
<td>1.7</td>
</tr>
</tbody>
</table>

CONCLUSION

Today’s role of lupins on red loams is not clearly defined for growers. Whilst they can provide significant rotational benefits including alternative weed control options, their yield volatility can cripple cash flow for growers. This volatility, however, provides a window into successful use of such a species. In those years when yields are above average they provide substantial financial benefits. Successful lupin growers currently utilise a production package that considers nutrition, weeds, rotation, marketing and risk management. Future agronomic research may only produce marginal benefits to these growers. There is no clear research gap that will offer significant rotational or financial benefits to these growers, with the possible exception of GM technology! However there could be substantial financial benefits to farmers with red loamy soils in only growing lupins in favourable seasons. Perhaps there is a need for these seasons to be more easily defined, or extension/development program that delivers this message to growers.

There are other circumstances where lupins are more readily justified in the system. Some growers may have a belief of greater rotational or system benefits than suggested in this analysis. In this case the required lupin yield may approach the long term average, making lupins far more viable. Certainly the required yield under this scenario is much less at higher cropping rates due to the benefits spreading over a larger area the following year.

KEY WORDS
lupins, STEP, annual profit, model

ACKNOWLEDGMENTS
Thanks to Caroline Peek and Cameron Weeks for their input. Thanks to NACC and NLP for funding.

REFERENCES

Project No.: NLP 053064-07MIG
Paper reviewed by: Peter Newman
Fertiliser placement influences plant growth and seed yield of grain crops at different locations of WA

Qifu Ma1, Zed Rengel1, Bill Bowden2, Ross Brennan3, Reg Lunt4 and Tim Hilder5
1Soil Science & Plant Nutrition, University of Western Australia, Crawley WA 6009
DAFWA: 2Northam Regional Office; 3Albany Regional Office; 4Baron-Hay Court, South Perth; 5Narrogin Regional Office

KEY MESSAGES

● In the 2007 season, fertiliser placements (shallow 5-7 cm, deep 18-20 cm or split with half at each depth) had similar wheat growth and grain yield at Newdegate where regular rainfalls occurred from sowing to maturity. At west Moora it was dry in October, and wheat yield components did not differ between fertiliser placements either, suggesting that low nutrient availability at the topsoils induced by drought in the late season may not affect wheat yield.

● Drip irrigation from mid August to late October increased wheat dry weight and grain yield, and 10 mm/week was more effective than 40 mm/4 weeks despite the same amount of water supplied in both treatments. There was no interaction between irrigation and fertiliser placement on plant growth and yield.

● Late N application (100 kg/ha urea at anthesis) significantly increased grain N% compared with the control that did not receive late N application.

● Placing fertilisers 15 cm away reduced shoot dry weight compared with placing fertilisers directly below the seed, but the reduction was less significant in lupin than in wheat or canola, suggesting lupin roots grow better horizontally than wheat and canola in search for nutrients and water.

AIMS

In the low to medium rainfall zones of Western Australia, surface soil layers dry out rapidly between rains, particularly late in the growing season; consequently, nutrient uptake by plants from the dry but nutrient-rich topsoil may be restricted. We conducted two field trials in the 2007 season to examine the effects of fertiliser placement on plant growth and seed yield in rain-fed crops and those supplemented with 10 mm irrigation/week or 40 mm/4 weeks, simulating three season types (rain-fed, frequent small rain events, less frequent but bigger rain events). Late N was applied to increase grain N content.

METHOD

The two field trials were conducted at Newdegate Research Station and west Moora. The rainfall over the growing season (May to October) was 220 mm at Newdegate, and 224 mm at west Moora. A pre-sowing soil survey showed low P and medium K levels at 0-30 cm at Newdegate, and very low to low P and K levels at 0-30 cm at West Moora (Table 1).

Table 1. Soil nutrient levels (mg/kg) prior to sowing at the trial sites in Newdegate and west Moora

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Newdegate</th>
<th>west Moora</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Colwell P</td>
<td>Colwell K</td>
</tr>
<tr>
<td>0-10</td>
<td>9</td>
<td>51</td>
</tr>
<tr>
<td>10-20</td>
<td>5</td>
<td>47</td>
</tr>
<tr>
<td>20-30</td>
<td>3</td>
<td>56</td>
</tr>
</tbody>
</table>

At Newdegate, wheat cv. Wyalkatchem was sown on 1 June. The trial had four fertiliser placements (nil fertiliser, shallow 5-7 cm, deep 18-20 cm or split with half at each depth). The fertiliser rates (kg/ha) at sowing were 19.3 P, 10.9 K, 15.9 S, 0.2 Cu and 0.3 Zn. Drip irrigation was applied from mid August to late October. It was a split-plot design, with the main plots for watering treatments (rain-fed, 10 mm/week or 40 mm/4 weeks) and the subplots for fertiliser placements in three blocks, totalling 36
plots. Each plot had an area of 1.5 by 23 m and comprised six rows, at a row spacing of 25 cm. Fifty kg urea/ha was topdressed seven weeks after sowing. At anthesis, 100 kg urea/ha was applied to one half of each of 36 plots to examine whether late N supply increased grain N.

At west Moora there were two experiments, one with various depths of fertiliser placement as at Newdegate (nil fertiliser, shallow 5-7 cm, deep 18-20 cm or split with half at each depth) and the other with variable horizontal placement (nil fertiliser, directly below the seed, or 15 or 30 cm away from the row at a depth of 5-7 cm). Wheat cv. Calingiri was grown in the fertiliser-depth experiment, and three crops (wheat cv. Calingiri, canola cv. Beacon and lupin cv. Mandelup) in the horizontal-fertiliser experiment. The fertiliser rates at sowing were the same as at Newdegate. Urea was topdressed in the early and mid seasons with a total of 150 kg/ha. The deep-fertiliser experiment had four blocks, and the treatments were randomly allocated to 30 x 1.8 m plots (25 cm row spacing) in each block. The horizontal-fertiliser experiment had two blocks, with the treatments randomly allocated to the 30 m plots (two rows, 30 cm row space). A weather station was installed at the field site, recording rainfall over the growing season.

From the fifth week after sowing, plant tops were sampled every three or four weeks for dry weight in the fertiliser-depth experiments at both sites. In the first two harvests single plants were randomly taken, followed by quadrat cutting in later harvests. In the final harvest yield components were measured, and grain N was determined for the late urea treatments at Newdegate. In the horizontal-fertiliser experiment at Moora, plant tops were harvested every two weeks from week 6 to anthesis.

RESULTS

Newdegate trial

The growing season started late with only 18 mm rainfall in May, but the months of June and July recorded 42 and 63 mm respectively, followed by regular rainfalls in August (32 mm), September (24 mm) and October (39 mm). Fertiliser application at any depth increased aboveground dry weight over the growing season compared to the nil control, whereas there was no significant difference between the shallow, deep and split placements (Figure 1). Drip irrigation of 10 mm/week or 40 mm/4 weeks from mid August to late October produced more plant dry weight than the rain-fed control, and 10 mm/week was more effective than 40 mm/4 weeks despite the same amount of water supplied in both cases.

![Figure 1](image_url)

**Figure 1.** Accumulation of aboveground biomass over the growing season of wheat cv. Wyalkatchem treated with four fertiliser placements (nil fertiliser, shallow 5-7 cm, deep 18-20 cm and half-shallow/half-deep), and the combined effect of fertiliser placement and irrigation (mid August to late October) on final aboveground biomass. There was no interaction between irrigation and placement.

The drip irrigation increased the number of ears compared to the rain-fed control. The number of ears was not different between 10 mm/week and 40 mm/4 weeks, but the former had higher grain yield than the latter (Table 2). Fertiliser application produced more ears and higher grain yields than the nil control, whereas the shallow, deep and split placements had similar ears and grain yields (Table 2). There was no interaction between irrigation and fertiliser placement on the number of ears and grain yield, probably due to the regular rainfalls in the late season.
Late N application (100 kg/ha urea at anthesis) increased grain N% significantly ($P = 0.01$) compared with the minus control (Table 3). The rain-fed plants had higher grain N% than the irrigated plants, but grain N% was similar between two irrigation treatments and was not affected by fertiliser placements.

### Table 2. Effects of irrigation (mid August to late October) and fertiliser placement on the number of ears and grain yield (wheat cv. Wyalkatchem). There was no interaction between irrigation and placement on yield components

<table>
<thead>
<tr>
<th>Irrigation treatment</th>
<th>Ears/m²</th>
<th>Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain-fed</td>
<td>184 a</td>
<td>1.94 a</td>
</tr>
<tr>
<td>10 mm/week</td>
<td>210 b</td>
<td>2.81 b</td>
</tr>
<tr>
<td>40 mm/4 weeks</td>
<td>206 b</td>
<td>2.53 c</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fertiliser treatment</th>
<th>Ears/m²</th>
<th>Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil fertiliser</td>
<td>170 x</td>
<td>2.12 x</td>
</tr>
<tr>
<td>Shallow (5-7 cm)</td>
<td>212 y</td>
<td>2.54 y</td>
</tr>
<tr>
<td>Deep (18-20 cm)</td>
<td>205 y</td>
<td>2.51 y</td>
</tr>
<tr>
<td>Half-shallow/half-deep</td>
<td>210 y</td>
<td>2.55 y</td>
</tr>
</tbody>
</table>

Means with different letters within either treatment are significantly different at $P \leq 0.05$.

### Table 3. Response of wheat grain N% to irrigation (mid August to late October) and late N (100 kg/ha urea at anthesis). There was no interaction between irrigation and late N supply

<table>
<thead>
<tr>
<th>+ late N</th>
<th>− late N</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain-fed</td>
<td>2.09</td>
<td>1.92</td>
</tr>
<tr>
<td>10 mm/week</td>
<td>1.86</td>
<td>1.68</td>
</tr>
<tr>
<td>40 mm/4 weeks</td>
<td>1.96</td>
<td>1.74</td>
</tr>
</tbody>
</table>

Means with different letters within the treatment of irrigation or late N application are significantly different at $P \leq 0.05$.

**West Moora trial**

1) **Deep-fertiliser placement**

The site had not been cropped for over ten years, and the soil had 2-4 mg P/kg and 15-35 mg K/kg at 0-30 cm. It was dry in the early (May, June) and late (October) parts of the season with the monthly rainfalls of 10-15 mm, whereas the mid season was wet (July 73 mm, August 61 mm and September 46 mm). Plants in the nil-fertiliser treatment had lower aboveground dry weight than the fertilised plants over the growing season. Fertiliser application increased the number of ears and grain yield, but no yield differences were found between the shallow, deep and split placements (Figure 2, Table 4).

### Table 4. Effects of fertiliser placement on yield components in wheat cv. Calingiri

<table>
<thead>
<tr>
<th>Ears/m²</th>
<th>Grain yield (t/ha)</th>
<th>Total dw (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil fertiliser</td>
<td>115 a</td>
<td>1.57 a</td>
</tr>
<tr>
<td>Shallow</td>
<td>153 b</td>
<td>2.27 b</td>
</tr>
<tr>
<td>Deep</td>
<td>158 b</td>
<td>2.28 b</td>
</tr>
<tr>
<td>Half-shallow/half-deep</td>
<td>164 b</td>
<td>2.43 b</td>
</tr>
</tbody>
</table>

Means with different letters in each column are significantly different at $P \leq 0.05$. 

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Crop Updates is a partnership between the Department of Agriculture and Food, Western Australia and the Grains Research & Development Corporation

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2) **Horizontal-fertiliser placement**

Placing fertilisers directly below the seed produced greater shoot dry weight than placing fertiliser 15 cm away at all harvests of the three crops (Figure 3). However, the growth difference between the two placements appeared to be smaller in lupin than in wheat or canola, suggesting that lupin roots grow better horizontally than wheat and canola in search for nutrients and water. The nil fertiliser and the 30-cm-away placement had similar low dry weight in wheat and canola, whereas the late harvests showed that lupin plants might have utilised the fertilisers placed at 30 cm away.

**CONCLUSION**

The two field sites in the 2007 season received the same rainfall but with different distribution (regular rainfalls at Newdegate, whereas at west Moora early and late parts of the season were dry and mid-season was wet). Irrigation from mid-August to late October increased wheat vegetative growth and grain yield, and the 10 mm/week irrigation was more effective than the 40 mm/4 weeks, probably because the weekly irrigation plus regular rainfalls had wetted the fertiliser depth longer and thus would increase nutrient uptake by plants. At both sites fertiliser application increased wheat growth and grain yield, but there were no differences between fertiliser placements (shallow 5-7 cm, deep...
18-20 cm or split with half at each depth), even under dry conditions in the late season at west Moora. This may confirm that late nutrient uptake has little effect on wheat grain yield. However, late N application significantly increased grain N% compared with the control, suggesting that this practice has high potential of increasing grain quality.

KEY WORDS
wheat, fertiliser placement, irrigation, plant growth, grain yield

ACKNOWLEDGMENTS
This project was funded by the Grains Research and Development Corporation.

Project No.: UWA 084
Paper reviewed by: Wen Chen
A review of pest and disease occurrences for 2007

Peter Mangano and Dusty Severtson, Department of Agriculture and Food, Western Australia (DAFWA)

KEY MESSAGES
Reports of pest and disease occurrences and their geographical distribution within the WA grainbelt are provided by contributors to the PestFax service throughout the growing season. The collation of this information into a recently developed database has enabled a summary of the 2002-2007 reports. This review provides an opportunity for awareness, discussion and ongoing evaluation of changing pest and disease status under the influence of important factors such as seasonal variation and varying farming systems.

Reports of crop disease and invertebrate pest incidence in 2007 were generally at acceptable severity and lower levels than those recorded in the years 2002 to 2006. However the impact of aphids on pasture and legume crops in southern agricultural areas was much higher than previous seasons. Much of the northern grainbelt experienced very dry conditions with reduced sowing opportunity and/or low yielding crops which also reduced the pest and disease incidence.

BACKGROUND
PestFax is an interactive information service on the diseases and pests which threaten crops and pastures throughout the grainbelt of WA. Weekly news updates during the growing season provide broadacre agribusiness practitioners with information on the plant diseases and insect pests which are currently posing a threat to crops and pastures. A large network of field agronomists, consultants, farmers and industry specialists provide weekly input.

Seasonal variations can encourage a larger than expected impact from irregular or less well known diseases or pest species. Farmers can be alerted to these situations and have the opportunity to inspect crops and take the necessary control measures to limit the impact. The PestFax service provides an avenue for regular information on beneficial organisms, integrated pest management options and general pest and disease information not readily available through other information outlets.

Limitations
- Reports to PestFax of pest and disease incidence and regional distribution are solely from voluntary input and therefore rely on the good will of readers and participants. Reports are often limited to pest and diseases that produce visually obvious above ground symptoms (e.g. rust disease or caterpillars chewing crops) therefore reports of crown and root attacking diseases, such as root lesion nematodes and blackleg cankers are usually only reported in severe cases. Viral diseases symptoms of are often not clear and are probably also under-reported.
- Specific pests or diseases of less widely grown crops (e.g. some pulse crops) may not be reported as frequently as others. This does not indicate that the disorder is any less serious.
- Reports are often most reliable for the first seasonal appearance of any pest organism and less frequently reported when a pest or disease is commonplace in a locality.
- Reports are infrequently confirmed by diagnostic laboratory analysis due to the effort and cost involved. However, a high level of confidence in the reports is assumed as the majority are from trained and experienced agronomists, DAFWA staff or other industry representatives.

AIMS
To measure the occurrence and locations of pest and disease incidence in the Western Australian grainbelt for the 2007 season. To make seasonal comparisons to other years (2002-2007).
METHOD
A database has been developed to tabulate information received via the PestFax service. Reports are entered into categories within the database including date, disorder and location. This information is then processed into summary reports and maps.

RESULTS AND DISCUSSION

Seasonal notes 2007
A delay in sowing opportunity and extended dry conditions characterised the crop establishment phase for most of the WA grainbelt. This contrasted with the Esperance region which mostly had good early opening rains and ideal growing conditions. The north eastern grainbelt experienced drought conditions for much of the year.

The season was generally characterised by a low level of pest outbreaks and few control failures were reported. Farmers in drought affected areas faced the difficult situation of deciding whether to apply pest control options when yield expectations were very low.

Cereal diseases

Wheat rusts
Wheat leaf rust was reported once in 2007 from volunteer wheat near Cranbrook (20 July), while reports of wheat stem rust were notably absent. This is the lowest number of reports of these rusts over the six years from 2002 to 2007 (Table 1).

The reported incidence of stripe rust in 2007 (44 cases) was less than that recorded for the previous three years (Table 1). There were no reports of stripe rust on volunteer wheat in 2007.

The most common wheat varieties reported to be infected with some level of stripe rust were Carnamah (moderately susceptible), Calingiri (moderately susceptible) and Wyalkatchem (intermediate resistance). These varieties are also popular and regionally suited varieties. Almost all infected crops reported had no seed dressing or in-furrow fungicide included in the seeding program.

The 2007 outbreak of stripe rust was first noted on a property south of Cunderdin in mid-August and in the following weeks spread to more widespread central-west and southern wheatbelt areas (Figure 1).

Only one reported case of stripe rust occurred in the Esperance area (West Scadden, 4 September). The low incidence in the Esperance and south coastal areas relative to the central area is interesting and may be explained by the earlier time of sowing, higher levels of fungicide use (seed dressings, in-furrow and foliar sprays) and wider use of resistant varieties. Fortunately the majority of the 2007 stripe rust outbreak occurred late in the season (mid to late September) which allowed adult plant resistance to be expressed in varieties with that characteristic, curtailing the potential extent of the disease.
Wheat streak mosaic virus (WSMV)

Only two cases of Wheat Streak Mosaic Virus (WSMV) were reported in 2007 (Table 1). The first was south of Koorda in which a paddock of Machete wheat at the stem elongation stage was noticeably displaying WSMV symptoms covering an area of more than 100 m². The second case was on a few isolated plants within a crop near Mount Madden. In both cases, samples were sent to the AGWEST Plant Laboratories where the disease was confirmed.

These two reports of WSMV in 2007 are significant in comparison with 2006 when the disease was confirmed to be present in WA for the first time. There were 36 reports of WSMV in 2006 spanning from Dongara to Esperance, but mostly from central agricultural areas.

Bacterial stripe blight

Bacterial stripe blight was evident in many oat crops in 2007. There were several reports to PestFax, samples submitted to AGWEST Plant Laboratories and many grower enquiries concerned with identification and management.

A major concern with this disease is mis-diagnosis and confusion with fungal diseases. Application of fungicide has no impact on control of this bacterial disease.
Table 1. Cereal disease, 2002-2007 yearly comparison of frequently reported diseases

<table>
<thead>
<tr>
<th>Disorders</th>
<th>Total reports</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2002</td>
</tr>
<tr>
<td>Rust – Wheat Stripe Rust</td>
<td>134</td>
</tr>
<tr>
<td>Rust – Wheat Leaf Rust</td>
<td>42</td>
</tr>
<tr>
<td>Rust – Wheat Stem Rust</td>
<td>8</td>
</tr>
<tr>
<td>Wheat Streak Mosaic Virus</td>
<td>0</td>
</tr>
<tr>
<td>Powdery Mildew</td>
<td>19</td>
</tr>
<tr>
<td>Yellow Spot</td>
<td>11</td>
</tr>
<tr>
<td>Septoria nodorum/tritici</td>
<td>14</td>
</tr>
<tr>
<td>Wheat diseases</td>
<td></td>
</tr>
<tr>
<td>Rust – Barley Leaf Rust</td>
<td>21</td>
</tr>
<tr>
<td>Powdery Mildew</td>
<td>20</td>
</tr>
<tr>
<td>Net Blotch (spot-type and/or net-type)</td>
<td>24</td>
</tr>
<tr>
<td>Scald</td>
<td>0</td>
</tr>
<tr>
<td>Oat diseases</td>
<td></td>
</tr>
<tr>
<td>Rust – Oat Leaf Rust (Crown)</td>
<td>0</td>
</tr>
<tr>
<td>Rust – Oat Stem Rust</td>
<td>2</td>
</tr>
<tr>
<td>Stripe Blight</td>
<td>4</td>
</tr>
<tr>
<td>Root diseases</td>
<td></td>
</tr>
<tr>
<td>Root Lesion Nematodes (Cereals)</td>
<td>18</td>
</tr>
<tr>
<td>Rhizoctonia Bare Patch (Cereals)</td>
<td>13</td>
</tr>
<tr>
<td>Cereal Cyst Nematodes (CCN)</td>
<td>3</td>
</tr>
<tr>
<td>Fusarium Crown Rot (Cereals)</td>
<td>1</td>
</tr>
</tbody>
</table>

Other reports of minor cereal diseases are not presented in this table.

Canola diseases

Three diseases of canola were reported during the 2007 growing season (Table 2). Two cases of clubroot were reported during the third week of September near Northampton and Esperance, and confirmed by the AGWEST Plant Laboratories. This disease has not been reported in previous years. Clubroot is more common in vegetable brassicas rather than oilseed brassicas, however inoculum levels may be increasing in some previously infected canola sites.

Downy mildew was reported from the Pingrup, Katanning, Williams and West River areas during June 2007. In all cases, the infection was confined to lower leaves while upper leaves remained healthy. The single report of blackleg during 2007 was from the Pingrup area. The low level of reporting does not imply that disease symptoms were absent in other canola crops but more likely that levels of infection were low or unremarkable relative to previous years.

Table 2. Comparison of canola disease incidence between 2002 and 2007

<table>
<thead>
<tr>
<th>Disorder</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackleg</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Damping Off (Fusarium, Rhizoctonia)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>White Leaf Spot</td>
<td>2</td>
<td>12</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Sclerotinia</td>
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<td>Downy Mildew</td>
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<tr>
<td>Beet Western Yellow Virus</td>
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<td>Cauliflower Mosaic Virus</td>
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<td>Turnip Mosaic Virus</td>
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<td>Root Lesion Nematodes (RLN)</td>
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<td>0</td>
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<td>Clubroot</td>
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<td>0</td>
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<td>0</td>
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</tr>
</tbody>
</table>
**Invertebrate pests**

**Mites and Lucerne Flea**

Redlegged earth mites (RLEM) were the most frequently reported invertebrate pest found attacking crop seedlings in 2007 (Table 3). The first hatchings of RLEM were reported from southern areas (Denmark, Scott River and Kojonup) in early May. Hatching in the central areas (Quairading) were delayed until early June, and only one incidence of damaging numbers of RLEM were reported from the drought affected northern area (Dongara) in early August.

Clover (Bryobia) and Balaustium mite damage in 2007 was reported at similar levels to 2006 and 2005. Both mites had an impact on late sown and moisture stressed crops with Balaustium mites having a continued impact into the cooler month of July throughout southern agricultural areas. Although predominately a pest of southern areas, damaging levels of Balaustium mite were found this year in the central agricultural area near Wannamal (Figure 2). This is an additional location to the few previous sightings (Gingin and Corrigin) of Balaustium in the central agricultural area.

The reports of lucerne flea damage (Table 3) were fewer than those recorded in previous years back to 2002.

**Table 3. Comparison of invertebrate pest incidence between 2002 and 2007**

<table>
<thead>
<tr>
<th>Pest</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
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<tr>
<td>Seedling establishment pests</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mites and Lucerne flea</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redlegged Earth Mites</td>
<td>16</td>
<td>14</td>
<td>51</td>
<td>23</td>
<td>33</td>
<td>17</td>
</tr>
<tr>
<td>Lucerne Fleas</td>
<td>18</td>
<td>10</td>
<td>35</td>
<td>26</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>Balaustium Mites</td>
<td>9</td>
<td>22</td>
<td>6</td>
<td>17</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Clover (Bryobia) Mites</td>
<td>17</td>
<td>11</td>
<td>4</td>
<td>15</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Blue Oat Mites</td>
<td>3</td>
<td>2</td>
<td>9</td>
<td>7</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Caterpillars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutworms</td>
<td>28</td>
<td>10</td>
<td>3</td>
<td>2</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Cockchafer</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Pasture Day Moths</td>
<td>25</td>
<td>1</td>
<td>8</td>
<td>6</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Pasture Webworms</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Weed Moths</td>
<td>0</td>
<td>15</td>
<td>3</td>
<td>0</td>
<td>2</td>
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</tr>
<tr>
<td>Beetles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetable Beetles</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>African Black Beetles</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Bronzed Field Beetles</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<tr>
<td>Weevils</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetable Weevils</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Weevils (Other)</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Desiantha Weevils</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Small Lucerne Weevils</td>
<td>9</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>European Earwigs</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Snails/slugs</td>
<td>4</td>
<td>4</td>
<td>17</td>
<td>4</td>
<td>11</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 2. Damaging levels of Balaustium mites reported during the growing season of 2007 (left) and all seasons 2002-2007 (right).
Table 3 continued …

<table>
<thead>
<tr>
<th>Pest</th>
<th>Total reports by year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2002</td>
</tr>
<tr>
<td><strong>Grain formation pests</strong></td>
<td></td>
</tr>
<tr>
<td>Caterpillars</td>
<td></td>
</tr>
<tr>
<td>Native Budworms</td>
<td>24</td>
</tr>
<tr>
<td>Diamondback Moths</td>
<td>22</td>
</tr>
<tr>
<td>Armyworms</td>
<td>15</td>
</tr>
<tr>
<td><strong>Aphids</strong></td>
<td></td>
</tr>
<tr>
<td>Aphids (Canola)</td>
<td>20</td>
</tr>
<tr>
<td>Aphids (Cereal)</td>
<td>50</td>
</tr>
<tr>
<td>Aphids (Lupins)</td>
<td>5</td>
</tr>
<tr>
<td>Aphids (Pastures and pulses)</td>
<td>2</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
</tr>
<tr>
<td>Locusts</td>
<td>1</td>
</tr>
<tr>
<td>Wingless Grasshoppers</td>
<td>1</td>
</tr>
<tr>
<td>Rutherglen Bugs</td>
<td>1</td>
</tr>
<tr>
<td>Pea Weevils</td>
<td>4</td>
</tr>
</tbody>
</table>

**African Black Beetles**

Adult African black beetles (*Heteronychus arator*) were reported as causing substantial damage to seedling pastures in south-western high rainfall areas from Pinjarra through to Cowaramup and Margaret River during mid-May 2007. The beetles were also troublesome to some cereal crops in coastal areas from Munglinup to Esperance during May and June. Adult beetles caused underground feeding damage to the seedlings and subsequent yellowing or death of some plants.

The incidence of African black beetle damage in 2007 was higher than in previous years since 2002, with many of the reports describing widespread areas being affected. Early season rainfall (April) usually coincided with areas where the African black beetles were most troublesome.

**Aphids**

Pre-season rainfall and good early growing conditions allowed aphid populations to build to high populations in the Esperance area from early May and further increase during June. Damaging levels of cowpea and blue-green aphids were reported on clover, vetch, biserrulla, medic pastures and legume crops, in the south-eastern agricultural area. This is the highest reported occurrence of damaging levels of these aphids on pastures and pulse crops in the last six years. Further reports of damaging numbers of pasture aphids were also reported from Corrigin, Cunderdin and Wyalkatchem during August and September 2007.

Some canola and cereal crops had aphid levels which exceeded economic spray threshold levels in 2007. Reports occurred from areas mainly in the south-eastern wheatbelt (the shires of Esperance and Ravensthorpe) but also extended from Badgingarra to Kellerberrin. However, the overall incidence of aphids on these crops was much lower than recorded for previous years (see Table 3).

**Locusts**

Some germinating crops in southern wheatbelt areas during May 2007 suffered minor damaged by localised swarms of adult Australian Plague Locusts which survived the Department of Agriculture and Food’s (DAFWA) spray campaign in spring 2006 and during February 2007. These areas include Ravensthorpe, Cascade, Jerdacuttup, Fitzgerald, Jerramungup, Wellstead and Mt Barker. The winged locust adults died out shortly after they reached the end of their reproductive cycle, however large numbers of eggs were laid by these locusts and these remained dormant over winter.

Locusts were troublesome again during spring 2007. The first hatchings of locusts were reported from the Munglinup area in mid-September followed shortly after with widespread hatchings in many southern wheatbelt areas. The Department sprayed approximately 32,500 hectares comprised of about 15,000 hectares in Salmon Gums, 16,500 in Ravensthorpe and about 1,000 hectares in Bremer Bay. This was significantly less than the 480,000 hectares sprayed during the 2006 DAFWA locust spray campaign.
Other pests

Cockchafers were of concern to some growers mostly in southern regions. This was probably related to the poor growing conditions (drought) and the inability of seedlings to grow and compete with the level of insect feeding damage. Cutworms caused extensive damage to unprotected canola, wheat and lupin crops in the Eradu, Northampton and Geraldton areas during June and July 2007.

Diamondback moths were reported at lower levels than previous seasons. However, they reached population levels that caused concern to canola growers in the Esperance/Ravensthorpe area during late September and October 2007. Although some crops were sprayed many other crops had only pockets with potentially damaging levels of diamondback moth grubs. Fortunately these populations either declined naturally or crops were swathed before economic crop damage occurred.

KEY WORDS
disease, pests, invertebrates, 2007, PestFax

ACKNOWLEDGMENTS
Supporters and contributors of reports to the PestFax service are gratefully acknowledged for their efforts and consistency in providing information that has benefited the whole of the grains industry.

Comment by researchers Geoff Strickland, Geoff Thomas, Rob Loughman, Manisha Shankar, Ravjit Khangura and Bill MacLeod is greatly appreciated.

The expertise of Rob Emery and Dominic McCosker in developing the PestFax database is gratefully acknowledged. Funding from the Grains Research Development Corporation (GRDC) via the National Pest Initiative Project (NIPI) together with core support from the Department of Agriculture and Food, Western Australia has enabled the project to develop.

Project No.: GRDC CSE 00029 – National Pest Initiative Project (NIPI)
Paper reviewed by: Bill MacLeod
Effect of stocking rates on grain yield and quality of wheat in Western Australia in 2007

Shahajahan Miyan, Sam Clune, Barb Sage and Tenielle Martin, Department of Agriculture and Food, Western Australia

KEY MESSAGES

- To utilise grazing wheat potential, and get maximum grain return, the use of low stocking rate is generally preferred over high stocking rate for a short period of time.
- Sheep condition score and liveweight improved over the grazing period.
- Grazing wheat may act as supplementary feed to help reduce the autumn/winter feed gap.
- Yitpi yielded significantly higher than EGA Wedgetail in this environment.

AIMS

The main aims of the trial were to compare grazing pressures on grain yield and quality of two wheat varieties and to determine the effect of stocking rate on the dual use of wheats.

METHOD

A field trial was conducted at Southern Brook in 2007 comparing a winter wheat (EGA Wedgetail), to a spring wheat (Yitpi) variety in a clay loam soil with pH 4.7 (CaCl₂), following three years of pasture. Soil details are presented in Table 1.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Top soil pH (CaCl₂)</th>
<th>Org. C (%)</th>
<th>P (mg/kg)</th>
<th>K (mg/kg)</th>
<th>Electrical conductivity (mS/m)</th>
<th>NO₃-N (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay loam</td>
<td>4.7</td>
<td>1.22</td>
<td>45</td>
<td>351</td>
<td>0.123</td>
<td>29</td>
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</table>

Plots were deep ripped and sown on 17 May 2007 at 110 kg/ha. Urea was applied at 50 kg/ha on 27 of June 2007. No early sowing opportunity existed due to lack of rain in April and early May. The site comprised of 18 plots randomised with ungrazed (0 DSE/ha), low grazed (20 DSE/ha) and high grazed (40 DSE/ha). The trial was grazed from 17 July to 7 August 2007. The plots were 50 m wide and 100 m long (0.5 ha).

Measurements of sheep, condition score and live weight and crop biomass, grain yield, grain protein, hectolitre weight and screenings were recorded.

Note: Screenings include whole and cracked grain.

RESULTS

In the months of March and April, the trial site received only 24 mm of rain, while the growing season rainfall from May to October was 229.5 mm. The ideal time of sowing for a long season winter wheat should have been in late April or early May.
Effect on plant biomass at Southern Brook

Yitpi consistently produced more biomass than the EGA Wedgetail under each grazing regime (Figure 1). Food on offer (FOO) was maintained under the low grazing regime but uneven grazing resulted in variation in plant maturity for grain production. The high grazing regime resulted in a decline in biomass production but grazing was more even and resulted in delayed but even plant maturity. The delay in maturity due to grazing resulted in a large decline in grain yield, particularly with EGA Wedgetail.

Figure 1. Average weekly food on offer (FOO) at Southern Brook, 2007.

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Figure 1. Average weekly food on offer (FOO) at Southern Brook, 2007.

Figure 1. Average weekly food on offer (FOO) at Southern Brook, 2007.

Figure 2. Average condition score at Southern Brook in 2007.

Figure 2. Average condition score at Southern Brook in 2007.

Figure 3. Average liveweight at Southern Brook in 2007.

Figure 3. Average liveweight at Southern Brook in 2007.
Effect on sheep liveweight and condition score at Southern Brook

Condition score improved over the grazing period (Figure 2). There was no difference in condition score between the varieties at each grazing regime but the high grazing pressure resulted in less improvement in condition score.

Sheep liveweight improved over the grazing period (Figure 3). Under both varieties at low grazing pressure, liveweight continued to increase cumulatively. However under the high grazing pressure liveweight began to decline in the last part of the grazing period. This coincides with a decline in biomass production and plant growth rate.

Grain yield and quality

Results from this trial show that there was a significant decrease in grain yield due to high grazing pressure for both wheat varieties. There was no grain yield difference between low and ungrazed treatments for EGA Wedgetail however there was in Yitpi. The high grazed wheat yielded on average of 0.77 t/ha compared to the ungrazed wheat of 2.01 t/ha which was 62% less (Table 2). The dual purpose wheat, EGA Wedgetail, produced significantly less grain yield compared to the commercial wheat Yitpi but the level of screenings was significantly lower for the dual purpose wheat. Presumably associated with weed competition during the growing season which reduces the N uptake by the crop, overall protein was low for both varieties, however there was a significant increase in protein in both wheats resulting from the high grazing regime probably due to forced maturity. Screening, hectolitre weight and protein increased with grazing at both varieties.

Table 2. Effect of grazing on grain yield and quality of wheat at Southern Brook in 2007

<table>
<thead>
<tr>
<th>Variety</th>
<th>Ungrazed</th>
<th>Low grazed</th>
<th>High grazed</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGA Wedgetail</td>
<td>1.57</td>
<td>1.57</td>
<td>0.46</td>
</tr>
<tr>
<td>Yitpi</td>
<td>2.45</td>
<td>1.79</td>
<td>1.08</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.58</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variety</th>
<th>Ungrazed</th>
<th>Low grazed</th>
<th>High grazed</th>
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</thead>
<tbody>
<tr>
<td>EGA Wedgetail</td>
<td>9.1</td>
<td>9.4</td>
<td>10.6</td>
</tr>
<tr>
<td>Yitpi</td>
<td>8.3</td>
<td>8.3</td>
<td>9.9</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.9</td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variety</th>
<th>Ungrazed</th>
<th>Low grazed</th>
<th>High grazed</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGA Wedgetail</td>
<td>82</td>
<td>82</td>
<td>83</td>
</tr>
<tr>
<td>Yitpi</td>
<td>83</td>
<td>84</td>
<td>84</td>
</tr>
<tr>
<td>LSD (0.05)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Variety</th>
<th>Ungrazed</th>
<th>Low grazed</th>
<th>High grazed</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGA Wedgetail</td>
<td>0.5</td>
<td>0.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Yitpi</td>
<td>0.9</td>
<td>1.2</td>
<td>2.5</td>
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<tr>
<td>LSD (0.05)</td>
<td>0.9</td>
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</tbody>
</table>

CONCLUSION

Sheep condition score and liveweight improved over the grazing period. Under both varieties at low grazing pressure, liveweight continued to increase cumulatively. Yitpi consistently produced more biomass than the EGA Wedgetail under each grazing regime.
High stocking rate significantly reduced grain yield compared to low stocking rate but there was no
difference in yield between ungrazed and low stocking rate for EGA Wedgetail, however there was for
Yitpi. Screening %, protein and hectolitre increased with grazing for both varieties. Yitpi yielded
significantly higher than EGA Wedgetail in this season/environment.

**KEY WORDS**
long season winter wheat, dual purpose wheat, stocking rate, grazing pressure, grazing wheat

**ACKNOWLEDGMENTS**
The authors wish to thank Allen Lawrence for use of land, Jane Speijers for statistical advice and
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**Project No.:** 67F Grain and Graze Avon
**Paper reviewed by:** Wal Anderson and David Kessell
Storing grain is not ‘set and forget’ management

Chris Newman, Technical Officer, Department of Agriculture and Food, Western Australia, Forrestfield

ABSTRACT

Management of farm stored grain is sometimes referred to as ‘crisis management’, finding solutions when things start to go wrong!

To produce a successful and profitable outcome from stored grain, management must commence as soon as the grain is loaded and continue at regular intervals until outturn.

Control of stored grain insects is pivotal to retain quality and the infrastructure built into the grain store will determine success of the program. Sealing and aeration may appear to be an additional charge attached to the capital cost of the silo but in fact are integral to enact successful management plans and should be regarded as part of the initial investment in large grain silos.

Investment in grain storage is a long term strategy and the equipment installed will ensure lower cost management operations in the future.

KEY MESSAGES

• Plan to expand the enterprise in the future – expansion is not compulsory but lack of a future plan may make expansion more difficult.
• Consider the quality of the storage before the size – better to have a grain store that will give complete control over the quality of the product than a larger store in which pests and grain condition cannot be controlled effectively.
• Complete control over the quality allows access to a broader range of markets.
• Consider sealing and aeration as part of the capital cost instead of an ‘optional extra’.
• Fumigation cannot be effective in an unsealed store and most likely will lead to increasing resistance to the fumigant used, compromising future insect control and posing a threat to the export stream.
• Large grain storages need gas recirculation devices to ensure total elimination of all insects present.
• Monitoring the fumigation is essential to be sure of success and comply with QA requirements.
• Maintenance of the seal is an annual task and the silo cannot be declared sealed until it has been tested and proved.
• Be aware of the hazards of handling quantities of phosphine in large grain stores.

Plan for success in post harvest grain marketing

Investment in grain storage must be viewed as a 15 year investment program and within that term, marketing of the product may change and the product stored may also change. To encompass change, careful planning of the grain pathway and silo infrastructure will provide long term flexibility for storage of a variety of grains to a range of markets. Modifying or adding equipment in the future is usually a more expensive exercise.

Future planning will never be easy but some consideration should be given to expansion of an enterprise so that investment can be staged. Crop yields will vary annually and unless you plan to store the entire crop it is better to consider storage with sufficient capacity for your current market with the surplus sold direct from harvester then add to existing storage as you develop your market.

Large silos are attractive because of the lower costs per cubic metre of storage if you intend to store large tonnage of a specific grade. However it may be worth considering installing smaller storages at a lower capital outlay which can be expanded as profitability permits. Smaller storages have the
advantage of greater flexibility to segregate, allowing access to very specific markets and quality control is more precise.

**Plan to deliver to Quality Assured standards**

Construct a smaller amount of high quality storage to ensure a quality outturn instead of opting for a lower cost larger system but without the essential infrastructure and inability to control quality in the long term. If your markets are within the food chain then the product will most likely be QA, which means within the quality bands proscribed by the buyer and insect free. If the storage is set up to deliver to the highest standards this opens up a full range of markets. If the storage does not have adequate infrastructure to deliver to QA standards then market opportunities will be limited.

**Storage infrastructure to achieve QA**

Cooling grain and keeping it in a cool condition is the best way to preserve the grain qualities that arrived in store from the field. Grain stored warm will gradually lose some of its baking qualities and germinability over a 12 month storage period. In addition, insect and microbial activity will continue unchecked leading to more serious quality losses. In a warm bulk of grain the temperature gradient between the walls and core drive air currents which can assist the transfer of moisture to the headspace and which may reach the point where moulds and bacteria become active. A temperature equalised grain bulk will not have air currents operating at the same rate and moisture in the headspace is less likely.

**Aeration**

Grain can be successfully cooled using an ambient air aeration system, this is a relatively low cost installation, adding 10-15% to the capital cost, but provides great benefits when marketing. Insect control will be enhanced considerably by keeping grain at 20°C or lower and these temperatures are achievable even in the warmer parts of the grain growing areas.

Aeration can be considered part of an integrated insect management program to reduce the reliance on phosphine by reducing the frequency of fumigation.

Ambient air passing through a bulk of grain alters the temperature in the interstitial space which causes the grain temperature to move towards equilibrium with the change. If the selected air has a lower relative humidity than the air surrounding the grain this action will be quite rapid due to the evaporative cooling effect.

The aeration can be controlled manually by observing local conditions but this has limitations and requires some effort to be successful. Automatic controllers remove the guesswork from the management process and reduce the labour costs and ‘inconvenience’ factor.

The larger the grain store the greater the necessity for aeration to prevent moisture migration to the headspace and it should be considered part of the initial investment plan when setting out the contract details. The initial budget may not permit additional cost but if plans are made to install aeration in future, then the groundwork can be laid at very little extra expense. When the concrete pad is laid it is a small extra cost to have duct trenches installed which can be fitted with mesh in future years and there is also a small additional cost to install the transition section in the silo wall that will eventually take the air duct from the fan. Additionally installing the venting system in the roof at ground level as it is assembled would prevent the need to work at heights when the silo is operational.

The key to insect control is to exploit their dependence on temperature for development. The cooler the conditions the longer the period from egg to adult in any of the stored grain insect species (example Table 1).

**Table 1.**

<table>
<thead>
<tr>
<th>Temp °C</th>
<th>Egg</th>
<th>Larvae</th>
<th>Pupa</th>
<th>Egg to adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>15</td>
<td></td>
<td></td>
<td>84</td>
</tr>
<tr>
<td>25</td>
<td>11</td>
<td>39</td>
<td>5</td>
<td>55</td>
</tr>
<tr>
<td>34</td>
<td>5</td>
<td>17</td>
<td>3</td>
<td>25</td>
</tr>
</tbody>
</table>

Temperatures colder than 20°C will further extend the life cycle but will not kill the insects until the temperature is sustained below 10°C, so if insects must be eliminated, a fumigation procedure will be essential. This will require the silo to be
sealed making it necessary that all aeration equipment is fitted with a facility to enable it to be sealed for the period of the fumigation (examples Figures 1 and 2). An alternative strategy may be to store all grain under aeration in unsealed storage and have one or two smaller ‘hospital’ silos into which it can be transferred for fumigation prior to sale. This plan may fit well for example, with an enterprise supplying mainly to feed lots and surplus grain fumigated for sale into a QA market.

Aeration management strategy

Remove the initial harvest heat by running the fans continuously for a period of time depending on the size of the grain store. The larger the store the longer the initial run period but for small silos run the fans for at least the first 24-48 hours and for large silos for about seven days. A temperature probe of some type installed in the peak of the grain stack will provide the best information but also simply sniffing the air coming out of the top of the stack is a useful determinant. The air will feel warm and moist for a time and smell musty before feeling cool and smell pleasant (normal grain smell).

Selecting cool air is not necessary for the initial period but after that run the fan in the cooler part of the day. An automatic controller is a better option for long term storage.

Sealing and fumigation

The only fumigant available for domestic grain trading is phosphine and can be used by unlicensed personnel. If the grain is to be eventually exported, Methyl Bromide (MB) can be used but its long term future is in question. The Montréal Protocol requires that MB will eventually be removed from use due to its ozone depleting characteristics. It is currently available for use in Australia only as a quarantine pre-shipment procedure. Alternative fumigant gasses to MB will be available in the future for quarantine pre-shipment and for use in the domestic market but it is most likely that these gasses will be available for use only by professional fumigators.

Fumigations will not be successful unless the gas can be retained within the grain bulk for sufficient time to control all stages of the insect. The cooler the grain the slower the insect metabolism and therefore the longer the exposure period to the fumigant gas to ensure complete eliminating of all life stages of the insect (egg, larvae, pupae and adult).

The egg and the pupae are the most tolerant of phosphine because they are in a less active, slow respiration stage. It is critical for success that these stages are eliminated (Figure 3).

Fumigation requires two factors for success, a threshold concentration of the gas and a time for which this concentration must be maintained. To eliminate all stages of the insect a concentration of phosphine must be maintained above 100 ppm, in the entire grain bulk, for 7 days at greater than 25°C commodity temperature and for 10 days between 25 and 15°C.

Carbon dioxide must be held at 35% for 15 days to control all insect species, to achieve this in a farm silo the gas is injected at the base of the silo to purge the atmospheric air and the gas cylinder turned off and the silo sealed when the concentration in the headspace reaches 60-80%. Sorption into the product will account for the excess CO². It is more expensive than phosphine and used mainly for higher value organic/bio-dynamic products.

Sealing will ensure that you will be able to fumigate successfully if your prospective markets demand insect free grain.

In an unsealed – or poorly sealed silo – the gas will be stripped out by the action of the wind on the surface causing a low pressure zone above the silo. This is also know as the chimney effect and is a cause of fumigation failure (Figure 3).

Sealing a bolted silo to retain the gas can be more economically accomplished during construction than sealing it from the outside in the future and in fact may add about 5% to the construction costs (Figures 4 and 5).

However a grain store can be effectively retro-sealed from the outside but this will be more expensive to accomplish and the maintenance of the seal will be greater because of the exposure of the seal coat to the elements (Figure 6).
Gas distribution

In silos smaller than 200 tonnes the distribution of the gas to the threshold concentration through the grain profile is normally successful without intervention and occurs within three days, at which point the fumigation period commences. In silos larger than 200 tonnes and especially flat floor silos the gas distribution will be slower and in some very large silos may not be achieved in all parts of the silo. It is recommended that a recirculation fan be installed in large silos and in some very wide silos a second fan be fitted. Figure 7 shows a recirculation fan that draws the gas down a tube from the headspace and blows it through the lower wall of the silo.

The aim of fumigation is to achieve the threshold lethal value in all parts of the silo as quickly as possible so that the time elapsed is consistent and there are no low value zones in the grain profile where insects may survive and be selected for resistance.

Grain insect resistance to phosphine

The total elimination of stored grain insects is needed to prevent damage and loss of value to the product but also to prevent spread of insects to uninfested premises. The other very important reason is to prevent the development of strong resistance within the local insect population. Weak resistance is widespread in WA but in the Eastern States strong resistance to phosphine has been detected in farm and central storage. This is the result of selection pressure in low concentrations of phosphine and the mating of weak resistant strains. The control of strong resistance adds to the challenge and cost to fumigate effectively and threatens the export stream so it is desirable that this added problem does not occur in WA.

Fumigating with the correct dose rate in a fully sealed and tested silo will ensure the complete elimination of all stages of stored grain pests.

Pressure testing farm silos

When a silo is delivered to farm direct from the factory it is most likely to be sealed to the recommended standard. When a silo is sealed as it is constructed on farm, a demonstration of the sealed standard should be regarded as part of the contract. Subsequently the pressure test should be conducted annually, after inspection and replacement of damaged seals, to ensure the storage is capable of holding the gas for the required period.

The test appears to be a daunting task in small silos and a huge task in large silos. However the procedure can be accomplished quite easily with a standard farm compressor. The pressure required is very low, around 250 Pascals but you will need large volumes to complete the test. This can be achieved with a venturi type air gun which draws in a large volume of air while using a relatively small volume of air from a compressor or use a vacuum cleaner set to blow (Figure 8). Inject the air through a PVC fitting inserted into the wall of the grain store. Alternatively a tubeless tyre valve can be inserted into the wall of the silo to conduct the air, remove the valve and direct connect an air line to speed up the operation.

Compress the silo to a pressure of 25 millimetres of water gauge and then time the decay of pressure. The silo should be able to retain half of the original level (down to 12 millimetres) for three minutes or longer (Figure 9).

From an engineering perspective, this standard is assuming minimal atmospheric influence on the pressures within the silo and it is recommended that the test be conducted under stable conditions if possible, for example full sun or full cloud and light winds and midday temperatures.

From a practical perspective the test on farm is more likely to be undertaken in less than perfect conditions. A full silo under strong wind or declining late afternoon temperatures is more likely to demonstrate a longer halving pressure due to the buffering effect of the grain bulk against a falling temperature. An empty or partially full silo could demonstrate a test considerably shorter than three minutes under the same conditions due to the internal air contracting more rapidly, however the seals may be adequate to retain the gas for an effective fumigation.

The test gives a reasonable indication of the quality of the seals in the candidate silo, and a degree of operator judgement is needed to factor the ambient conditions into the result.
**Phosphine monitoring and Phoscards**

The test of a successful fumigation is to measure the concentrations in different parts of the grain store. Electronic measuring devices give an instant readout of the gas value in that zone and daily measurements chart the progress of the fumigation and allow decisions to prescribe a ‘top up’ if gas values are falling too quickly. Hand held units are relatively expensive (around $2300) but are a small cost compared to loss of value of product in a large grain store.

A very low cost alternative is to use a small piece of copper placed in the grain store in the farthest accessible point away from the gas introduction port. The most convenient form of copper is a Phoscard® developed by the Department of Agriculture and Food and supplied by CBH. Exposing a piece of copper to phosphine gas for the recommended fumigation period and concentration will cause it to turn green/black signifying a successful fumigation. This can only be accessed at the conclusion of the exposure period and if it has failed to change colour a re-fumigation after re-checking the silo is indicated.

**Phosphine formulation**

The most common formulation of phosphine is the solid, aluminium phosphide tablet form which has been available in Australia since the 1950s. The use of this formulation in large silos presents a logistical and safety challenge to spread the tablets thinly and apply them to the headspace many metres above ground level. The tablets need to be well spaced on a tray to allow atmospheric moisture to activate the phosphine gas and prevent excessive heating. Failure to spread them out can result in incomplete gas release as the aluminium hydroxide residue from the tablets, seals off the underlying layers and prevents atmospheric moisture reaction and in a worst case scenario create sufficient heat to self combust. The aluminium hydroxide powder retains 1% phosphine that will only release in the presence of moisture, this could be in the stomach of an animal or breathed in if the operator is not wearing a face mask. It is important to prevent this powder entering the grain or being blown around.

A more recent formulation is the blanket or bag chain (Figures 10 and 11) where the phosphine in powder form is contained in joined paper sachets. Once the container is opened atmospheric moisture penetrates the sachets and releases the phosphine. On retrieval after the fumigation is complete the powder is retained and cannot blow around and injure the operator.

**Insect monitoring**

Insect monitoring is part of an integrated pest management program, providing information to initiate control. If aerating pitfall traps installed in the peak of the grain will give early warning of infestation. When fumigation is complete it is also wise to monitor the grain for insect activity in the event the fumigation was unsuccessful or if the silo has been opened for part outloading. Aeration of grain store may also continue after fumigation leaving it vulnerable to invasion.

The most likely point of entry for grain insects is through the upper vents when the aeration is turned off and also the easiest place to install insect traps is at the peak of the grain.

Commercial insect traps are not easy to obtain but home made traps can be made from receptacles such as drink cans with some fly mesh taped across the top. Push these in level with the surface of the grain and inspect them monthly for signs of insect activity.

**CONCLUSION**

The establishment of a grain storage complex requires consideration of the markets you will be supplying and how you will achieve the quality required. It will never be cheaper to install the infrastructure required at the time of building the complex and must be given high priority to ensure success of the enterprise.

**KEY WORDS**

grain storage, fumigation, aeration

Paper reviewed by: Rob Emery, Senior Stored Grain Entomologist, Department of Agriculture and Food, Western Australia
Figure 4

Figure 5

Figure 6
Figure 7

Figure 8

Fill oil to here

Start
Fill up to central line with recommended oil.

Silo inflated
Using a farm compressor, pump air through the tubeless tyre valve until the fluid moves down to the bottom line.

Oil level should take at least 3 minutes to fall to the half-way mark.

Figure 9
Improving understanding of soil plant available water capacity (PAWC): The WA soil water database (APSoil)

Yvette Oliver, Neal Dalgliesh and Michael Robertson, CSIRO Sustainable Ecosystems

KEY MESSAGES

- Understanding of soil types and their Plant available water capacity (PAWC) can improve farmers and advisors understanding of yield variability across a paddock, identify poor performing areas and determine subsoil constraints.
- PAWC information for a soil can assist with management decisions such as sowing date and fertiliser rates using tools such as Yield Prophet®.
- GRDC funded workshops have been held with farmers since 2002, and will be held in 2008/09 on measuring and monitoring soil water with interested farmer groups and advisors.
- PAWC data for about 100 sites has been collated into a web accessible database called APSoil (http://www.apsru.gov.au/apsru/), where the soils are grouped by WA Agricultural region (northern, central and south coast) and then WA soil group. However, it is still helpful to measure your own soil as PAWC can vary with depth of horizon and subsoil constraints, but the database is a great start.

AIMS

- To improve farmers and advisors knowledge about the value of understanding soil PAWC through GRDC funded workshops.
- To provide access to PAWC information from soils around Western Australia with a web accessible database: APSoil, ASRIS and Google Earth.
- To give some examples of how knowledge of PAWC can assist with management decisions using Yield Prophet®.

METHODS

Workshops

There has been a need to increase farmers and advisors understanding about PAWC and collect information on the full range of soils in the wheatbelt. A number of GRDC funded workshops have been held with farmers since 2002, and will be held in 2008/09 on measuring and monitoring soil water. Additional workshops also incorporate precision agriculture tools to help with understanding of spatial variability of soils and PAWC.

Workshop participants learn about PAWC, what it is, how to measure it and how to use this information. Simply, the PAWC defines how much water the soil can hold that is accessible by a crop, and is determined by the drained upper limit (DUL) and the crop lower limit (CLL). The DUL is the amount of water that a fully-wet soil is able to hold after drainage has ceased. The CLL is how much water the crop can extract from the soil profile. The CLL can be affected by soil type but also constraints such as compaction, acidity and salinity. It can also vary with crop species, being influenced by rooting patterns, where some crops have deeper roots than others.

Simple, farmer friendly methods to measure PAWC have been developed and are demonstrated in the workshop to enable farmers and consultants to measure the PAWC for individual soils on their own paddocks.
The APSoil database

PAWC has been measured at approximately 100 sites in WA (and over 500 nationally) over 2002-2007, through projects involving GRDC, CSIRO, DAFWA and farmer groups. Data which until recently was only available to those who had actually done the measurements has now been collated into a publicly accessible database called APSoil (http://www.apsru.gov.au/apsru/), in which the soils are grouped by WA Agricultural region (northern, central and south coast) and WA soil group. The data can also be accessed through the Australian Soil Resource Information System (ASRIS) at http://www.asris.csiro.au/index_ie.html. In addition Google Earth™ is now able to be used to view the location of sites spatially with soil data able to be downloaded for personal use. The necessary .kml file is available from both the ASRIS and APSRU websites. So far 83 sites have been entered into APSoil, covering the majority of soil groups and it is being continually updated. Most of the soils in the APSoil database have been checked for validity at that site, by their ability to correctly predict the wheat yield using Yield Prophet®.

RESULTS

APSoil database

The APSoil database contains a large amount of information about a soil profile. General information such as location, region, WA soil group classification, comments about the source of the data and the validity of the data (Figure 1). APSoil contains information about the soil water such as the components of PAWC (drained upper limit and crop lower limit), bulk density and saturated water content (Figure 1 for PAWC graph and Figure 2a). The soil profile information includes data on the soil chemistry such as organic carbon, pH, and other characteristics where measured (Figure 2b). The database also contains information required for the use of models such as APSIM.

The APSoil database can be used to provide Yield Prophet® users with estimated PAWC parameters for a soil type where no soil measurements have been taken. Each soil is geo-referenced, (without reference to the farmer’s identity), so local soils can be chosen. To use the database, a farmer or consultant needs to choose their region and select a soil type they feel matches their own soils. To do this they need to have some understanding of the soil texture, depth to layer change, possible rooting depth or depth to bedrock and soil constraints.

Figure 1. The APSoil database. The general information and PAWC graph is shown for a Yellow deep sand_poor sand at Mingenew in the Northern Agricultural region of WA.
Why should I measure my own PAWC?

While the database contains ~100 soil profiles covering the cropping soils in WA, there is no substitute for measuring your own soil. This is highlighted in Table 1, where within the WA super soil group there is a range of PAWC’s. For example the PAWC of a deep sand can range from 62 mm to 167 mm due to various limitations on the ability of crop roots to access the subsoil caused by salinity, sodicity, acidity, boron toxicity, aluminium toxicity, and even hardpans. Also the deep sands with roots to 2.5 m may include a gutless white sand which has very low PAWC of 3 mm/10 cm (or 75 mm PAWC) and a yellow sand with a PAW of 4.5 mm/10 cm (112 mm PAWC). For duplex soils, the depth of the duplex can range from 5-30 cm for a shallow duplex or 30-80 cm for a deep duplex, causing large variation in the PAWC.

Table 1. The PAWC and range of PAWC’s measured for the WA soil groups, the number of sites measured and the % of the WA agricultural regions these soils represent

<table>
<thead>
<tr>
<th>WA Supersoil groups</th>
<th>WA APSoil group</th>
<th>Average PAWC and range of PAWC’s</th>
<th>Average root depth</th>
<th>No. B</th>
<th>% WA Agricultural region C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow loam and Shallow sands</td>
<td>Shallow soils2</td>
<td>54</td>
<td>0.5</td>
<td>1</td>
<td>7.6</td>
</tr>
<tr>
<td>Ironstone gravelly soils</td>
<td>Gravels and Gravels and Duplex sandy gravel</td>
<td>80 (41-126)</td>
<td>-</td>
<td>8</td>
<td>10.0</td>
</tr>
<tr>
<td>Sandy duplex</td>
<td>Shallow sandy duplexes</td>
<td>66 (50-115)</td>
<td>0.6</td>
<td>5</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>Deep sandy duplexes</td>
<td>89 (44-199)</td>
<td>0.9</td>
<td>12</td>
<td>14.1</td>
</tr>
<tr>
<td>Loamy duplex</td>
<td>Shallow loamy duplexes</td>
<td>69 (38-95)</td>
<td>0.6</td>
<td>6</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>Deep loamy duplexes</td>
<td>105 (52-178)</td>
<td>0.9</td>
<td>12</td>
<td>1.8</td>
</tr>
<tr>
<td>Deep sands</td>
<td>Sands</td>
<td>110 (62-167)</td>
<td>2.5</td>
<td>13</td>
<td>15.8</td>
</tr>
<tr>
<td>Sandy earth</td>
<td>Sandy earths</td>
<td>111 (75-167)</td>
<td>2.5</td>
<td>12</td>
<td>8.0</td>
</tr>
<tr>
<td>Loamy earth</td>
<td>Loamy earths (deep loam)</td>
<td>140 (82-254)</td>
<td>2.5</td>
<td>6</td>
<td>9.5</td>
</tr>
<tr>
<td>Cracking Clay and Non-cracking Clay</td>
<td>Clays</td>
<td>157 (70-245)</td>
<td>2.1</td>
<td>8</td>
<td>2.7</td>
</tr>
<tr>
<td>Rocky or stony soils</td>
<td>Rock or stony soils</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.0</td>
</tr>
<tr>
<td>Wet or waterlogged soils</td>
<td>Wet/saline soils</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6.9</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>83</td>
<td>18.8M ha</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A soils < 80 cm depth over bedrock, B = number of sites entered into APSoil. C = area of these soil groups in WA Ag region – preliminary data from Denis van Gool.
Using soil and PAWC information

With knowledge of the soil PAWC, a soil from APSoil and historical climate information of the type available from SILO database, we can use Yield Prophet® to look at a number of different scenarios including: a) the impact of PAWC on yield potential over a range of seasons using long term weather records; b) the impact of variable seasonal finishes on yield (say when conditions are known until the end of June); c) the value of stored moisture on yield expectations; d) the effect of sowing date on yield – both historically and as the season progresses (i.e. how late can I sow and still break even); and e) the potential benefits of in-crop nitrogen application based on known starting soil nitrogen and seasonal conditions to a particular date (e.g. late June).

Below is an example from Kellerberrin for a deep sand with a PAWC of 117 mm and a shallow loamy duplex with a PAWC of 60 mm. The figures show the range of wheat yield potentials when the soil has stored water on 27 April (as measured in 2006 after 180 mm rain since January) or has no stored water on 27 April using (such as in 1994 where only 7 mm rain fell since January) using Kellerberrin climate data from 1904-2005 when Wyalkatchem wheat was sown on 30 May.

![Figure 2. Probability of wheat yield potential in Kellerberrin for (a) deep yellow sand with 55 mm stored water or no stored water on 27 April and (b) shallow loamy duplex with 20 mm of stored water or no stored water on 27 April.](image)

In this example, the median yield (50% probability) is 1.5 t/ha for both the deep sand and shallow loamy duplex when there is no stored water (Figure 2). The presence of soil moisture in April (55 mm for the deep yellow sand and 20 mm for the shallow loamy duplex), increases the potential yield (or shifts the curve to the right), with the median yield increasing by 1 t/ha in the deep sand and 0.5 t/ha in the shallow loamy duplex. The shallower duplex soils benefits less from the stored water as it is unable to store the same amount of water as the deep yellow sand due to its lower PAWC. This also results in a lower yield potential. Therefore the knowledge of the yield potentials for the different soils with and without stored water can assist in crop management decisions such as fertiliser rates.

CONCLUSIONS

There is value in understanding PAWC and the amount of stored soil water available for production at the start of the season. It provides you with the opportunity to better predict yield potential and therefore fertiliser requirements. A database of soil water characteristics is available to estimate PAWC and use in Yield prophet, however some knowledge of the soil is of benefit to fine tune soil locally. Workshops are available which can assist farmers and growers with understanding and measuring PAWC.

KEY WORDS

yield potential, soil type, fertiliser, crop management
ACKNOWLEDGEMENTS

Farmers who participated in workshops, DAFWA, CSIRO and farmer groups who provided soil PAWC data and Dennis van Gool (DAFWA) for soil type distribution in WA and GRDC for funding of projects.

GRDC Project No.: CSA0011
Paper reviewed by: Roger Lawes
The impact of management decisions in drought on a low rainfall northern wheatbelt farm

Caroline Peek and Andrew Blake, Department of Agriculture and Food, Western Australia, Geraldton

KEY MESSAGES
The 2006 and 2007 seasons represented two years in which a large number of growers in the Northern wheatbelt suffered considerable financial losses to their farm business. These losses were primarily the result of poor seasons but were also influenced by how growers responded to the season in adjusting their cropping programs and inputs.

The 2008 season may provide an opportunity to move forward. How growers manage the seasonal conditions, their ability to absorb risk and to finance their planned operations will influence the impact that this approaching season will have on the farm business.

AIMS
To investigate the influence that management decisions had on the financial fortunes of a farm business in the drought seasons of 2006 and 2007 and to suggest how this may influence the management decisions in 2008.

METHOD
A representative model farm located in the < 325 mm rainfall zone of the Northern wheatbelt was constructed in STEP based on production and financial information sourced from grower, consultant and BankWest benchmark data and the local knowledge of the authors. STEP is a computerised series of whole farm annual financial budgets used to investigate the consequences that different management decisions can have on the progressive annual cash flow.

Farm size is 4315 ha and the average long term debt at the start of the analysis period is $500,000. Annual yields varied between soil types. In 2006 and 2007 yields were estimated from actual harvest data. 2008 average yields are based on long term average yields from grower data.

Table 1. Wheat price, wheat yields, lamb and ewe prices used in the STEP analysis 2006-2008

<table>
<thead>
<tr>
<th></th>
<th>Wheat price farm gate $</th>
<th>Wheat yield t/ha</th>
<th>Lamb price $/hd</th>
<th>Ewe price $/hd</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>$200</td>
<td>0.0-0.7 t/ha</td>
<td>$45</td>
<td>$20</td>
</tr>
<tr>
<td>2007</td>
<td>$339</td>
<td>0.4 t/ha</td>
<td>$45</td>
<td>$20</td>
</tr>
<tr>
<td>2008</td>
<td>$245</td>
<td>0.6-1.8 t/ha</td>
<td></td>
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</tbody>
</table>

* Varies with soil type and season.

With the benefit of hindsight the fortunes of the low rainfall farm were modelled over the 2006 and 2007 seasons. Several different ways that growers responded to the season were investigated. A small grower survey was done to assist with setting these scenarios.

SCENARIOS IN THE ANALYSIS
1. Sowing the whole program or no crop in 2006 followed by a 2007 program where only the least risky soil types were sown with normal fertiliser inputs. This situation was run through to an average 2008 season with a large cropping program to wheat.
2. Sowing a reduced program in 2006, followed by a 2007 program where only the least risky soil types were sown with either reduced or normal fertiliser input strategy. This situation was also run through to an average 2008 season with a large cropping program to wheat.
3. Using a situation of reduced cropping program in 2006 and reduced fertiliser inputs in 2007, the farm was analysed with several potential 2008 scenarios. These included:
   • an average season with a larger than average cropping program to wheat;
• an average season where the cropping program is confined to the better producing soil types to simulate situations where there are restrictions on seasonal finance;
• a larger than average cropping program with a reduction in average yield of 200-400 kg/ha depending on soil type to simulate a poorer than average season;
• a larger than average cropping program with reduced fertiliser inputs and a reduction in average yield of 200-400 kg/ha depending on soil type;
• the reduced cropping program scenario with the 200-400 kg/ha yield reduction.

The analysis looked at the annual surplus or deficit that the farm business returned in each year. This included variable, fixed and capital costs, taxation and interest repayments but not principal repayments. All livestock was sold in 2006 and 2007. It also looked at the cumulative financial position of the farm after three years.

This should be viewed as a comparative analysis relevant to the management scenarios applied to the model farm. Individual farm businesses will vary widely.

RESULTS

Table 2. Monthly rainfall received (mm) at Mullewa and Morawa during 2006 and 2007 compared with long term average rainfall

<table>
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<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mullewa 2006</td>
<td>31</td>
<td>13</td>
<td>2</td>
<td>18</td>
<td>1</td>
<td>2</td>
<td>19</td>
<td>18</td>
<td>38</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>Mullewa 2007</td>
<td>26</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td>25</td>
<td>4</td>
<td>10</td>
<td>12</td>
<td>7</td>
<td>0</td>
<td>18</td>
<td>153</td>
<td></td>
</tr>
<tr>
<td>Mullewa Av.</td>
<td>13</td>
<td>17</td>
<td>19</td>
<td>21</td>
<td>48</td>
<td>65</td>
<td>60</td>
<td>42</td>
<td>22</td>
<td>13</td>
<td>9</td>
<td>8</td>
<td>337</td>
<td></td>
</tr>
<tr>
<td>Morawa 2006</td>
<td>92</td>
<td>39</td>
<td>1</td>
<td>23</td>
<td>6</td>
<td>7</td>
<td>20</td>
<td>18</td>
<td>25</td>
<td>5</td>
<td>7</td>
<td>11</td>
<td>254</td>
<td></td>
</tr>
<tr>
<td>Morawa 2007</td>
<td>26</td>
<td>16</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>13</td>
<td>36</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>2</td>
<td>4</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>Morawa Av.</td>
<td>14</td>
<td>18</td>
<td>23</td>
<td>22</td>
<td>46</td>
<td>60</td>
<td>54</td>
<td>39</td>
<td>22</td>
<td>15</td>
<td>11</td>
<td>9</td>
<td>333</td>
<td></td>
</tr>
</tbody>
</table>

2006 season

Many areas of the low rainfall NAR received significant rainfall over the summer leading up to the 2006 season (see Table 2). The amount received was however variable and the distribution patchy as is typical with summer thunderstorms. For example Morawa received over 130 mm of rain during January and February. This wet up soil profiles, leaving residual stored soil moisture on deeper soil types. Growers who received this significant summer rainfall went into autumn 2006 with increased confidence in their yield potentials.

Some areas did not receive much summer rainfall. Mullewa received less than 30 mm during January and February and with evaporative losses this would provide little in terms of stored soil moisture for the coming winter’s crops. The next significant rainfall was on the first of April which is too early to seed cereal crops. The traditional planting window during late April, May and June provided no wet seeding opportunities but many growers dry seeded large areas during this period. Many paddocks had stored soil moisture at depth but growers could not get crops germinated to make use of this moisture. Some dry seeded crops did germinate on small rainfall events during April, May and June.

A survey conducted with growers from the Mullewa and Yuna areas indicated that growers took three main approaches to 2006 and these were examined as part of the financial analysis presented here. A surprisingly high number seeded their full program (much of it dry) despite the extremely late break and a less than favourable seasonal outlook. The majority seeded a reduced cropping program focussing on their better soil types. A small minority did not seed any of their planned cropping program. It is worth noting that many growers did not reduce their cropping inputs leaving them more financially exposed in the event of crop failure, possibly because stored soil moisture provided confidence in their yield potentials.

Analysis confirms what intuition would indicate and what hindsight shows. Growers who sowed their whole program in 2006 were likely to be worse off than those who reduced their programs. Where the program was not sown there was a similar outcome to where only the least risky soil types were sown. This result was influenced by significant spraying for summer weed germination so a reasonable amount of money had already been spent up front prior to making sowing decisions.
Extended supplementary feeding of livestock was costed at $42,000 and destocking generated revenue of $89,500.

**2007 season**

Little summer rainfall fell in the January to March period leading up to season 2007 so the majority of soil profiles were dry going into the autumn period. April, May and the first three weeks of June provided no wet sowing opportunities. Rainfall during late June and early July provided some sowing opportunities and germinated dry sown crops.

During late autumn the 2007 seasonal outlook was better than during 2006. However with the lack of sub soil moisture and the very late break most growers reduced their cropping program focusing on better soil types. Many did however seed paddocks with low yield potential where these paddocks were at risk from wind erosion in an attempt to stabilise these paddocks. Most growers reduced cropping inputs at seeding in 2007. This was because many soil tests were indicating high levels of available nitrogen, the price of seed and fertiliser had increased and growers were taking a generally more conservative approach following the difficulties of the 2006 season.

Reducing fertiliser inputs in 2007 reduced the annual deficit (Table 3). Yield was not affected by fertiliser reduction as it was low as a result of poor moisture levels.

Livestock cost $18,000 to feed and were all sold for $74,000. They have not been replaced. Proceeds from these sales must be offset by the requirement to account for the deficit between closing and opening livestock inventory values over the two seasons.

**2008 season**

A range of scenarios are possible with the interactions of season with high wheat prices, restricted ability of some businesses to access seasonal finances, high fertiliser prices and increases in some herbicide costs. The STEP model was used to look at 5 scenarios (Table 3).

The largest annual surplus of $388,000 (Table 3) depends on a return to average season and the ability to finance a cropping program of 90% of arable area with $670,000 variable input costs (Table 4). However if a reduced program of 57% of arable area is sown and average yields are achieved then a healthy surplus of $195,000 (Table 3) is returned with a variable input cost of $457,000 (Table 4).

If the yields are reduced by 200-400 kg/ha due to a below average finish the surplus is reduced to $144,000 with a big program and with a smaller program $68,000 is returned (Table 3). While an extra $212,000 in input costs for the bigger program (Table 4) leads to an additional surplus of $193,000 compared to the reduced program in an average season, a yield reduction results in the additional surplus falling to $76,000, highlighting the risk associated with a larger cropping program.

If soil tests indicate that fertiliser inputs can be reduced, then risks are minimised when a reduced yield due to unpredictable seasonal conditions occurs. This is effect is magnified in a big program (Table 3).

**Risk and reward**

While surpluses can be returned under reduced yields, it becomes increasingly risky to spend money on a large cropping program. It is up to individual growers with regard to their respective business' position to determine whether the lure of increased profits warrants the greater risk associated with the significantly higher total variable input costs of a larger cropping program. Particularly growers need to assess whether further losses under any cropping program can be absorbed by their business without compromising future viability.

**Cumulative financial position**

While potential large annual surpluses might be available in 2008, none of the scenarios completely recover the accumulated deficits from 2006 and 2007. The scale of recovery is as dependent on how growers manage the 2008 season as much as the cumulative position from 2006 and 2007. There is an opportunity to regain some lost capital and also a risk of placing the business in a position that could make recovery difficult.
Table 3. Summary of the comparison of the Annual surplus/deficit and the 3 year cumulative financial position that the model farm returned under the different management scenarios

<table>
<thead>
<tr>
<th>Management Scenarios</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal fertiliser inputs into 2007 cropping program and large cropping program 2008</td>
<td>$-388</td>
<td>$-211</td>
<td>$382</td>
<td>$-177</td>
</tr>
<tr>
<td>Reduced cropping program 2006</td>
<td>$-310</td>
<td>$-211</td>
<td>$382</td>
<td>$-101</td>
</tr>
<tr>
<td>No cropping program 2006</td>
<td>$-312</td>
<td>$-211</td>
<td>$382</td>
<td>$-103</td>
</tr>
<tr>
<td>Reduced cropping program 2006, reduced fertiliser inputs in 2007 cropping program and varying 2008 scenarios</td>
<td>$-310</td>
<td>$-185</td>
<td>$388</td>
<td>$-63</td>
</tr>
<tr>
<td>Large program and average yields 2008</td>
<td>$-310</td>
<td>$-185</td>
<td>$144</td>
<td>$-343</td>
</tr>
<tr>
<td>Large program, reduced yields 2008</td>
<td>$-310</td>
<td>$-185</td>
<td>$239</td>
<td>$-233</td>
</tr>
<tr>
<td>Large program, reduced yields 2008, reduced fertiliser</td>
<td>$-310</td>
<td>$-185</td>
<td>$195</td>
<td>$-285</td>
</tr>
<tr>
<td>Reduced program 2008</td>
<td>$-310</td>
<td>$-185</td>
<td>$68</td>
<td>$-430</td>
</tr>
</tbody>
</table>

Table 4. Annual area cropped (ha) to primarily wheat for each of the systems. Variable expenditure is also shown for the projected 2008 season

<table>
<thead>
<tr>
<th>System</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2008 variable expenditure $,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole program sown 2006</td>
<td>2480 ha</td>
<td>1735 ha</td>
<td>3865 ha</td>
<td>$669</td>
</tr>
<tr>
<td>Reduced program 2006</td>
<td>1015 ha</td>
<td>1735 ha</td>
<td>3865 ha</td>
<td>$669 or $532*</td>
</tr>
<tr>
<td>Reduced program 2006 and 2008</td>
<td>1015 ha</td>
<td>1735 ha</td>
<td>2465 ha</td>
<td>$457</td>
</tr>
</tbody>
</table>

* Lower fertiliser inputs.

CONCLUSION

In 2006 and 2007 the low risk approach of reduced cropping program and inputs gave the best relative outcome over seasons. However there is still a significant financial loss sustained and growers will be keen to recoup some of these losses. The future of some farm businesses will rely on a profitable outcome in 2008.

In 2008 wheat prices are potentially high and input costs are high. Individual growers should assess their own situations to find out how much yield is needed on each soil type to cover variable costs and contribute to fixed and capital costs. There could be the ability to reduce fertiliser input costs depending on soil test results. The ability of the business to absorb a higher risk approach and the availability of seasonal finance will influence the size of the cropping program in 2008. There are potential profits to be made but with the possibility of higher than average cropping programs planned there is also considerable risk.

KEY WORDS

risk, season, STEP

Project No.: 05N114-01

Paper reviewed by: Allan Herbert, Rob Grima and Sam Harburg
Cullen – a native pasture legume shows promise for the low-medium rainfall cropping zone

Megan Ryan, Richard Bennett, Tim Colmer, Daniel Real, Jiayin Pang, Lori Kroiss, Dion Nicol and Tammy Edmonds-Tibbett, School of Plant Biology, The University of Western Australia and Future Farm Industries CRC

KEY MESSAGES

• Native herbaceous perennial legumes have not previously been examined in detail for pasture potential. The natural adaptation of some species to low average annual rainfall, drought and acid soils with inherent low fertility means they may be useful additions to pastures in situations where lucerne is not well suited.

• Preliminary investigations show Cullen is a genus with particular promise. After growing for 12 months at Buntine, C. australasicum had 23 accessions with higher persistence than lucerne, 10 accessions with higher average biomass and seven accessions that were higher in both measures than lucerne.

• Preliminary glasshouse trials also show C. australasicum had high concentrations of carboxylic acids in the rhizosphere, which may indicate ability to access poorly soluble phosphorus sources.

• A Future Farm Industries CRC project involving DAFWA, SARDI and UWA is likely to commence selection and breeding of C. australasicum in 2008.

AIMS

We aim to identify native perennial legumes with broad application as pasture components in environments where lucerne is not well suited. Their potential will be judged by better performance than lucerne in the target environment. Overall project aims are to:

1) Determine whether species of Cullen can outperform lucerne in terms of productivity and persistence.

2) Acquire as much information as possible about the ecology and agronomy of Cullen to allow targeting of future selection and breeding activities.

METHOD

Analysis of the climates and soils of natural distributions suggests that at least seven species of Cullen native to Australia have potential to be developed as perennial legumes for low-input pastures in difficult climates and soils in the wheatbelt of Western Australia (Bennett et al. 2006). The natural distributions of three of these species are shown in Figure 1.

Seed was collected from populations of Cullen around Australia and stored at the Genetic Resource Centres at the South Australian Research and Development Institute (SARDI) and the Department of Agriculture and Food, Western Australia (DAFWA), and at the University of Western Australia (UWA). Root nodules were collected at the same time and bacteria have been isolated and stored at
Rutherglen Department of Primary Industries (DPI), Victoria. A series of experiments have been conducted. Preliminary results from two of these experiments are reported in this paper; field trials managed as part of Richard Bennett’s PhD and a glasshouse study managed as part of Jiayin Pang’s postdoctoral studies.

**Field trials**

One hundred accessions of nine Australian *Cullen* species were sourced from collections at the Australian Medicago Genetic Resource Centre in South Australia, the Australian Tropical Crops and Forages Genetic Resource Centre in Queensland and from the collection held at UWA. Germplasm was also sourced of *Lotus corniculatus* cv. San Gabriel, *L. australis* (Accession SA 33610, a native perennial legume under development by the FFI CRC), and lucerne cvs Sardi 10 and Sceptre. Trial sites were located at Shenton Park, Perth (under irrigation), and 22 km west of Buntine, Western Australia. At Shenton Park the soil was a sandy loam, while at Buntine, the soil was a deep sandy loam, with a pH(1:5 H₂O) range from 5.4 to 6.8 over the first 1.2 m. Seedlings were transplanted to the field on 6 December 2006 at Shenton Park and 7 September 2006 at Buntine. At Buntine, three replicates, each containing three seedlings of each *Cullen* and *Lotus* population and 6 seedlings of each lucerne cultivar were planted over three blocks (24 m × 15 m) in a 1 m grid. A similar design was followed at Shenton Park. The Buntine site experienced a four month dry period between January and April 2007, with the break of the season in May. Seedlings were hand-watered two weeks after transplanting with 500 mL (simulating a 15 mm rainfall event). Plants remaining alive on 30 November 2006 were considered to be established and survival (persistance) at later dates was calculated based on this number. All plants were cut back to 5 cm from the crown in January following damage from Australian plague locusts during November. Plants were again cut to 5 cm from the crown on 26 September 2007 and leaf and stem portions were dried for 7 days at 40°C and weighed.

**Glasshouse trial – response to phosphorus**

The response to phosphorus addition of one of the best performing *C. australasicum* accessions from the Buntine site and lucerne cv. Sardi10 was studied in a glasshouse at UWA. Root rhizosphere carboxylic acid concentrations were measured when plants were two months old. Carboxylic acids may aid plant roots to access poorly soluble forms of phosphorus in soils. Root systems were gently removed from the bulk soil. The roots were shaken slightly to remove excess soil and the remaining soil was defined as rhizosphere soil. The whole root systems were transferred to a 100 mL vial, and washed in a measured amount of 0.2 mM CaCl₂ solution ranging from 20 to 70 mL. The root system was gently dunked in the solution until as much rhizosphere soil as possible was removed. Care was taken to minimise root damage. A subsample of the rhizosphere extract was then filtered using 0.2 µm syringe filter into a 1 mL HPLC vial. The vial was acidified with one drop of concentrated phosphoric acid, and transferred to a -20°C freezer until HPLC analysis.

**RESULTS**

**Field trials**

Detailed measurements at Shenton Park showed a large degree of diversity among the collection in characters such as growth habit (prostrate vs erect types) and flowering time. For instance, in the most promising species, *C. australasicum*, 33 accessions took < 122 days after sowing to flower (24 of these < 91 days), while 77 accessions took > 216 days. At Buntine there was a high level of drought stress during 2007, but quite a few accessions of *C. australasicum* (and one each of *C. pallidum* and *C. pustulatum*) had 100% persistance (Figure 2). All *Cullen* species except *C. patens* had accessions which persisted better than Sardi 10. Both lucerne cultivars had persistence < 85%. Compared to the best performing lucerne cultivar, *C. australasicum* had 23 accessions with higher persistence, 10 accessions with higher average biomass and 7 accessions that were higher in both measures (Figure 2). If productivity per plant is multiplied by persistance, the best performing *C. australasicum* accession yielded more than twice that of Sardi 10 and around 4 times that of Sceptre (49.0, 24.2 and 13.0 g, respectively). Both *Lotus* species yielded poorly, although *L. australis* had a persistence of around 65%. Plants in best performing *C. australasicum* accessions were around 70 × 50 cm while lucerne plants were around 50 × 50 cm, but denser than *C. australasicum* due to a greater number of stems.
Figure 2. The relationship between productivity in September (biomass after eight months regrowth) and persistence (percentage survival of plants) of all *Cullen* populations, two lucerne cultivars (Sceptre and Sardi 10), *Lotus australis* and *L. corniculatus* at Buntine. Dashed lines are centred over Sardi 10, the best performing lucerne cultivar.

**Glasshouse trial – response to phosphorus**

When grown with 6 mg P/kg sand, *C. australasicum* had a four to five times higher concentration of carboxylic acid around the root rhizosphere than lucerne (Figure 3). In *C. australasicum*, total rhizosphere carboxylic acids were much higher at 6 mg P/kg sand than 48 mg P/kg sand, while for lucerne there was no difference (Figure 3).

![Figure 3. Concentration of carboxylic acid in the root rhizosphere of *C. australasicum* and lucerne grown with either 6 or 48 P mg/kg sand (mean ± s.e.).](image)

**HOW WILL NATIVE PERENNIAL LEGUMES FIT INTO FARMING SYSTEMS?**

*Cullen australasicum* grows mainly during spring and summer and is largely dormant in cool winters. Thus, it may be best used as a companion to annual species in low value or low input areas or systems. Permanent perennial pastures or five to six year pasture phases would be most appropriate. The palatability of *C. australasicum* is variable. Poorly palatable varieties may encourage stock to preferentially graze annual pasture and weed species during winter and spring, leaving the *Cullen* as green feed for stock in summer.

Members of the *Cullen* genus are known to produce isoflavones and furanocoumarins, which can cause photosensitisation. Seeds may have high concentrations of these chemicals. Although there are no reports of *C. australasicum* causing damage to stock, further research is required. Animal interactions need further study.

Our results show *Cullen* species are productive and persistent when cut at 3 or 6 month intervals. Thus we expect that *C. australasicum* would be well suited to systems with long intervals between intensive grazing events, but it may also be suited to less intensive grazing at shorter intervals. The results from the Buntine field site show *Cullen* has good drought tolerance. The ability of *C. australasicum* to hold onto leaves under water stress may allow it to be used as a green ‘living
haystack' which could be used strategically to fill feed gaps in summer or autumn, or during drought. The plant form of *C. australasicum* may also make it suitable for use as a nursery paddock, offering protection to animals at lambing.

Domestication potential of *C. australasicum* is excellent. *Cullen australasicum* produces seeds high in the canopy, making conventional header harvesting possible. Research is underway to determine the best seed harvesting methodology. There is variation in seed production and retention characteristics and selection of lines with good seed production should be a priority for cultivar development.

CONCLUSION

Native perennial legumes from the genus *Cullen* have potential to outperform lucerne on infertile, acid soils in the low-medium rainfall belt of the Western Australian wheatbelt. *Cullen australasicum* currently shows greatest promise. The preliminary results showing high rates of carboxylic acid exudation by *C. australasicum* are exciting and may indicate ability to access poorly soluble pools of soil phosphorus; a follow-up experiment is underway. Selection and breeding may further improve the performance of *C. australasicum*. A germplasm collection of ~50 accessions of *C. australasicum* is available and characterisation of agronomic traits is in progress.

There are a number of on-going research projects focussed on *C. australasicum*, other *Cullen* species and other native perennial legumes not discussed in this paper. These projects are examining the ability of *Cullen* species to cross with each other (molecular markers have been developed for this purpose), nutritive value, and tolerance of herbicides, drought, waterlogging and soil acidity. Two species, *C. cinereum* and *C. graveolens* (an annual), will be trialled in 2008 on heavy clay soils with subsoil constraints at Mukinbudin (< 300 mm average annual rainfall). These two species show remarkable productivity under similar conditions in the Fortescue River Floodplain in northern Western Australia (Nicol 2006). The herbicide tolerance of *C. australasicum* will be trialled in 2008 at Medina, Perth.

Due to the promising results on the pasture potential of *C. australasicum*, a FFI CRC project involving DAFWA, SARDI and UWA is likely to commence selection and breeding of *C. australasicum* in 2008.

KEY WORDS

native legumes, perennial pastures, *Cullen*, phosphorus

ACKNOWLEDGMENTS

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REFERENCES


Paper reviewed by: Sarita Bennett
Climate risk management tools – useful, or just another gadget?

*Further analysis of yield forecasting models in the WA wheatbelt*

Lisa Sherriffa, Kari-Lee Falconerb, Daniel Gardinerb and Ron McTaggarc
Department of Agriculture and Food, Western Australia; aNortham, bMoora, cAlbany

**KEY MESSAGES**

- Yield forecasting tools aim to assist farmers/farm managers in making tactical crop management decisions, with respect to variable inputs such as fertiliser and fungicide applications, as well as the decision to sow or not when the season gets off to a very poor start.

- Yield forecasting tools can help a manager understand the ‘chances’ of achieving a certain yield. They cannot predict the final crop yield without knowing what the remainder of the season will be like with regards rainfall and temperature.

- The tools vary considerably in their complexity and ease of use, thus different tools will appeal to different users. In addition, it is important to be aware of the limitations of each tool, and to calibrate them locally to ensure that they produce meaningful data over differing seasons.

- Farmers across the wheatbelt involved in this study found the information produced by the workshops and bulletins increased their awareness of the available climate risk management tools, enabled them to correctly interpret the information and understand where the tools may be useful when making climate risk management decisions.

- However, opinions were divided on whether or not the tools were actually useful. Some farmers found it reassuring that the yield forecasts were ‘backing up their own assessments’ of the crop. Others felt that the lack of confidence in forecasting the season finish (a climate outlook issue not a yield tool issue), particularly earlier in the season when the majority of the decisions are being made, decreased their confidence in using this information for decision making.

- The majority of farmers involved in this study believe the three most important factors to consider when making crop management decisions are: available stored soil moisture, time of sowing and visual assessment of the crop.

**AIMS**

Seasonal variability has a major impact on farming operations. A number of climate risk management tools have been developed in an effort to enable farm managers to minimise this risk. Yield forecasting models aim to assist farmers to ‘play the season’ with respect to variable inputs such as fertilisers and fungicides.

Although yield forecasting tools have been investigated previously in the Northern Agricultural region by the Mingenew Irwin Group *(Weeks, Robertson, Oliver, Fairbanks, Agribusiness Crop Updates 2007)*, a further analysis has been conducted through the AcCLIMATise project to include farms in the Central and Southern wheatbelt. This wider analysis encompasses a variety of soil types and rainfall zones throughout the entire WA cropping area, from Geraldton to Esperance.

A number of potential yield models were assessed such as *Yield Prophet, PYCAL* and *STIN XL*, in the following areas:

1. Ease of use.
2. Accuracy of crop yield prediction throughout the season, i.e. ‘ground-truthing’.
3. Usefulness and place in assisting decision making on farm.

This paper delivers the findings over two consecutive seasons, 2006 and 2007, where the models were tracked against Wheat and Barley crops, with the results published throughout the year in a series of bulletins for each agricultural region.
In addition, the attitudes and thoughts of the farmers participating in the trial work were documented, with respect to dealing with seasonal variability and the use of yield forecasting models when making tactical decisions for the farm.

**METHOD**

A number of yield forecasting tools were analysed – PYCAL (DAFWA), STIN XL (DAFWA) and Yield Prophet (CSIRO/Birchip Cropping Group). Sites were monitored on a number of different farms and associated soil types in the Northern Agricultural Region (NAR), Central Agricultural Region (CAR) and the Southern Agricultural Region (SAR), across all rainfall zones.

*Model calibration*

Following the identification of trial sites, each tool was calibrated according to the specific paddock (i.e. soil type). PYCAL and STINXL were very easy to calibrate, in that all was required was historical yield and rainfall data to ascertain the crop water use efficiency from that paddock.

However, Yield Prophet’s calibration was far more extensive. Soils were sampled to a depth of at least 1 m and sub samples taken every 10 cm over at least three holes in a representative section of the paddock. These samples were then chemically tested for pH, nitrates, ammonia, organic carbon %, electrical conductivity, physically tested for soil texture and finally, a starting soil moisture percentage was measured. Following this, estimates were made of the crop lower limit (CLL) and drained upper limit (DUL) of the soil, along with soil bulk density. Crop information such as variety, plant density and stubble density were also included.

Once the models were calibrated and the cereal crops sown, daily rainfall data was entered along with nitrogen inputs as required. The models were run throughout the season and the predicted yields documented.

*Delivery of results*

There were four main avenues utilised to deliver the results, along with other important seasonal climate and weather information. These were the regional ‘AcCLIMATise Bulletins’, AgMemo newsletters, climate risk management workshops and trial site field days. Each of these avenues were targeted to farmers, agribusiness agronomists/consultants and farmer groups.

Regional AcCLIMATise Bulletins were produced throughout the season, and contained information on regional climate outlooks and trial site specific data such as rainfall to date, crop management information and yield forecasts from the various tools.

Articles posted in the regional AgMemo publications also commented on climate and weather information to date, although yield forecasts were generally at a shire level, to give farmers a feel for the situation across many shires and associated soil types within a region.

Climate risk management workshops were held each year to present and discuss the latest climate risk management information available. Discussions centred around how best to use this information when making farm management decisions, with specific reference to yield forecasting models and seasonal forecasts.

Field days were also held at some of the trial sites throughout the regions. In the SAR, yield estimates were done in situ by counting tillers at Zadocs 35 to obtain a feel for potential yield. This was then followed by head and grain number counts closer to harvest, to get a final yield, which was then compared to the models.

**RESULTS**

*Yield forecasting models*

The table below dictates the final yield predicted by each of the models compared with the actual paddock yield for each of the trial sites, for seasons 2006 and 2007 (Tables 1 and 2). In 2006 (Table 1), PYCAL, Yield Prophet and STIN XL had 67%, 61% and 71% of predictions within 0.5 t/ha
respectively. PYCAL and Yield Prophet tended to over-estimate yields as opposed to STINXL, which tended to under-estimate yields. In 2007 (Table 2), PYCAL, Yield Prophet and STIN XL had 63%, 71% and 100% of predictions within 0.5 t/ha respectively. All three models tended to overestimate yields in this season.

Table 1. Trial results season 2006

<table>
<thead>
<tr>
<th>Location</th>
<th>Variety</th>
<th>Soil type</th>
<th>Actual yield</th>
<th>PYCAL</th>
<th>Yield Prophet</th>
<th>STIN XL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morawa (West of Gutha)</td>
<td>Tammarin Rock</td>
<td>Red/brown non cracking clay</td>
<td>1.2</td>
<td>1.1</td>
<td>1.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Morawa (West of Gutha)</td>
<td>Tammarin Rock</td>
<td>Brown loamy earth (gravely)</td>
<td>1.6</td>
<td>1.1</td>
<td>1.1</td>
<td>0.8</td>
</tr>
<tr>
<td>East Perenjori</td>
<td>Eradu</td>
<td>Sand over gravel</td>
<td>0.4</td>
<td>1.0</td>
<td>0.9</td>
<td>NA</td>
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<tr>
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<td>Carnamah</td>
<td>Red loam</td>
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<td>0.5</td>
<td>1.1</td>
<td>NA</td>
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<tr>
<td>Corrigin</td>
<td>Mundah barley</td>
<td>Yellow sandy earth</td>
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<td>4.7</td>
<td>2.4</td>
<td>NA</td>
</tr>
<tr>
<td>West Kulin</td>
<td>Tammarin Rock</td>
<td>Shallow sandy duplex</td>
<td>1.7</td>
<td>2.5</td>
<td>2.6</td>
<td>2.1</td>
</tr>
<tr>
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<td>Carnamah</td>
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<td>1.2</td>
<td>2.6</td>
<td>1.6</td>
<td>1.7</td>
</tr>
<tr>
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<td>2.5</td>
<td>1.7</td>
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<tr>
<td>Jerramungup</td>
<td>Sapphire</td>
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<tr>
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<td>3.1</td>
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<td>2.1</td>
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<tr>
<td>Cascades</td>
<td>Bonnie Rock</td>
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<td>3.5</td>
<td>2.8</td>
<td>3.6</td>
<td>NA</td>
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<tr>
<td>Neridup</td>
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<td>2.8</td>
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<td>3.3</td>
<td>NA</td>
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<tr>
<td>Howick</td>
<td>Sapphire</td>
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<td>Gravel</td>
<td>2.2</td>
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<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

**PYCAL**: 67% of predictions within 0.5 t/ha of actual, with 61% over-estimations and 22% under-estimations.

**Yield Prophet**: 61% of predictions within 0.5 t/ha of actual, with 88% over-estimations and 12% under-estimations.

**STIN XL**: 71% of predictions within 0.5 t/ha of actual, with 43% over-estimations and 57% under-estimations.
### Table 2. Trial results season 2007

<table>
<thead>
<tr>
<th>Location</th>
<th>Variety</th>
<th>Soil type</th>
<th>Actual yield</th>
<th>PYCAL</th>
<th>Yield Prophet</th>
<th>STIN XL</th>
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<tbody>
<tr>
<td>Morawa (West of Gutha)</td>
<td>Tammarin Rock</td>
<td>Red/brown non-cracking clay</td>
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<td>1.0</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Morawa (West of Gutha)</td>
<td>Tammarin Rock</td>
<td>Brown loamy earth (gravely)</td>
<td>0.6</td>
<td>0.6</td>
<td>0.2</td>
<td>0.9</td>
</tr>
<tr>
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<td>Bonnie Rock</td>
<td>Red shallow loamy duplex</td>
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<td>0.6</td>
<td>0.4</td>
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<td>0.1</td>
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<tr>
<td>Yuna</td>
<td>Calingiri</td>
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<td>1.2</td>
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<td>NA</td>
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<tr>
<td>Yuna</td>
<td>Bonnie Rock</td>
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<td>Wyalkatchem</td>
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<td>Tardun</td>
<td>Wyalkatchem</td>
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<td>Yellow sandy earth</td>
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<td>2.3</td>
<td>3.9</td>
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<tr>
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<td>Stirling Barley</td>
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<td>2.2</td>
<td>1.6</td>
<td>1.9</td>
<td>NA</td>
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<tr>
<td>East Wickepin</td>
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<td>1.9</td>
<td>2.1</td>
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<tr>
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<tr>
<td>Jacup</td>
<td>Annuello</td>
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</tr>
<tr>
<td>Salmon Gums</td>
<td>Hamelin Barley</td>
<td>Loamy sand over clay</td>
<td>2.4</td>
<td>2.3</td>
<td>2.4</td>
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<tr>
<td>Cascades</td>
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<td>2.4</td>
<td>NA</td>
</tr>
<tr>
<td>Neridup</td>
<td>Baudin Barley</td>
<td>Sand over loamy gravel</td>
<td>4.9</td>
<td>3.6</td>
<td>5.2</td>
<td>NA</td>
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<tr>
<td>Mt Madden</td>
<td>Wyalkatchem</td>
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<td>1.7</td>
<td>3.0</td>
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<tr>
<td>Hopetoun</td>
<td>Saphire</td>
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<tr>
<td>Hopetoun</td>
<td>Saphire</td>
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<td>2.7</td>
<td>3.7</td>
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<tr>
<td>Hopetoun</td>
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<td>3.7</td>
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<tr>
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<tr>
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<td>Baudin</td>
<td>Sandy</td>
<td>2.4</td>
<td>2.5</td>
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<td>NA</td>
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</tbody>
</table>

**PYCAL:** 63% of predictions within 0.5 t/ha of actual, with 67% over-estimations and 25% underestimations.

**Yield Prophet:** 71% of predictions within 0.5 t/ha of actual, with 55% over-estimations and 36% underestimations.

**STIN XL:** 100% of predictions within half a tonne of actual, with 71% over-estimations and 29% underestimations.

**Post planting nitrogen applications**

Yield forecasts were intended to assist farmers and advisors in making tactical decisions on variable inputs such as nitrogen and fungicides. However season 2006 was one of the driest seasons on record for many shires in the wheatbelt, and as a result many farmers did not add further nitrogen following seeding. In 2007, the wheatbelt endured another dry start to the year (except for Esperance), with it finishing the same for the Northern Ag Region. However timely rains for the Central and Southern regions in July made for a much brighter picture for farmers in these regions, where many applied additional nitrogen. Any additional yield resulting was rewarded handsomely due to the exceptional grain prices.

A number of tools for nitrogen forecasting can be used in conjunction with the yield forecasts such as **Yield Prophet**, **Select Your Nitrogen** and the **Nitrogen Calculator**. See Jeremy Lemon’s paper in the 2007 Agribusiness Crop Updates booklet: **Nitrogen Decision Tools – choose your weapon**.
CONCLUSION

How do the different models stack up?

Local calibration of all the tools is required to produce meaningful yield forecasts. Yield Prophet was far more time consuming and required the user to have a considerable knowledge of soil type water relations in order to input ‘sensible’ data into the model. However, STIN XL and PYCAL were relatively much simpler, where calibration was difficult only if farmers had not kept good paddock records. Generally, there was little interest by farmers in doing the detailed soil characterisations required by Yield Prophet themselves (i.e. to determine how much plant available water a specific soil actually holds). In future, to make this tool more useable, representative soil characterisations of the key soil types in each region would have to be developed by soil scientists, and included into the tool for uses to select. The soil characterisations are an integral part of the model, and if done so incorrectly by the user, will possibly render the forecasts useless.

The accuracy of the information produced by the models varied between seasons and in some instances soil types, which would be expected as the soil water relations between the two are paramount. Understanding the limitations of the models plays a major role in determining the potential use and accuracy in each season.

Season 2006 was exceptional because despite the large amount of stored soil water in many areas prior to planting, its very late break meant the wetting profiles in many soils did not meet resulting in challenging conditions for crop establishment. This led to a number of complications when using PYCAL, due to the very late plantings dates but also as the 100 mm of summer rains fell in three days the model cannot take into account water run-off. Also due to the very late plantings in many cases, the crop phenology data may not have been accurate enough. In the case of the Central Ag Region, PYCAL yield forecasts were often much higher than expected, particularly on the lighter soils. Yield Prophet performed better over this season. However, season 2007 had limited summer rain, stored moisture levels were only marginal and as a result of this PYCAL performed better relative to 2007, particularly on the lighter soil types. This example demonstrates the need to be aware of the different model limitations, and how they will impact seasonal results. Season 2006 also highlighted examples of where the models may need improvement!

In the Southern Ag Region, farmers in most years have a problem with waterlogging, and crops need to be managed to optimise Nitrogen usage to improve tiller survival. However the dry winters for 2006 and 2007 seasons meant that farmers needed to be more prepared for earlier sowing opportunities. General comment from the Albany regional shire work is that farmers tend to over-estimate yield in the paddock, and this was also seen with the use of the PYCAL model. However carrying out tiller, head and grain counts in situ was far more accurate. In addition, many found decile graphs tracking the actual growing season rainfall against decile 3, 5 and 9 seasons was useful in determining the likelihood of season finishes.

The Northern Ag region experienced drought conditions over both seasons. The forecasts were useful for many who had to decide whether or not to sow in both seasons (seeding was late June in both seasons). Both PYCAL and Yield Prophet performed reasonably although harvest results were limited in 2006. In 2007 yield prophet performed better than PYCAL as it factors soil type into the equation which was essential in such a dry year.

Generally most farmers across the wheatbelt indicated that the most valuable time for them to receive a good yield estimate was at pre-sowing and six weeks after sowing. The accuracy of the yield forecasts produced early post sowing were found to be quite different throughout the regions. In the CAR yield forecasts were often closer to actuals when forecast a few weeks post sowing, then again towards the end of the season but this was the reverse in the southern region.

When looking at the trial results Tables 1 and 2, the tools were within half a tonne of predicting the actuals about 60-70% of the time. STINXL fared much better in season 2007, although the tool was not utilised at as many sites. Many paddocks had a huge degree of soil type variation, and the models were calibrated on the dominant soil type, which means that the forecasted result may need to be ‘weighted’ across the paddock for a number of soil types to enable more accuracy.
How should the models be used?

In general, comments from farmers across the wheatbelt were very similar. Many did not have confidence in the yield forecasts, and experienced farmers found their own estimates when walking though the paddocks were as good. However, there is the opportunity for these models to be useful if farmers had purchased a new property with which they had little experience, or, younger/newer farm managers could use them to go through ‘what if’ scenarios.

In addition, some farmers did not access the models directly through websites or CD ROM, as they were unsure how to navigate their way through the programs and interpret the results. Hence many were supportive of the AcCLIMATise Bulletin, which included the site specific results of each paddock, along with the climate projections from the different bodies for the rest of the season. Many found the bulletins “made them more aware of what information was available and what it meant”, and often ‘reinforced decisions’ they had already made. Workshops held throughout each season also assisted farmers in determining how to correctly interpret climate outlooks and yield forecasts, and determine their overall place in the decision making process. These findings highlight the need for farmers to have assistance in interpreting the information at a local level, by consultants or DAFWA staff/publications.

The models used forecast crop yields on a sliding scale, depending on the possible finish to the season from that point. If climate outlooks were accurate, this could narrow down the range in yield probabilities quite considerably. In addition, climate forecasts do not give any indication as to rainfall distribution, and the finish of the season can make a massive difference, especially over the grain filling period. For example in 2006 the season finish was poor, however a good 15 mm rainfall in October 2007 was ‘worth a tonne in yield’ to many farmers in the central and southern regions. However, most farmers have little faith in the WA climate outlooks, and as such they are not ranked highly in their decision-making. The majority found them ‘interesting, but not very useful’. Although there had been an alarming shift to increase the emphasis on the outlook by some farmers in the Northern Ag region, which may have been due to the impact of two failed seasons – with the outlook providing the only positive indications at the start of the season.

As a result, most farmers still rank stored soil moisture at the beginning of the year, and time of sowing as the most critical elements in deciding when and how much to sow. Following planting, some ‘play the season’ with respect to additional inputs, or others stick to a tried and true plan based on the law of averages and what’s worked in the past. Either way, climate outlooks are not high on the priority list, and yield forecasting models ‘re-enforce the importance of regular crop monitoring’. It is critical for farmers to temper the forecasts using their own knowledge, measurements and experience, and to view them as only one part of an information package.

KEY WORDS
climate risk management, yield forecasting models

ACKNOWLEDGMENTS

Thankyou to those involved in the AcCLIMATise project, with particular thanks to the farmers with on farm trials, and those who supplied data: John Gardiner, Jeremy Lemon and Leanne Bee of DAFWA and Cameron Weeks of Planfarm.

Project No.: DAW49
Paper reviewed by: Ian Foster
Benefits of crop rotation for management of Root Lesion Nematode (RLN, *Pratylenchus neglectus*)

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

KEY MESSAGES

- Consecutive wheat crops significantly increase the risk of developing yield limiting populations of RLN.
- Following a resistant crop, fewer nematodes remain in the soil to infect subsequent crops.
- Reduction in RLN level translates to higher yield in the following cereal crop.

BACKGROUND AND AIMS

*Pratylenchus neglectus* is the predominant RLN species in WA, infesting at least 40% of cropping paddocks. The resistance or susceptibility of crop species and cultivars to *P. neglectus* has been characterised from Statewide Crop Variety Testing trials. All tested cultivars of field pea, faba bean and lupin are resistant. Oat and barley cultivars are moderately resistant. All chickpea, canola and wheat cultivars are susceptible. Although *P. neglectus* is the most common RLN species in WA, other *Pratylenchus* species also occur and are referred to as RLN, but these can have a different range of susceptible and resistant crops.

Although there are no resistant cultivars of wheat, there is sufficient variation in susceptibility that variety selection in rotations can be a useful tool in managing the impact of *P. neglectus*. Intensive cropping of susceptible species (particularly wheat) will, however, lead to increase in nematode levels. Resistant or moderately resistant cultivars will effectively reduce nematode levels when used in rotations. Crop rotation is the key to reducing RLN and the damage caused by these pests.

Rotation trials were conducted over two seasons (2005 and 2006) to demonstrate the benefits of crop rotation for the management of *P. neglectus* by measuring soil nematode levels and crop yields.

METHOD

Trials were established at two sites which were sown to rotation crops in 2005 and re-sown with a susceptible or moderately susceptible wheat in 2006.

- The site selected at Newdegate Research Station was infested with 6.0 *P. neglectus*/g dry soil (measured in April 2005).
- The site selected at the Great Southern Agricultural Research Institute (Katanning) was infested with 4.2 *P. neglectus*/g dry soil (measured in March 2005).

In 2005, cultivars of different crop species were sown to establish differing nematode levels. A Latin square design of 4 main treatment (Brookton and Wyalkatchem wheat, Sona chickpea and Kaspa field pea) plots (40 m x 10 m) was sown across 8 replicates.

In 2006, randomised split plots (20 m x 10 m) of Carnamah or Wyalkatchem wheat were sown over the main treatments from 2005.

In Statewide Crop Variety Testing trials, Brookton and Wyalkatchem wheat were shown previously to be the wheat cultivars which are the most susceptible and least susceptible, respectively, to *P. neglectus*. Kaspa field pea is consistently resistant to *P. neglectus*. Carnamah wheat is susceptible.

Soil from all plots was sampled each year at sowing and at anthesis to determine *P. neglectus* density.
RESULTS

Consecutive wheat crops resulted in the development of significantly higher nematode levels compared to wheat following chickpea or field pea (Tables 1 and 2). Including moderately resistant wheat (Wyalkatchem) in the rotation also reduced nematode levels compared to the susceptible cultivars, Brookton and Carnamah.

Table 1. *P. neglectus* g dry soil measured at anthesis in 2006 after Carnamah and Wyalkatchem wheat following different crops grown in 2005 at Katanning

<table>
<thead>
<tr>
<th>2005 Crop</th>
<th>Carnamah 2006</th>
<th>Wyalkatchem 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brookton</td>
<td>11.26</td>
<td>7.92</td>
</tr>
<tr>
<td>Wyalkatchem</td>
<td>9.52</td>
<td>3.78</td>
</tr>
<tr>
<td>Sona</td>
<td>4.64</td>
<td>1.91</td>
</tr>
<tr>
<td>Kaspa</td>
<td>0.23</td>
<td>0.51</td>
</tr>
</tbody>
</table>

LSD 5% 2005 crop main effect = 3.20.
LSD 5% 2006 crop main effect = 2.27.

Table 2. *P. neglectus* g dry soil measured at anthesis in 2006 after Carnamah and Wyalkatchem wheat following different crops grown in 2005 at Newdegate

<table>
<thead>
<tr>
<th>2005 Crop</th>
<th>Carnamah 2006</th>
<th>Wyalkatchem 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brookton</td>
<td>11.49</td>
<td>6.75</td>
</tr>
<tr>
<td>Wyalkatchem</td>
<td>11.24</td>
<td>8.0</td>
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<tr>
<td>Sona</td>
<td>6.74</td>
<td>6.85</td>
</tr>
<tr>
<td>Kaspa</td>
<td>3.31</td>
<td>3.0</td>
</tr>
</tbody>
</table>

LSD 5% 2005 crop main effect = 2.88.
LSD 5% 2006 crop main effect = 4.07.

For the Katanning trial (Table 1), there were 95% fewer nematodes in wheat following rotation with field pea compared to continuous wheat. At Newdegate (Table 2) there were 66% fewer nematodes in wheat following rotation with field pea compared to continuous wheat. Consecutive crops of moderately resistant wheat (Wyalkatchem) produced fewer nematodes than consecutive crops of susceptible cultivars (Brookton and Carnamah).

Reduction in *P. neglectus* density due to rotation significantly affected yield of the subsequent wheat crop (Tables 3 and 4). At Katanning, wheat following field pea yielded 20-25% more than wheat after wheat, and 16-28% more at Newdegate.

Table 3. Yield (t/ha) of Carnamah and Wyalkatchem wheat in 2006 following crops grown in 2005 at Katanning

<table>
<thead>
<tr>
<th>2005 Crop</th>
<th>Carnamah 2006</th>
<th>Wyalkatchem 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brookton</td>
<td>1.523</td>
<td>1.605</td>
</tr>
<tr>
<td>Wyalkatchem</td>
<td>1.566</td>
<td>1.634</td>
</tr>
<tr>
<td>Sona</td>
<td>1.803</td>
<td>1.935</td>
</tr>
<tr>
<td>Kaspa</td>
<td>1.755</td>
<td>2.024</td>
</tr>
</tbody>
</table>

LSD 5% 2005 crop main effect = 0.15.
LSD 5% 2006 crop main effect = 1.03.

Table 4. Yield (t/ha) of Carnamah and Wyalkatchem wheat in 2006 following crops grown in 2005 at Newdegate

<table>
<thead>
<tr>
<th>2005 Crop</th>
<th>Carnamah 2006</th>
<th>Wyalkatchem 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brookton</td>
<td>0.972</td>
<td>1.046</td>
</tr>
<tr>
<td>Wyalkatchem</td>
<td>0.989</td>
<td>1.136</td>
</tr>
<tr>
<td>Sona</td>
<td>1.172</td>
<td>1.38</td>
</tr>
<tr>
<td>Kaspa</td>
<td>1.248</td>
<td>1.263</td>
</tr>
</tbody>
</table>

LSD 5% 2005 crop main effect = 0.16.
LSD 5% 2006 crop main effect = 0.11.
CONCLUSION

- Consecutive wheat crops, particularly if cultivars are susceptible, lead to higher soil populations of *P. neglectus*.
- A resistant crop such as field pea significantly reduces the level of *P. neglectus*.
- Moderately resistant wheat cultivars result in fewer *P. neglectus* when compared to susceptible cultivars.
- Reduction in nematode level was 66-95% following a resistant crop.
- Wheat grown after field pea yielded 16-28% higher, however the other beneficial effects of growing field pea in the rotation cannot be discounted.

KEY WORDS

nematode, rotation, yield

ACKNOWLEDGMENTS

DAFWA Research Support Units expertly sowed, maintained and harvested trials at Katanning and Newdegate.

DAFWA Nematology staff Ali Bhatti, Dyane Jardine, Sarah Collins and Christine Castalanelli sampled and processed soil from trials for nematode extractions.

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Paper reviewed by: Bill MacLeod