Profitable break crop management guide

A summary of key findings from GRDC funded project CSP00146

(also incorporating information generated by GRDC project CWF00009)

Introduction

The Grains Research & Development Corporation (GRDC) Crop Sequence Initiative was established to address concerns within the grains industry at the intensification of cereal cropping that occurred during the Millennium drought. Continuous wheat had become increasingly common in many grain production areas, despite a wide range of other crop options being available. In part the preference of wheat over other crops were based on the perception that cereals were less risky and more profitable; especially in the face of variable climatic conditions. However, in most areas there were growers who ran profitable farming systems that challenged this perception as they actively embraced broadleaf break crops such as canola and legume pulse crops, or routinely included a legume-dominant pasture phase as part of their cropping sequence.

Projects within the Crop Sequence Initiative aimed to generate new information on how crop choice and sequence could affect grain productivity and profitability, and to give growers necessary knowledge and confidence to appropriately and profitably integrate a greater range of crops into their system.

Project CSP00146 represented a collaboration between CSIRO, NSW Department of Primary Industries (NSW DPI), the Victorian Department of Economic Development, Jobs, Transport and Resources (ECODEV; previously Vic DEPI, or Vic DPI) and leading Grower Groups in the Southern Region based in either the lower rainfall (Birchip Cropping Group [BCG], Central West Farming Systems [CWFS]), medium-high (FarmLink, Riverine Plains), or high rainfall zone (Southern Farming Systems [SFS], MacKillop Farm Management Group [MFMG]), or have a focus on irrigated systems (Irrigated Cropping Council [ICC]). An overview of the experimentation undertaken by CSP00146 with the different Grower Groups between 2010 and 2015 can be found in Appendix F.

A sister project in the Crop Sequence Initiative in the Southern Region was undertaken by the Low Rainfall Cropping Group (project CWF00009) which represented an alliance of Grower Groups from the low rainfall grain production areas of NSW, Victoria and SA which included BCG, CWFS and Mallee Sustainable Farming Systems (MSFS) – see map below to indicate the general geographic locations of the Grower Groups participating in both these projects.

Much of the experimentation and on-farm trials undertaken by these two projects aimed at answering one or more of the following questions:

1. Can a break crop be as profitable as wheat?

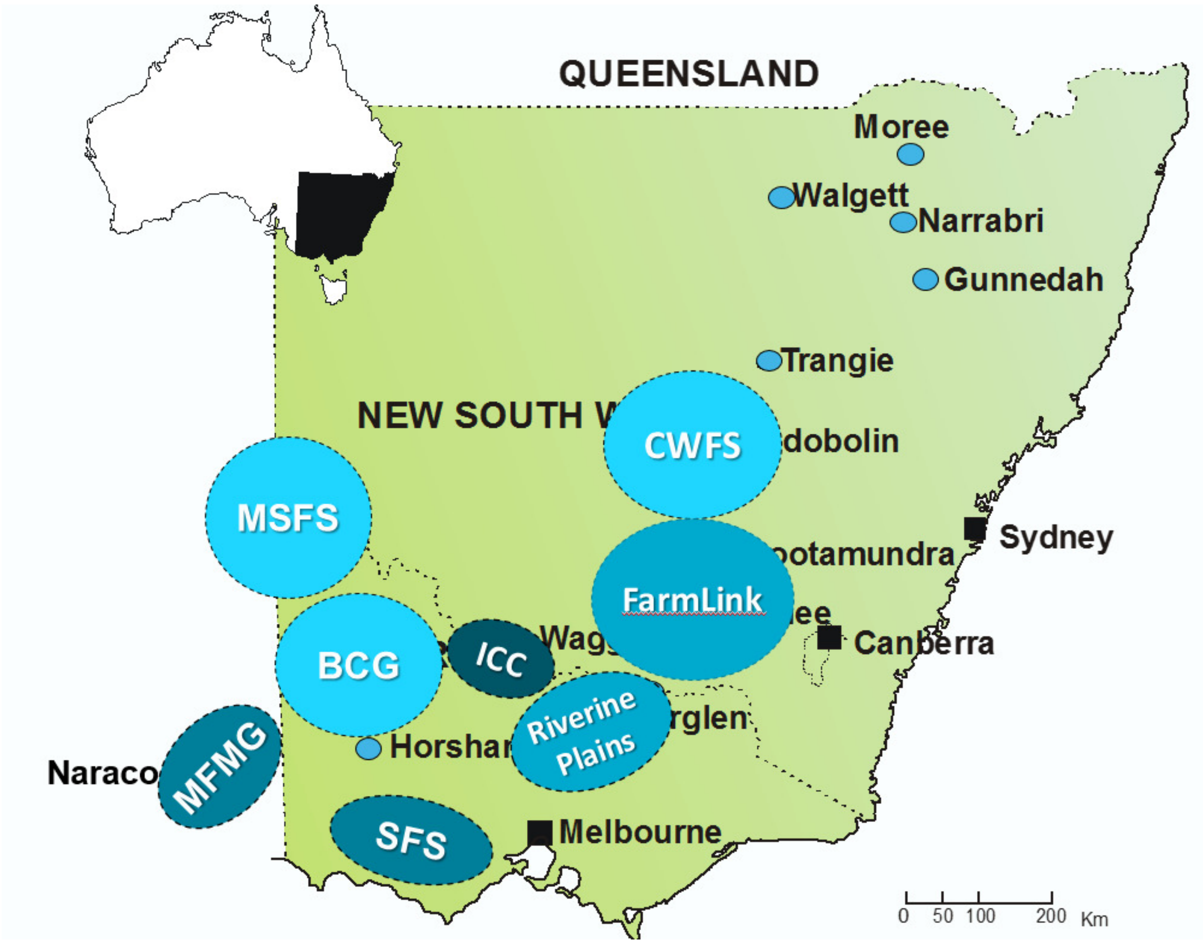
2. Are sequences that include break crops more profitable than continuous wheat?

3. Can a weed problem be managed more cost effectively with a break crop than in a continuous cereal system?

4. What effects do break crops have on soil nitrogen availability?

5. What break crop should I grow?

Participating Grower Groups and locations



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Address: NSW DPI Condobolin Agricultural Research & Advisory Station, 1 Fifield Road, Condobolin

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Mallee Sustainable Farming Systems

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Riverine Plains

www.riverineplains.com.au

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What is meant by the term 'crop sequence'?

Growing different crop types in a rotation is not a new concept. Indeed a recent review of the subject (Angus *et al.* 2015) indicates that the value of rotations in increasing yield has been recognised since the 10th century BCE in China and the 4th century BCE in Greece, and there was widespread adoption of rotations in England and continental Europe by the end of the 18th century. The context of the use of the term crop sequence here is to specifically avoid implying the more traditional and rigid rotational pattern where one specific crop type always follows another. We are advocating a much more flexible approach where the choice of crop is made in response to the need to address agronomic issues, market and seasonal needs and opportunities.

Why did we need to reconsider the management of crop sequences?

Grain growers consulted at the beginning of the project in 2010 indicated that they realised that they should be including broadleaf species in their cropping program to reduce disease incidence for cereals, control weeds, and to improve soil nitrogen (N) fertility. However, the area sown to pulse legume crops or canola had dramatically declined in the previous 8-10 years, and in areas such as the low rainfall region of southern Australia less than 5% of growers were using break crops. Furthermore, despite greater than 60% of the grain being grown following pastures, many of the pastures in the late 2000's were dominated by annual grasses and had low legume contents, so would be providing little rotational benefit to following crops.

Many grain growers acknowledge that they are likely to suffer some yield penalty by more intensive cereal cropping. However, their perception of the possible size of yield losses in the order of 10-15% (based on 2008 grower and agribusiness survey results collated by John Kirkegaard and Michelle Watt of CSIRO as part of GRDC project CSP00115) underestimates the true value of break crops. Data collated from many research trials from Australia and around the world indicate average yield improvements of 20-50% equivalent to 1.1-1.8 tonnes of grain by wheat grown following a legume in the absence of N fertiliser and 0.8 additional tonnes of grain per ha if wheat is grown after canola compared to wheat on wheat (Angus *et al.*, 2015).

There are many good reasons why growers had reduced the frequency of use of broadleaf species: late starts to the growing season, drought and risk aversion. Yet it appeared that much of the decline could also be attributed to the wide-spread perception that broadleaf options were not as profitable as cereals. Certainly low and fluctuating grain prices for pulses hadn't helped. Nor had the generally higher input costs to grow canola rather than wheat or barley. But much of the focus seemed to be on the financial returns from the broadleaf phase in isolation from its potential beneficial impacts on the longer-term financial performance of subsequent cereal crops.

Much of the project's experimental and communications program was based on the assumption that in the absence of high grain prices for canola or pulses, growers are most likely to want to sow broadleaf break crops to address specific agronomic problems when growing cereals associated with evidence of reduced crop performance due to: (a) difficult to manage grass weeds, (b) low soil N fertility, or (c) disease. The project examined the productivity and financial implications of growing legumes or canola in various genotype x environment x management (GxExM) and end-use (grain, brown manure, hay, forage) combinations in cereal-based systems, to re-evaluate the full value of integrating broadleaf species in a cropping sequence.

The following sections provide a summary of some of the key project findings at different levels of detail.

Tips on how to navigate this document using hyperlinks (words highlighted in blue)

1. Click on the research question of interest under 'Direct Links'
   E.g. '1. Can a break crop be as profitable as a cereal?'
2. This will then direct to a Summary Heading
   E.g. 'Break crops for profit – a single year comparison'
3. At the end of the text which answers the initial question there will be a list of Farmer Groups
   E.g. 'FarmLink'
4. By clicking on the Farmer Group of interest it will redirect to a list of trials in that region
   E.g. Junee Reefs, Eurongilly Exp. 1, Eurongilly Exp. 2 etc.
5. Then click on the trial of interest
   E.g. Junee Reefs
6. Contained here will be specific examples for that site answering the original research question.
7. Lastly, at the end of this explanation is another link to access all further information relating to that site, i.e. 'For more trial information (including methods) CLICK here'.

NOTE: If clicking on links does not re-direct to new page, you may need to hold down the 'Ctrl' button whilst left hand clicking on the mouse or uncheck "use ctrl+click to follow hyperlinks" option by File>Options>Advanced options.

DIRECT LINKS

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Break crop management considerations

Break crops for Profit – a single year comparison

Short-term profitability of grain production of any given crop at a paddock level is determined by the price received for the grain, its yield and the input costs incurred to grow it. One of the key considerations when choosing a canola or legume break crop is: can it be as profitable as a cereal in its own right?

All the experimental trials described in the following sections used continuous wheat as a biophysical and economic benchmark against which the performance of break crops (and their impact on following crops) were compared. Several studies included wheat treatments grown with low inputs to minimise production costs, as well as high inputs to target ambitious, but potentially achievable, grain yields for the district.

In summary, the results from all the plot trials and farmer case studies undertaken between 2010 and 2015 in high, medium and low rainfall environments indicated that there was at least one break crop option that could be as profitable, if not more profitable than wheat.

Canola was shown to be the most widely adapted break crop and returned higher gross margins than wheat in the majority of trials across the rainfall zones and years. Results from trials at Junee Reefs and Eurongilly NSW (see Junee Reefs and Eurongilly Exp 1), are examples of where canola was much more profitable than wheat most of the time (by between $522-$1009/ha). Lupins grown for grain in low and medium rainfall areas were more profitable than various wheat treatments in a number of experiments (e.g. see Chinkapook, Junee Reefs, Eurongilly Exp 1 and Eurongilly Exp 2). Faba beans or sub-clover cut for hay were more profitable options for the medium-high rainfall areas or under irrigation (see Yarrawonga, Naracoorte and Kerang Q1). Whilst field peas, chickpeas and lentils were shown to be more profitable options (up to $100/ha per year over 4 years) on certain soil types in low rainfall areas (see Mildura). Follow the links for regional specific trial results relating to single year break crop profitability:

Birchip Cropping Group

Farmlink

Irrigated Cropping Council

MacKillop Farm Management Group

Mallee Sustainable Farming Systems

Riverine Plains

Southern Farming Systems

Profitability of break crop sequences

Longer-term profitability is dependent on how a crop sequence contributes to the income of the whole farming system. In which case, it is important to consider the trade-offs between the cost of production (risk) and potential profit (reward) of different break crop options and end-uses. This will be largely influenced by local factors such as: rainfall, timing of the autumn 'break', soil type, soil water and soil N availability, herbicide history, weed dynamics and the risk profile for any given grower. Break crops have been shown to reduce costs associated with managing weeds and disease and improving N supply for following wheat crops. The versatility of break crops for different end uses (e.g. grain, hay/silage, brown manure and grazing) can also allow for better seasonal risk management.

Crops grown after break crops are consistently higher yielding than continuous wheat (Figure 1 & Figure 2) and require lower input costs; consequently, cumulative economic returns for sequences that include break crops tend to be greater over a 3-5 year timeframe. Angus *et al.* (2015) collated 180 comparisons of canola-wheat versus wheat-wheat sequences and almost all experiments demonstrated a yield benefit (i.e. data points for yield after canola were above the 1:1 dashed line) which represented an average 0.8 t/ha additional grain for wheat grown following canola (Figure 1).

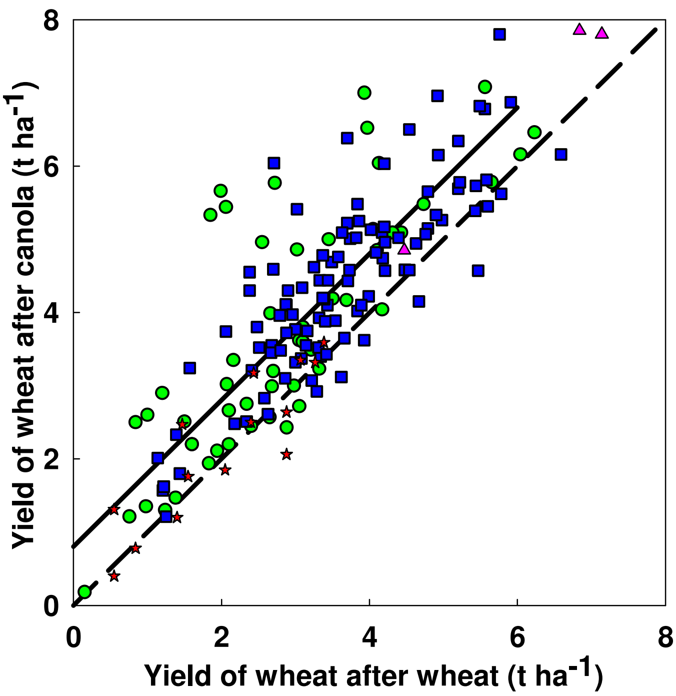


Figure 1. Yield of wheat after canola compared with wheat after wheat growing in the same experiments. Symbol colours represent experimental locations. Green circles, Australia; Blue squares, Sweden; Pink triangles, Other Europe; Red stars, North America. The 1:1 dashed line represents equal yield (Angus *et al.* 2015).

Angus et al (2015) also accumulated data from 300 experiments which included legume-wheat and wheat-wheat sequence comparisons (Figure 2). The results from these studies suggested that on average an additional 0.7 to 1.6 t/ha of wheat grain was harvest after a legume crop depending upon the species. Some of these observed increases in wheat yields after canola or legumes may be derived from providing a range of weed contol options, the breaking of cereal disease cycles, changes in soil structural characteristics that encourage a deeper rooting depth by following crops, or the carry-over of residual soil water (Kirkegaard *et al.*, 2008; Kirkegaard and Hunt, 2010). In the case of legumes, the effects on soil biology and increased availability of N and other nutrients can also be very important components of the yield benefits (Peoples *et al.*, 2009; Angus *et al.* 2015). In some instance these benefits can last for several subsequent cereal crops.

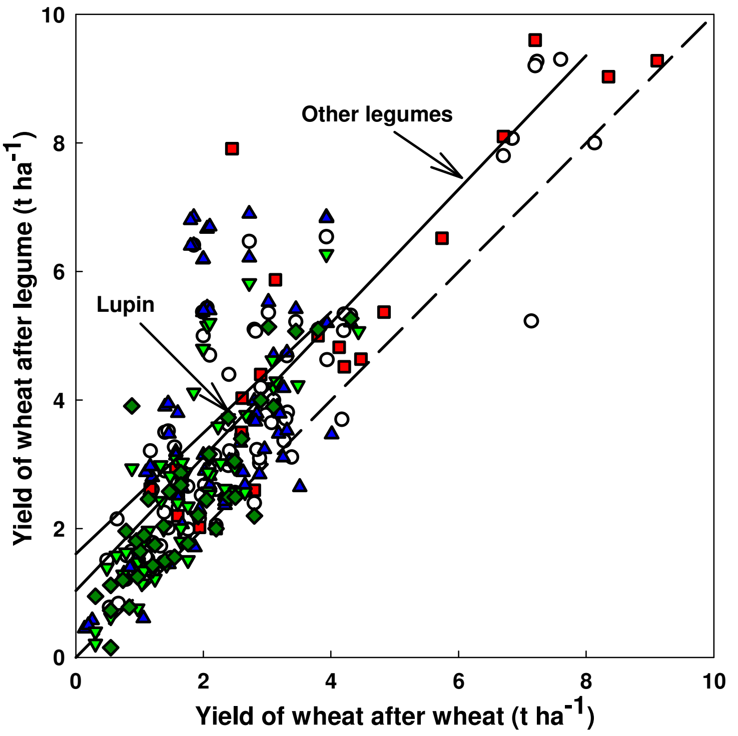


Figure 2. Yield of wheat after grain legumes compared with wheat after wheat growing in the same experiments. The dashed lines represent equal yields and the solid lines represent fitted equations. Symbols represent field pea, ○; faba bean, ■; lupin, ▲; chickpea, ▼; lentil, ♦ (Angus *et al.* 2015).

The cumulative gross margins over multiple years of a crop sequence is one useful measure for determining the profitability of break crops in a farming system. In most instances, it can be found that the most profitable sequences involving three years or greater contain at least one break crop. In the presence of a major constraint to wheat production such as a high weed burden, sequences involving 'double breaks' can be the most profitable (see Eurongilly Q2).

Environmental suitability of different species will be a key determinant in deciding on which break crop to grow where. What will grow well and provide the most profitable break in the Western Districts of Victoria is likely to differ from the best option available in the Central West region of NSW. Growing break crops for maximum profit requires careful management and consideration of both environmental factors such as rainfall and soil type along with recent paddock fertiliser and herbicide histories. Growers should always consult their advisors and local agronomists, but decision-trees such as that developed by BCG for the southern Mallee (Appendix A) or the attached break crop checklist (Appendix B) can provide a starting point when choosing break crop suitability. Matching legumes to a well suited environment is particularly important as individual species are generally less well adapted to the range of environments than canola and the potential break crop benefit could be greater (Angus *et al.* 2015).

Follow the links for regional specific trial results relating to whole crop sequence profitability:

Birchip Cropping Group

Central West Farming Systems

Farmlink

Irrigated Cropping Council

MacKillop Farm Management Group

Mallee Sustainable Farming Systems

Riverine Plains

Southern Farming Systems

Managing weeds with break crops

There is growing evidence that the number of populations of grass weeds around Australia are now resistant to many of the common herbicides used in cereal production. Difficult to manage weeds reduce the productivity and profitability of cereals by competing for light, soil water and nutrients. For instance, on-farm experimentation undertaken in southern NSW indicated that for every additional tonne of ryegrass dry matter present at spring within a wheat crop, there was grain yield penalty of around 0.5 t/ha (see Eurongilly Q3). The rotation of chemical groups that is possible with break crops through the use of alternate pre-emergent and post-emergent grass selective herbicides, spray-topping, hay or silage cutting and brown manuring all help to reduce seedbanks, and therefore decrease the incidence of herbicide resistant (and susceptible) weed populations.

Herbicide resistant annual ryegrass is a particular problem in many cropping regions of SE NSW (Broster *et al.* 2013), Victoria and SA (Malone *et al*. 2014). A number of trials were established in southern NSW (see Eurongilly and Wagga Wagga Q3), and Victoria (Lake Bolac and Inverleigh Q3) to address the questions 'can ryegrass populations be managed cost-effectively under break crops?' and 'can you buy your way out of needing a break crop?' As part of these field trials, weed seedbanks, spring weed and crop dry matter and final panicle numbers were all measured.

It was found that the greatest reduction in weed pressure could be achieved by applying a range of control strategies to a break crop or fallow rather than attempting to continue to manage the problem within wheat. The latest management options available to control grass weeds in wheat (pre- and post-emergent herbicides, high plant populations and high nutrient supply to increase wheat's ability to compete with weeds) were less effective and cost twice as much as those used in most break crops ($142/ha cf $56/ha) (see Eurongilly Q1).

In the presence of a high density of herbicide resistant ryegrass it was also found that 'single breaks' were not adequate to reduce weed seedbanks and in-crop weed competition in wheat that they needed to be used in conjunction with costly inputs as described above during the wheat phase to achieve some measure of control. 'Double breaks' (two broad leaf break crops or cereal hay grown in sequence) were shown to be a better option for reducing ryegrass seedbank numbers and were amongst the most profitable 3-year sequences.

Similar experimentation to the ryegrass management trials undertaken in southern NSW were established as part of the Low Rainfall Cropping Project, to examine the impact of brome grass on the productivity and profitability of sequences including single or double break options. These studies also found that single breaks were not sufficient to reduce brome grass numbers to manageable levels and that rotations including breaks had greater average yearly gross margins than continuous cereal rotations (see Mildura and Chinkapook).

Follow the links for regional specific trial results relating to weeds:

Birchip Cropping Group

Farmlink

Irrigated Cropping Council

Mallee Sustainable Farming Systems

Southern Farming Systems

Managing nitrogen with break crops

Many experimental trials have demonstrated that there is commonly a close relationship between soil mineral N and wheat yield across a range of environments in eastern Australia (Figure 1). Figure 1 also indicates that both soil mineral N and wheat yields are generally lower following wheat crops and highest following legumes. The amount of N mineralised from legume residues that becomes available for a subsequent crop can be influenced by legume species and its end use (ie. whether it is grown for grain or brown manured, grazed or cut for hay), and the amount of rainfall over the summer fallow between crops.

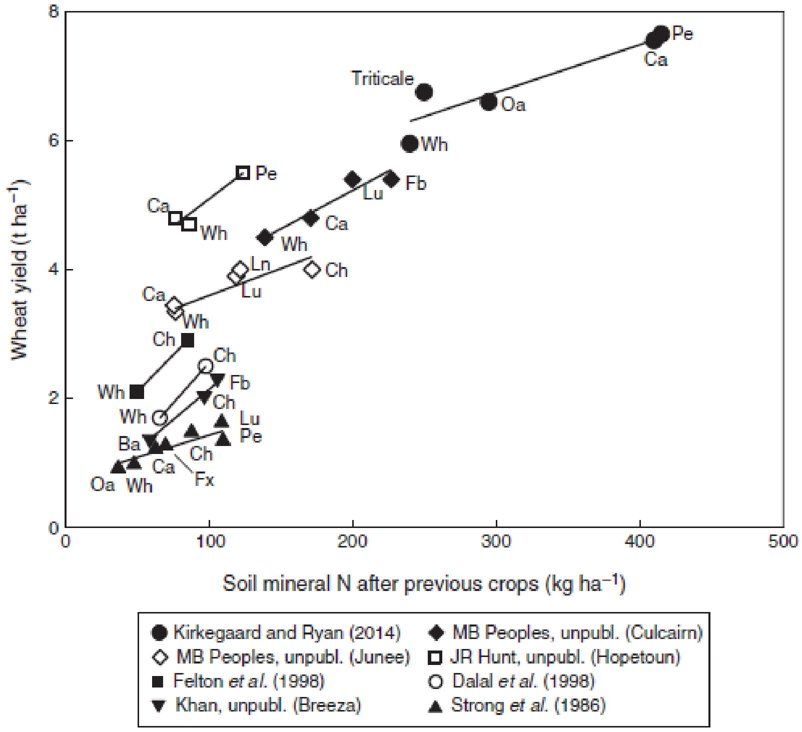


Figure 1 Relationship between residual soil mineral N in the root-zone (_0.9 m) after different crops and grain yield of the following wheat crop. Each set of symbols and the fitted line is from a different field experiment. Wh, Wheat; Ba, barley; Oa, oats; Ca, canola; Fx, flax; Pe, field peas; Ln, lentils; Ch, chickpeas; Fb, faba beans; Lu, lupins; Fa, fallow (Angus *et al* 2015).

Cost-effective supply of legume N is dependent on productive and efficient biological N_2 fixation (Please refer to Appendix C for a summary of key findings arising from the GRDC-funded project experimentation, including on-farm measures of N_2 fixation from commercial pulse crops and pastures). Matching species choice to the environment was the primary factor that impacted the total amount of N_2 fixed (kg N/ha) in the regions studied. The more dry matter (DM) that a legume can produce, the greater the potential for N_2 fixation. Where a species is well suited and doesn't have any obvious constraints to N_2 fixation (e.g. herbicide residues, low soil pH, no or failed rhizobial inoculation, or soil mineral N concentrations greater than 100 kg N/ha) it is likely legumes will be deriving more than half of their N requirements for growth from N_2 fixation. Under these conditions it is common for around 15-20 kg shoot N to be fixed per ha on average for every tonne of legume shoot DM that is accumulated during the growing season. An easy way for growers to estimate the likely amounts of N_2 fixed being achieved in their own crop is to take advantage of the observation that the harvest index (proportion of above-ground biomass partitioned in grain) of crop legumes is often 30-35%. Therefore, the total shoot dry matter accumulated by a pulse crop would approximate 3 x the weight of legume grain harvested (t/ha). Consequently the amounts of shoot N fixed (kg N /ha) would equate to approximately 60 x harvested legume grain yield (t/ha).

A healthy, productive legume crop sourcing its N requirements predominately from the atmosphere will be well positioned to provide a net contribution of N for the benefit of subsequent crops. In short, when choosing a legume break crop “grow what you can and grow it well” for maximum input of N into the cropping sequence.

Individual studies have explored the various constraints to effective rhizobia nodulation to allow for efficient N_2 fixation. There are no native rhizobia naturally present in Australian soils that are capable of forming root nodules on agriculturally important legumes. Consequently no nodules will be formed and N_2 can be fixed when a new legume crop or pasture species is grown for the first time unless the seed or soil is inoculated with the correct strain of rhizobia (note: different legumes often require different specific rhizobial strains to form functional root nodules – this can be determined by digging up some root systems and slicing nodules in half with a knife or razor; effective N_2-fixing nodules will appear red inside). There is currently not a commercially available test for measuring background rhizobia, so it is not possible to determine whether sufficient numbers of the right rhizobia will have survived in the soil since the last time the same legume had been grown to adequately nodulate the coming season’s crop. Poor nodulation can result in depressed crop growth, low inputs of fixed N, and up to 1 t/ha lower grain yields (see Culcairn trial). At the current cost of peat inoculants it is regarded as cheap insurance to always inoculate legume seed (see Watchupga East inoculation x N experiment Q4). Other trials have investigated the impact of certain herbicide applications and residues on N_2 fixation, for instance Group A chemicals on vetch growth at Boree Creek NSW (2012) and Group B herbicides in lentils at Rupanyup Vic (2011). Adhering to label recommendations, in particular plant-back periods is important for maximising N_2 fixation.

Profitable N management in crop sequences can be improved with the use of budgeting tools, including ‘rules of thumb’ (see Appendix E), that factor for starting soil mineral N, N mineralisation, and potential yield as determined by crop water use and supply. Water and N are often the key yield drivers in wheat dominant farming systems. Nitrogen availability to wheat crops is increased from the mineralisation of N contained in legume residues or the addition of synthetic fertiliser (‘bagged N’). There are good opportunities for the use of both sources of N, for instance whilst legume N can be a low risk option as it can be largely ‘free’, the use of fertiliser N in canola in a year of good canola prices can result in good gross margins. Mineralisation rates and timing is largely determined by rainfall, but can be heavily influenced by previous crop choice and management. For example, studies undertaken by Alan Mayfield in SA some years ago (unpublished data) demonstrated that incorporation of legume residues prior to the summer fallow can significantly increase levels of soil mineral N. However, other more recent trials have failed to show such a large effect (see Lockhart and Ariah Park Case Studies).

Ultimately how well N is managed will determine input costs and will have implications for both short and long-term profits.

The end-use of a crop (cut for silage/hay, grazed, harvested for grain or brown manured) is a management decision that has the potential to impact both soil water and soil N. For example, brown manured crop or pasture legumes have been shown to have higher starting soil mineral N and soil water for a subsequent crop than a legume harvested for grain. However, where a subsequent wheat crop does not receive enough rainfall there can be too much N and this can result in 'haying off' as occurred in a vetch termination trial at Birchip in 2013 (see Birchip Q4).

Clearly soil water reserves and rainfall will be critical factors determining potential biomass production by wheat and/or grain yield. The most notable management decisions to impact on soil water availability for wheat were either fallow the soil in the previous year, or the timing of termination of the preceding break crop or pasture. Well managed long fallows left behind the greatest residual soil water, followed by where crops or pastures had been brown manured, cut for hay or grazed. The least amount of water was left behind when break crops were harvested for grain. Whether differences in soil water established at the end of a growing season were subsequently maintained for the benefit of the next crop sown in the following autumn was largely influenced by summer rainfall.

Fallow management can also impact on N mineralisation. Experiments in the GRDC Water use efficiency initiative demonstrated that if summer fallow weeds are allowed to grow, they reduce mineral N available to the next crop by 1.5 kg/ha for every 1 mm of water they use (Hunt *et al.* 2013). Therefore, a well-managed fallow can improve both soil water and N availability.

Follow the links for regional specific trial results relating to nitrogen:

Birchip Cropping Group

Central West Farming Systems

Central West Farming Systems

Farmlink

Irrigated Cropping Council

MacKillop Farm Management Group

Mallee Sustainable Farming Systems

Riverine Plains

Southern Farming Systems

Managing disease with break crops

Diverse crop sequences are needed to reduce the risk of root and foliar crop disease incidence. PreDicta B tests can be used to measure the presence of soil borne pathogens that can damage wheat. Seasonal conditions will determine whether these pathogens build up to high enough numbers to be for disease to be expressed. For example, from 2010-2015, of more than 25 break crop trials, only two trials had detectable disease incidence. One was the irrigated trial at Kerang, Vic which had crown rot. In this case, it took only one break crop to control the disease. The other was at Mildura where Rhizoctonia was present. In this case, disease inoculum was seen to increase once the rotation was returned to the wheat phase; inoculum levels were lowest after canola treatments. Crop rotation is equally important for break crop species and where seasonal conditions are conducive to disease it is important that preventative strategies (e.g. application of fungicides) are put in place to minimise crop biomass and yield loss.

Take home message

The results from experimental comparisons of crop sequences of at least two and three years' length undertaken over the last five years in the SE Australian cropping belt were consistent with findings from previous local and global research (Angus *et al.* 2015) that has demonstrated that sequences including break crops tend to be more productive than continuous wheat.

Due to the rising populations of herbicide resistant weeds, the potential break crop benefit is becoming increasingly important as the cost of controlling these weeds in cereals is progressively becoming more expensive and less effective over time. However, the flexibility of break crops extends beyond herbicide use, and includes an array of possible end uses. This allows for greater versatility in a range of season types with varying rainfall.

Key conclusions derived from five years of study were:

1. Given the grain prices and growing seasons experienced between 2010 and 2015, break crops were as profitable, and in many cases more profitable, than wheat.

2. Cropping sequences that include at least one break crop tend to be more productive and profitable than continuous wheat when using best management practices.

3. Controlling herbicide-resistant grass weeds in continuous cereal crops was more expensive and less effective than alternative options available in break crops.

4. Wheat grain yield can be expected to be reduced by around 0.5 t/ha for every tonne of in-crop grass dry matter present in spring.

5. In the presence of a high density of herbicide resistant ryegrass a 'single break' was not adequate to reduce weed seedbanks and subsequent in-crop weed competition. 'Double breaks' (two broad leaf break crops, or break crop - cereal hay sequence) reduced ryegrass seedbank numbers to manageable levels and were amongst the most profitable sequences.

6. Legumes commonly fix between 15-20 kg shoot N/ha for every tonne of shoot dry matter grown.

7. Net inputs of fixed N (i.e. total amounts of N fixed – N removed or lost) tended to be greater for brown manure crops and pasture legumes than pulses grown for grain because of the large amounts of N exported from the paddock in high-protein grain.

8. Around 20% of commercial pulse crops and pastures may be experiencing constraints to N fixation.

9. Soil mineral N measured in April tended to be similar following wheat and canola crops, but could be 40 or 90 kg N/ha greater than after wheat where a legume had been grown for grain or brown manure; respectively.

10. Estimates of apparent net mineralisation over the summer fallow represented the equivalent of 0.11-0.18 kg N/ha per mm rainfall, 7-11 kg N per tonne stubble residue dry matter (DM), or 22-32% of the total N estimated to be remaining in above- and below-ground legume residues at the end of the previous growing season.

11. The efficiency of recovery of residual legume N by wheat (25-40%) may be comparable to fertiliser N applied at sowing, but tended to be lower than top-dressed fertiliser N applied at stem elongation just prior to the peak period of crop N demand (45-60%).

12. The flexibility of break crops extends beyond herbicide use, and includes an array of possible end uses. This allows for great versatility under a range of season types with varying rainfall.

13. Break crops can reduce the cost and risk of cereal production.

Unfortunately, no firm conclusions could be drawn on the use of break crops as a strategy to control cereal diseases since disease was evident in only one of the 25 experiments and on-farm trials undertaken during the project.

For further information and detail relating to specific trials please contact your local Grower Group participants in either project CSP00146, or its sister project undertaken by the Low Rainfall Cropping Group (project CWF00009).

Regional specific examples from recent local research

Birchip Cropping Group

Q.1 Can a break crop be as profitable as a cereal?

- Chinkapook

Q.1 Chinkapook

Chinkapook Sequence x Year (2011-2014) crop Gross Margins ($/ha) where either one or two break crops were grown in 2011 or 2012, which was subsequently followed by two wheat crops.

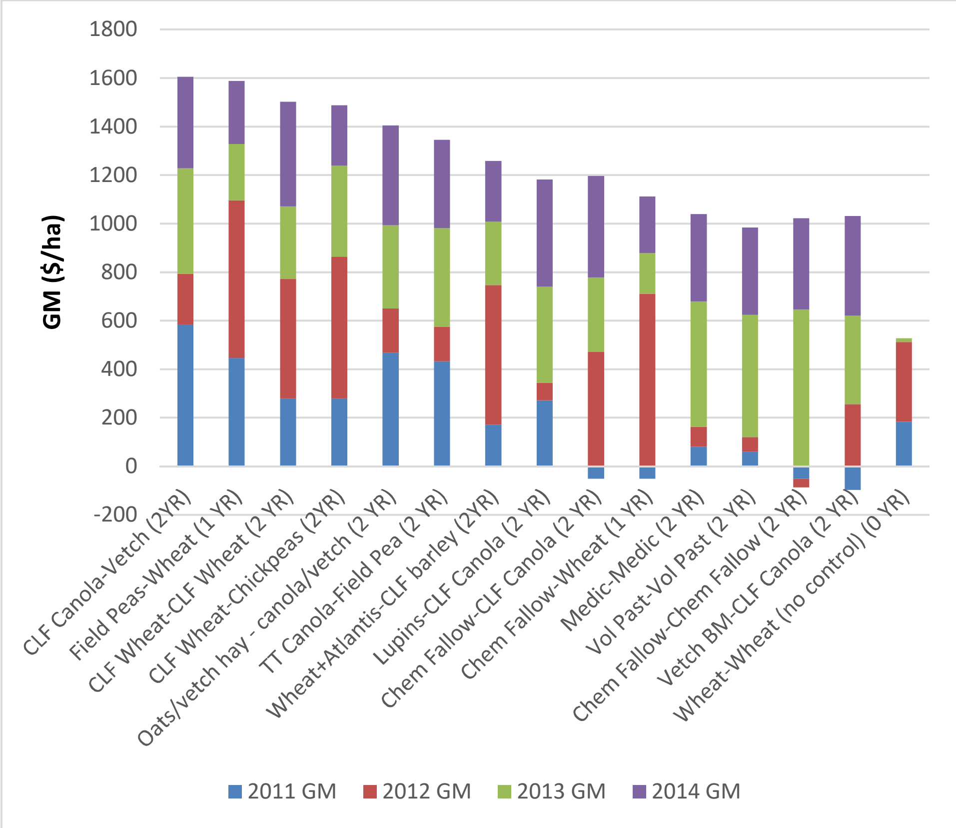
Crop Sequence (2011 – 2012)	Gross Margin ($/ha)				
	2011	2012	2013	2014	Cumulative
CLF Canola-Vetch	585	208	435	378	1626
Field Peas-Wheat	446	650	232	260	1564
CLF Wheat-CLF Wheat	280	492	299	431	1502
CLF Wheat-Chickpeas	280	584	375	249	1497
Oats/vetch hay - canola/vetch	468	182	343	412	1408
TT Canola-Field Pea	433	142	406	364	1344
Wheat+Atlantis-CLF barley	172	575	261	251	1268
Lupins-CLF Canola	272	73	395	442	1181
Chem Fallow-CLF Canola	-51	473	305	418	1145
Chem Fallow-Wheat	-51	711	168	233	1028
Medic-Medic	81	81	518	360	1040
Vol Past-Vol Past	60	60	504	360	984
Chem Fallow-Chem Fallow	-51	-36	647	375	934
Vetch Bm-CLF Canola	-98	256	365	411	997
Wheat-Wheat (no control)	183	329	16	*	528
p-value	<.001	<.001	<.001	0.02	<001
lsd	126	183	104	132	303

Results from the Chinkapook site indicate that a break crop can be as profitable as a cereal in a given year, although this is highly dependent on seasonal conditions and prices. More specifically, break crops can increase profitability in years with high summer rainfall. However, single year returns were also highly affected by the preceding crop sequence. High value break crops delivered high economic returns. Generally the high value break crop outweighed the benefits from a lower value break crop that also increased soil water and N availability, or delivered improved weed control.

Q.2 Are sequences including break crops more profitable than continuous wheat?

- Chinkapook
- Birchip Vetch termination and end use experiment

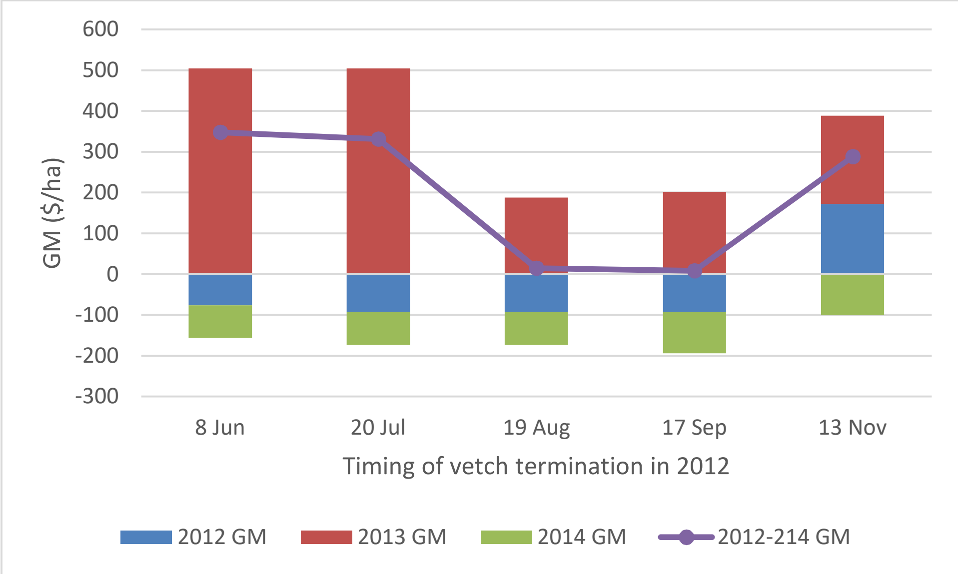
Q.2 Chinkapook



Crop sequence versus Gross Margin (GM $/ha) in 2011-14

Sequences including break crops demonstrated comparable profitability to continuous Clearfield (CLF) wheat over a 3-4 year timeframe. The highest cumulative gross margin was CLF Canola-Vetch ($1626/ha), followed by Field Peas-Wheat ($1564/ha) and CLF Wheat-CLF Wheat ($1502). High input sequences can be profitable when abundant soil moisture allows for increased yield, but this is sensitive to price movements. The increased yield following the long chemical fallow treatment was not sufficient to compensate for the loss of income over the period of fallow.

Q.2 Birchip Vetch termination and end use experiment



Timing of vetch termination in 2012 versus Gross Margins (GM $/ha) in 2012-14 and cumulative Gross Margin.

June and July vetch termination treatments had a three year (2012-2014) cumulative profit of $348/ha and $331/ha. These gross margins resulted from higher wheat yields in the first wheat crop after vetch due to increased soil water. In the year following the later vetch terminations, wheat yields were lower due to a combination of low soil water, high N availability and poor grain size and weight. GMs of only $14/ha and $8/ha were achieved in these cases. The harvested vetch grain treatment made a profit in both the first and second years. No treatments made a profit in year three due to poor yields under the extremely low rainfall conditions that prevailed during the experiment.

Q.3 Can a weed problem be managed more cost effectively with break crops than in a continuous cereal system?

- Chinkapook

Q.3 Chinkapook

The Chinkapook trial site had a high brome grass weed burden. Two years of break crops were substantially more effective than a single year break in reducing brome grass numbers and seedbank. Clearfield technology demonstrated the greatest cumulative gross margin along with the most effective control of brome grass. More generally, this trial indicated that two year break sequences that include legumes, Clearfield canola or Clearfield wheat could profitably reduce brome grass numbers to low levels.

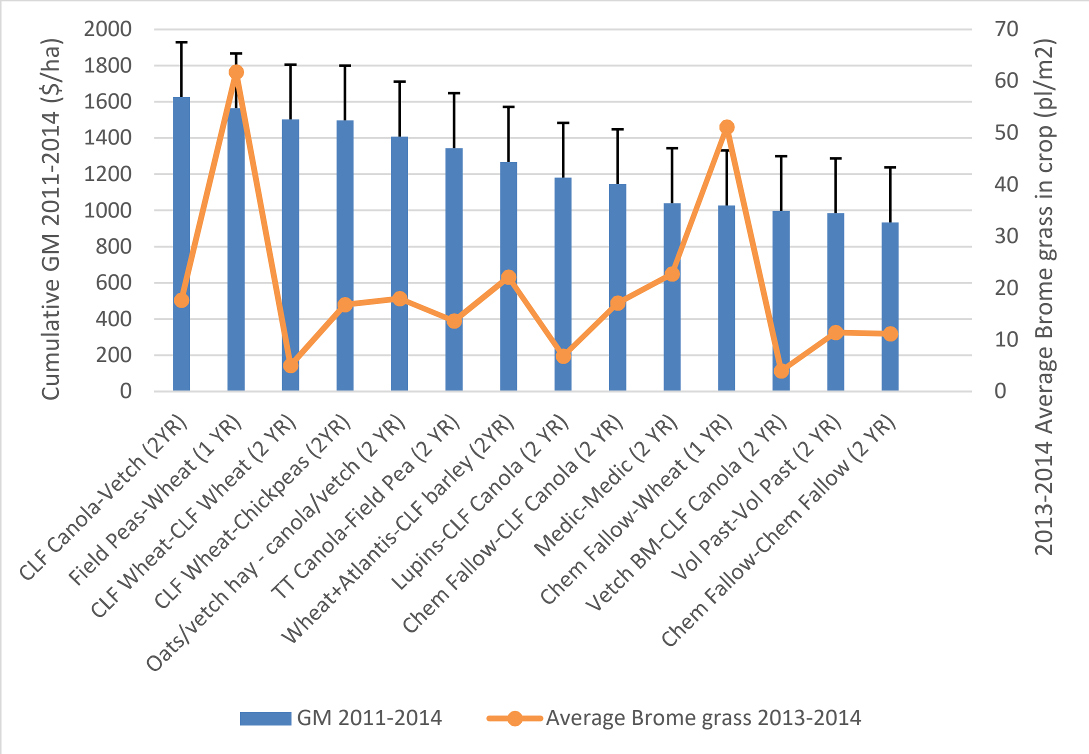


Figure 1 Crop sequence versus cumulative Gross Margin in 2012-2014 (GM $/ha) and average in-crop Brome grass count (pl/m^2).

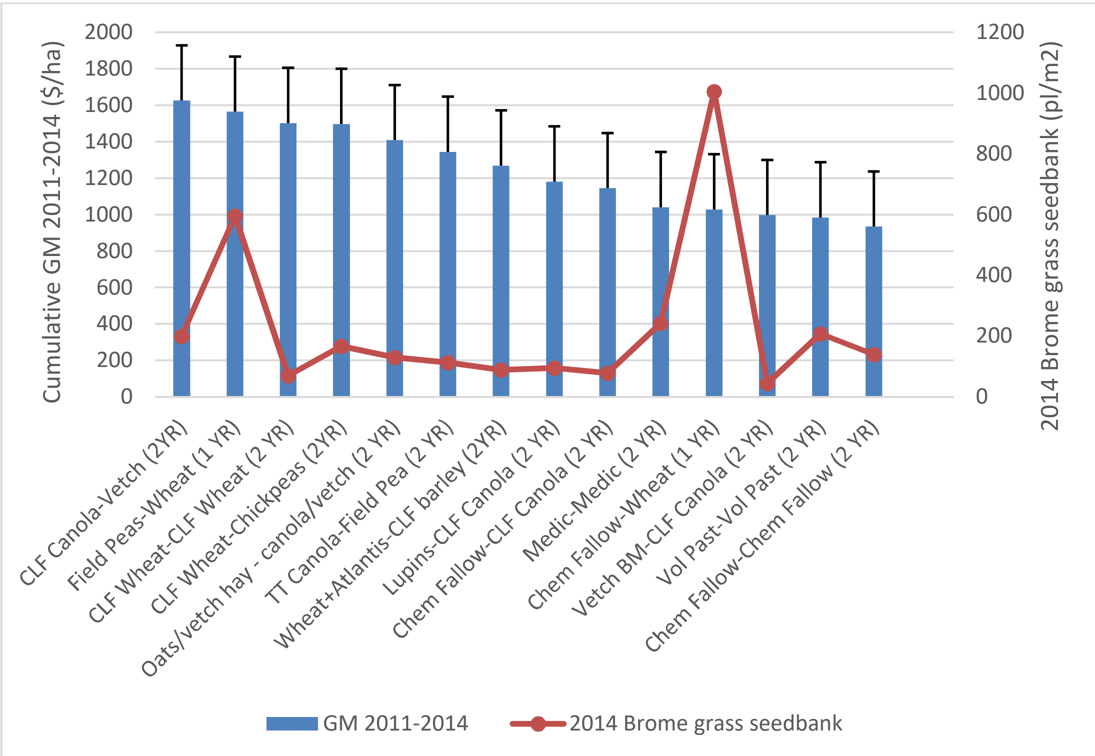
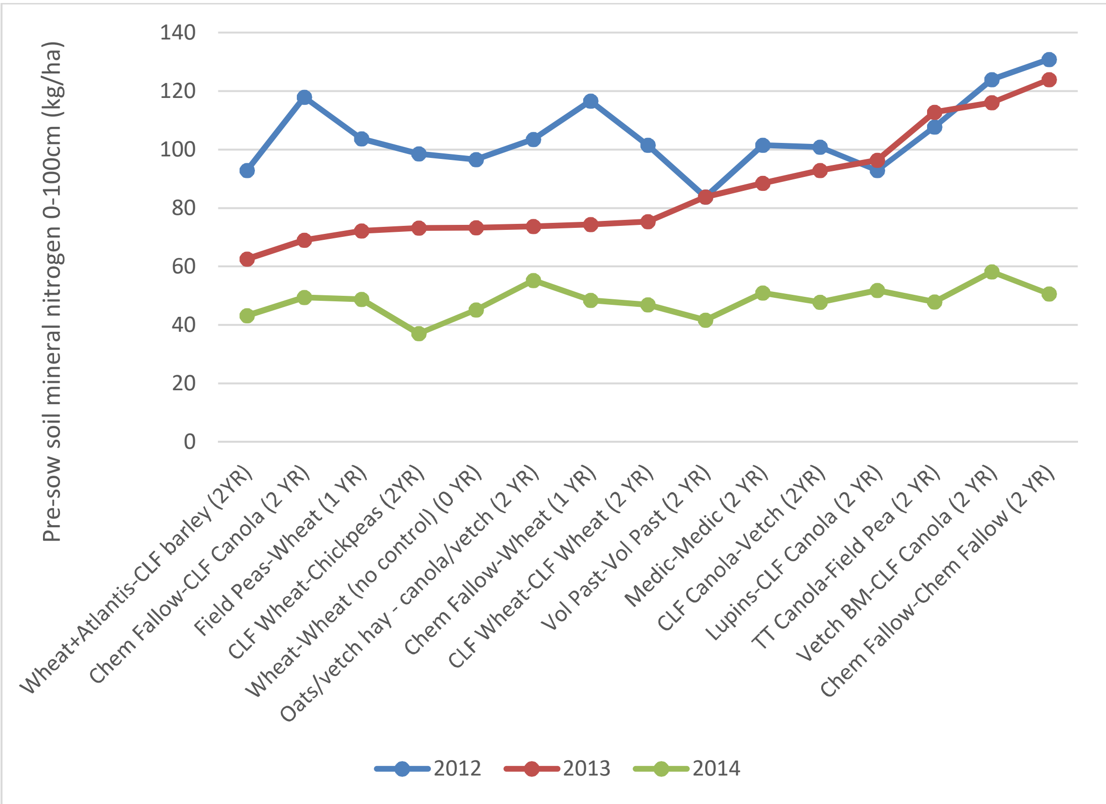


Figure 2 Crop sequence versus cumulative Gross Margin in 2012-2014 (GM $/ha) and 2014 Brome grass seedbank (pl/m^2).

Q.4 What effects do break crops have on soil nitrogen availability?

- Chinkapook
- Birchip Vetch termination and end use experiment
- Watchupga East inoculation x N experiment

Q.4 Chinkapook



Crop sequence versus pre-sowing soil mineral nitrogen (kg N/ha) in 2012-14

Chemical fallow and vetch brown manure treatments displayed the highest concentrations of soil mineral N in 2012. In 2013, chemical fallow-chemical fallow, vetch brown manure-CLF canola and TT canola-field pea sequences resulted in the highest soil mineral N. In 2014 pre-sowing soil mineral N was not significantly different across sequences. Average pre-sowing soil N across all three years showed that consecutive wheat grown in 2013 and 2014 used more N than applied, and additional N from a legume break crop or fertiliser would be necessary for any subsequent crop.

For more detailed trial information Click Here.

Q.4 Birchip Vetch termination and end use experiment

Early termination of vetch (3 months after sowing) had higher soil N in the following year prior to sowing wheat, compared with later termination timings. Higher soil N was likely due to a longer period of N mineralisation over winter and summer. Residual nitrogen from vetch brown manure can carry over for two years and influence cereal crop growth. The hay end use treatment had significantly lower pre-sow soil N compared to other termination treatments. Post-harvest soil N was between 33 to 39 kg N/ha and no differences were found between other treatments.

Soil available nitrogen (0-120cm) for 5 different vetch termination timings as measured post-harvest 2012, 2013 pre-crop and post-harvest

2012 Vetch termination treatment	2012 Post-Harvest Soil N (kg N/ha) 0-120cm	2013 Pre-sow Soil N (kg N/ha) 0-120cm	2013 Post-Harvest Soil N (kg N/ha) 0-120cm
6 June (3 months after sowing)	158[a]	150[a]	22
18 July (4 months)	122[ab]	132[b]	22
19 August (5 months)	108[b]	127[b]	21
17 September (6 months)	113[b]	132[b]	23
13 November Harvest (control)	89[b]	108[c]	23
Sig. diff.	P=0.03	P=0.02	NS
LSD (P=0.05)	39	23	
CV%	22	17	20

For more detailed trial information Click Here.

Q.4 Watchupga East inoculation x N experiment

This trial examined whether inoculation, or applications of fertiliser N impacted on pulse grain yield. The paddock was last sown to an inoculated (Group E) vetch crop seven years previously. Field peas (also nodulated by Group E rhizobium) gained little net benefit from inoculation implying adequate numbers of rhizobia persisted over this period of time. Nitrogen topdressing also had little effect on growth or yield.

Table 1 Field pea grain yield, treatment cost, and return on investment

Treatment	Yield (t/ha)	Income ($/ha)*	Treatment cost ($/ha)	Return on investment ($)
Nil inoculant + nil N	1.04	312	0	
Group E inoculant + nil N	1.08	324	4.5	2.7

Nil inoculant + 23kgN/ha	0.99	297	25	-0.6
Group E inoculant + 23kgN/ha	1.06	318	29.5	0.2
Sig. diff. LSD (P=0.05) CV%	NS – 15.4			

*Field pea price = $300/tonne. N = $25/ha (urea @ $500/t divided by 0.46%N=$1.09/kgN x 23kgN/ha), Peat inoculant = $4.5/ha (Nodulaid @ $0.48/kg applied to seed sown at 95kg/ha)

By contrast inoculating chickpeas which had not previously been grown at the site provided a $60/ha return on investment. A single 25 kg N/ha topdressing with N fertiliser was insufficient to compensate for the absence of soil rhizobia.

Table 2 Chickpea grain yield, treatment cost, and return on investment

Treatment	Yield (t/ha)	Income ($/ha)*	Treatment cost ($/ha)	Return on investment ($)
Nil inoculant + nil N	1.02[c]	408	0	
Group N inoculant + nil N	1.70[a]	680	4.5	60
Nil inoculant + 23kgN/ha	1.26[b]	504	25.0	4
Group N inoculant + 23kgN/ha	1.61[a]	644	29.5	8
Sig. diff. *Inoculation* *N* *Inoculation x N* LSD (P=0.05) *Inoculation* *N* *Inoculation x N* CV%	 P<0.001 NS P=0.008 0.11 – 0.16 8.2			

*Chickpea price = $400/tonne, N = $25/ha (urea @ $500/t divided by 0.46%N=$1.09/kgN x 23kgN/ha), Peat inoculant = $4.5/ha (Nodulaid @ $0.48/kg applied to seed sown at 95kg/ha)

For more detailed trial information Click Here.

Central West Farming Group

Q.2 Are sequences including break crops more profitable than continuous wheat?

- Condobolin

Q.2 Condobolin

Crop sequence trials- Replicated trials were established in a paddock with a long history of intensive cereal cropping. Agronomic constraints to cereal production in this paddock included grass weeds, soil borne disease and declining soil fertility. The trial consisted of up to 21 unique crop sequences which included both one and two-year break phases in 2011 and/or 2012 followed by wheat in 2013 and 2014 (Table 1). However, the Lucerne treatment consisted of three years of Lucerne and wheat on the fourth year. The treatments were selected by the CWFS farmer group in consultation with local farmers and advisors in the region. The trial also maintained a continuous wheat treatment for the four years of the trial as a benchmark to assess the impact of the other crop sequences.

Table 1: Details of the Condobolin crop sequence trial, including break crop phases and unique sequences for each year (2011-2014).

Treatment cluster	Varieties 2011	Varieties 2012	Varieties 2013	Varieties 2014
Canola - Cereal	1. Hyola 575CL	Livingston	Livingston	Livingston
Cereal – Cereal	2. Hindmarsh	Livingston	Livingston	Livingston
Legume (Field Peas, Lupins, Chickpeas) - Cereal	3. Mandelup, 4. Slasher, 5.Twilight	Livingston	Livingston	Livingston
Grazing cereal- Grain cereal	6. Oats- Yarran	Livingston	Livingston	Livingston
Pasture – Cereal	7. Serradella, 8. Vetch (Morava)	Livingston	Livingston	Livingston
Canola- Legume	9. 44Y84CL, 10. Hyola 575CL	Mandelup, Twilight	Livingston	Livingston
Legume (Lupins) – Canola	11. Luxor, 12. Hat trick	44Y84CL, Hyola 575CL	Livingston	Livingston
Grazing cereal- Grazing cereal	13. Wedgetail	Wedgetail	Livingston	Livingston
Pasture – Canola	14. Vetch (Morava)	44Y84CL	Livingston	Livingston
Pasture – Pasture	15. Lucerne, 16. Volunteer 17. Clover/medic mix, 18. Serradella	Lucerne, Volunteer Clover/medic mix, Serradella	Lucerne Livingston	Livingston Livingston
Fallow – Fallow	19. Chemical Fallow	Chemical Fallow	Livingston	Livingston
Pasture - summer crop	20. Volunteer pasture, Shilohi millet	Summer crop	Livingston	Livingston
Cereal – Cereal (wheat on wheat)	21. Livingston	Livingston	Livingston	Livingston

During the trial, agronomic management was tailored for each individual sequence to help maximise the profitability of that rotation and to correct any agronomic constraints as they emerged. For example, N inputs, varieties, sowing dates or herbicide applications were varied depending on the level and type of agronomic constraints in each rotation.

The trial was intensively monitored for a range of agronomic parameters. Prior to sowing, soil fertility and root disease inoculum was measured in the topsoil while soil N and water were measured down the soil profile. Grass weeds populations were also monitored over the course of the trial by measuring weed seed banks and in-crop weed numbers.

Gross Margins were calculated for each treatment in each season using the Rural Solutions 'Farm Gross Margin and Enterprise Planning Guide' as a base. Costs were calculated using the actual inputs used in the trial and the values provided in the corresponding gross margin guide. Each year gross margins were calculated using the five-year average price stated in the 2015 guide (Table 2). Treatment grain yields were used for calculating income and 85% of dry matter (DM) yield was used for calculating hay yield. For grazing livestock, income was calculated using the dry sheep equivalent (DSE) cereal zone gross margin for a prime lamb enterprise and a nominal stocking rate of 2 DSE per winter grazed hectare, irrespective of pasture production.

Table 2: Enterprise prices used in the calculations of gross margins

Enterprise	Price	Notes
Wheat grain	$271/t	All assumed APW quality
Barley grain	$225/t	All assumed feed quality
Lentils grain	$628/t	
Field Pea grain	$265/t	
Chickpea (Desi) grain	$414/t	Assumed $50/t below Kabuli chickpea price
Canola grain	$522/t	
Oaten hay	$148/t	
Legume hay	$198/t	Assumed $50/t above oaten hay
Mixed legume/non-legume hay	$173/t	Assumed $25/ above oaten hay
Livestock (grazing)	$66/ha	Cereal zone prime lamb: $33/DSE/ha x 2 DSE ha

In the first year, the break crop phases in rotations substantially increased yields of subsequent wheat crops in comparison to continuous wheat (Fig 1). In addition, although the control treatment of wheat on wheat was top dressed with 23 kg N/ha, the wheat crop after the legume break crops such as lupins, chickpea and vetch still yielded better.

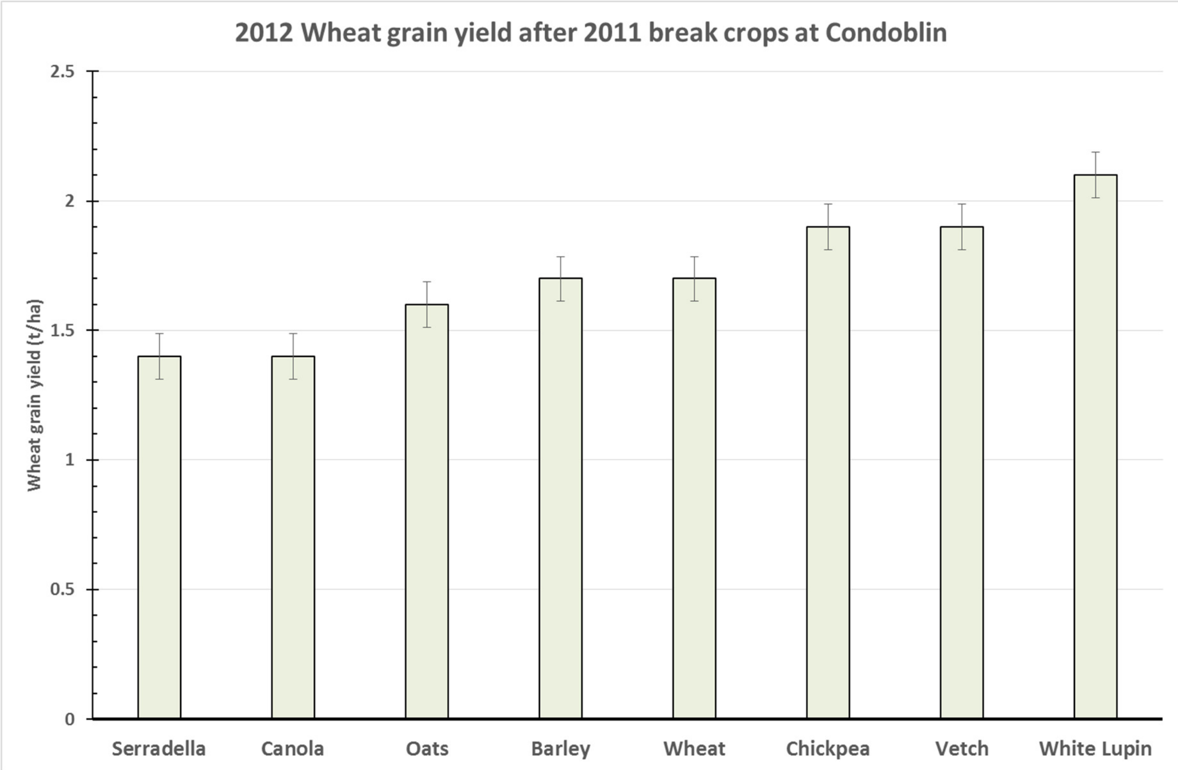


Figure 1: 2012 wheat grain yield after 2011 break crops and pasture at Condobolin.
LSD @ 5% 0.23, P<0.001, %CV 8.4

Table 3 provides a yield summary after 2011 and 2012 single and double break phases respectively. The wheat production yield differences in 2013 ranged between 0.1 to 1.2 t/ha above the 2.1 t/ha achieved by the wheat on wheat sequence. The double breaks were more effective in improving subsequent yields and contributed to higher gross margins than single break phases in 2013. However, in 2014 there were no significant yield differences possibly due to above average rainfall.

Table 3 Wheat grain yield in 2013 and 2014 after 2011 and 2012 break crops and pastures (a mix of 1 and 2 year break phases).

2011 Crop	2012 Crop	2012 yield t/ha	2013 yield t/ha	2014 Yield t/ha
Canola-44Y84CL	Lupins - Mandelup		3.0	4.0
Chemical Fallow	Chemical Fallow		3.0	3.3
Grazing wheat - Wedgetail	Vetch - Morava		2.5	4.0
Chickpea - Hat trick	Canola-44Y84CL		2.4	3.9
Chickpea - PBA Slasher	Wheat - Livingston	1.75	2.1	3.9
Canola - Hyola 575CL	Wheat - Livingston	1.59	2.2	4.0
Pasture - Clover/medic	Pasture - Clover/medic		3.3	3.6
Vetch - Morava	Wheat - Livingston	1.89	2.3	4.3
Lupins - Luxor	Wheat - Livingston	2.02	2.2	3.9

Lupins - Mandelup	Canola-44Y84CL		2.3	4.0
Vetch - Morava	Canola-44Y84		2.4	3.9
Pasture - Millet	Vol Pasture		2.7	3.9
Barley - Hindmarsh	Wheat - Livingston	1.66	2.1	3.7
Oats- Yarran	Wheat - Livingston	1.55	2.4	3.8
Pasture -Serradella (Cadzi)	Pasture -Serradella (Cadzi)		3.0	3.6
Canola - Hyola 575CL	Field peas - PBA Gunyah		2.8	3.9
Pasture - Serradella	Wheat - Livingston	1.35	2.4	4.1
Field peas - PBA Twilight	Canola-44Y84CL		2.1	3.6
Pasture - Lucerne	Pasture - Lucerne		0.0	4.0
Wheat - Livingston	Wheat - Livingston	1.74	2.2	4.2
Wheat - Lincoln	Wheat - Lincoln	1.72	2.1	3.6
	LSD	0.23	0.24	0.78
	P- Value	P<0.001	P<0.001	NS
	% CV	8.4	8.3	11.6

In summary, the crop sequence experimentation undertaken in Central West NSW demonstrated that crop sequences which included a brassica or legume break cros can be as profitable as, and in many instances more profitable than, continuous wheat.

Q.4 What effects do break crops have on soil nitrogen availability?

- Condobolin

Q.4 Condobolin

Figure 2 and 3 reflect the differences in available soil N at different depths based on break crop and pasture phases for 2012 and 2013 respectively. There were significant differences in available soil N at 0-60 and 0-120cm as a result of one year break crops and pastures. The legumes contributed the most soil N led by field peas and followed by vetch and narrow lupins.

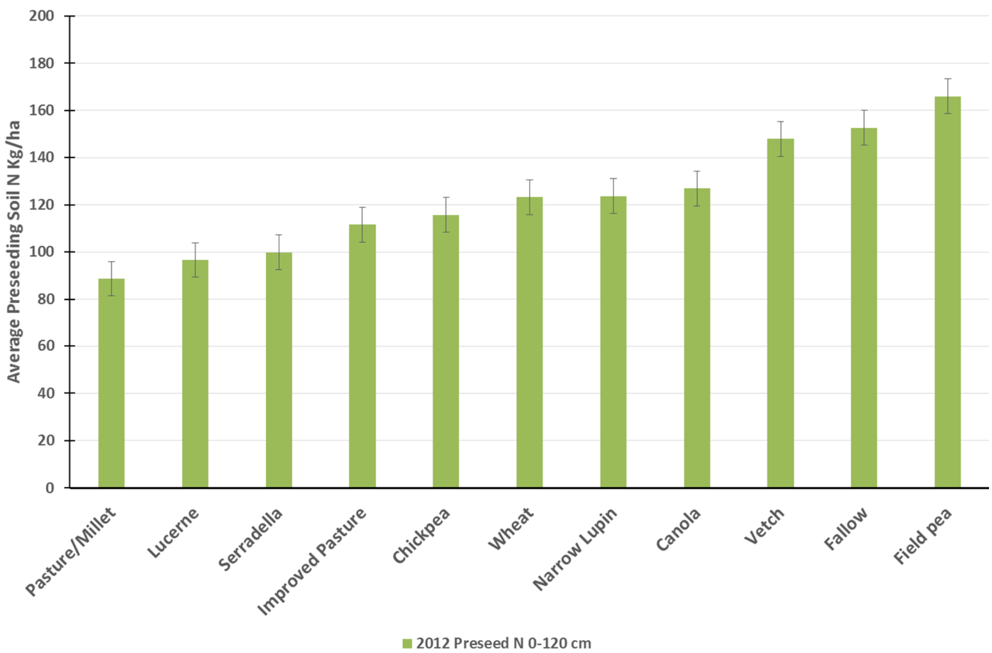


Figure 2. Pre-seeding soil mineral N (0-120cm) in 2012 after one year break crop phases involving legumes and pastures at Condobolin (LSD 5% = 38.4, P<0.001)

After 2 years of break crop and pasture phases the available soil N at 2013 pre-seeding is presented in Figure 3. Clearly there were benefits for growing legumes in the 2-year rotations regardless of whether they were grown in the first or second year. Although, the 2-year fallow had the highest soil mineral N, (0-90 cm) there was no income benefit. The pasture break phases contributed to high mineral N in the soil, especially the Serradella.

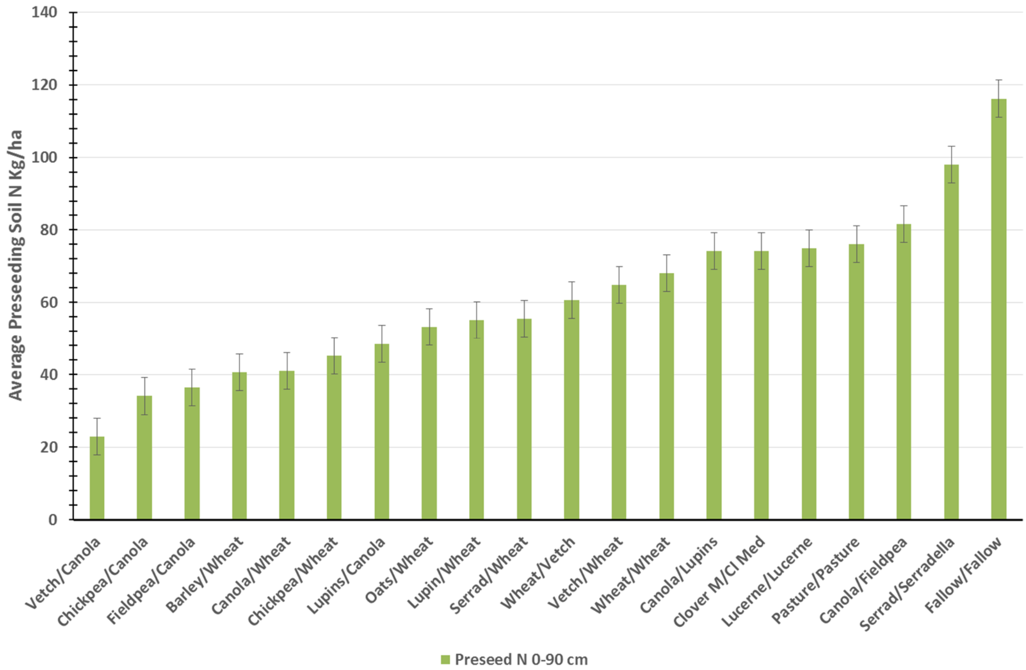


Figure 3. Pre-seeding soil mineral (0-90cm) in 2013 after two year break crop phases involving legumes and pastures at Condobolin (LSD 5% = 36.3, P<0.001).

Case Studies

Trundle and Lake Cargelligo

On-farm evaluation of different break crop options was undertaken by sowing paddock-scale replicated strips of wheat, and canola, peas, lupin, chickpea or fallow using farmer equipment at Trundle, or Lake Cargelligo, NSW in 2011. Wheat was sown over all treatments in 2012.Grain yield benefits of between 0.3 to 0.6 t/ha compared to the yields of wheat on wheat were observed but the effects were only significant at Lake Cargelligo (see Tables 1 and 2). Wheat was sown on the same strips again in 2013 to assess the second year impact after break crops. This time there were significant yield differences at Trundle. The yield benefits at both locations were higher by 0.2 to 0.5 t/ha compared to the yields of wheat on wheat (2.8 to 3.0 t/ha). The grain protein was higher for wheat oversown after a legume crop providing benefits for a more profitable classification for the wheat grain.

Table 1. Impact of break crops on 2012 and 2013 wheat yield at Trundle

2011 Break crop		2012 Wheat		2013 Wheat	
	Yield (t/ha)	Yield (t/ha)	Grain Protein	Yield (t/ha)	Grain Protein

Crop			%		%
Chickpea	1.0	2.4	10.3	3.3	9.2
Field pea	1.0	2.3	10.9	3.5	9.5
Lupin	0.4	2.6	11.0	3.4	11.1
Wheat on wheat	2.1	2.0	10.6	3.0	9.0
P Value		***NS***	***NS***	***P<0.001***	***P<0.001***
LSD 5%		***0.5***	***0.78***	***0.08***	***0.6***

Table 2. Impact of break crops on 2012 and 2013 wheat yield at Lake Cargelligo

2011 Break crop		2012 Wheat		2013 Wheat	
Crop	**Yield (t/ha)**	**Yield (t/ha)**	**Grain Protein %**	**Yield (t/ha)**	**Grain Protein %**
Canola	1.3	2.5	9.6	3.2	11.1
Fallow	0.0	2.7	9.8	3.3	10.5
Lupins	1.1	2.6	10.0	3.0	12.3
Wheat on barley	1.7	1.9	9.5	3.2	10.3
Wheat on wheat	1.8	2.1	9.9	2.8	11.2
P Value		***P<0.05***	***NS***	***NS***	***NS***
LSD 5%		***0.5***	***1.1***	***0.5***	***1.6***

FarmLink

Q.1 Can a break crop be as profitable as a cereal?

- Junee Reefs
- Eurongilly Exp 1
- Eurongilly Exp 2
- Wagga Wagga Exp 1
- Wagga Wagga Exp 2

Q.1 Junee Reefs

Results from experiments undertaken by CSIRO and FarmLink in southern NSW (3 experiments established between 2011-13, see below) where break crops were followed by 2 years of wheat demonstrated that canola and legume break crops can frequently be as profitable, and in a number of instances considerably more profitable, than wheat. Canola was consistently the most profitable break crop.

Phased Experimental Years

At Junee Reefs in 2011 when all crops were grown, lentils were also more profitable than wheat and lupins were also more profitable than low input wheat. While relative grain prices for wheat and break crops (particularly canola in 2011) was an important profit driver, the ratio of profit:input cost for break crops in the year they were grown was also often higher than for wheat. For example, the Table below indicates $1.60-$3 profit for every $1 spent on variable costs for canola and lentil compared to $0.90-$1.30 per $1 spent on wheat.

Comparisons of grain yield, income, variable costs and gross margins of cereals and various break crops grown for grain or brown manure (Bm) at Junee Reefs, NSW in 2011.

(*Values in parenthese represent the contribution of input costs to total variable costs). Crops arranged in order of descending gross margin*.

Crop & input	Grain yield (t/ha)	Gross income[a] ($/ha)	Total variable costs ($/ha)	Gross margin ($/ha)	Profit/cost ratio
Canola - low	3.2 (46% oil)	$1,581	$381 ($181)	$1,199	3.1
Canola - high	3.3 (49% oil)	$1,604	$571($334)	$1,033	1.8
Lentils	3.2	$1,165	$455 ($172)	$710	1.6
Barley	6.3	$945	$386 ($130)	$559	1.4
Wheat - high	5.2	$1,056	$544 ($324)	$511	0.9
Lupin	3.5	$770	$315 ($164)	$455	1.4
Wheat - low	4.8	$744	$319 ($117)	$425	1.3
Chickpeas	1.8	$792	$406 ($296)	$386	1.0
Pea Bm	0	$0	$139 ($104)	-$139	-1.0
Lupin Bm	0	$0	$150 ($115)	-$150	-1.0

For more trial information (including methods) CLICK here

Q.1 Eurongilly Exp 1

There is substantial evidence indicating wide-spread resistance or partial resistance of annual ryegrass (ARG; *Lolium rigidum* Gaudin) to a wide range of herbicide groups across south eastern Australia (Broster *et al.* 2013). Consultation with grower groups and agribusiness collaborators identified difficulties in managing grass weeds as a main constraint to wheat production, and the primary driver of decisions to grow broadleaf break crops.

In year 2012, an on-farm experiment was established in a paddock near Eurongilly that had been identified as having a herbicide-resistant ARG population (Eurongilly experiment 1). The most profitable crops were RR and TT canola which returned grain yields and gross margins of 3.5t/ha (GM =$1259/ha) and 3t/ha (GM = $1166/ha), respectively. The next most profitable crops were lupins (grown for grain) @ $683/ha (yield = 3.1t/ha), wheat (High input) @ $257/ha (yield = 3.2t/ha), wheat

(Low input) @ $250/ha (yield = 2.0 t/ha), with the brown manure or fallow treatments having negative returns (-$45 to -$250/ha). Therefore, it was shown that in the presence of a high weed burden, there were multiple broadleaf options that were more profitable than wheat in a single year.

This experiment, also aimed to test whether or not you can 'buy your way out of needing a break crop' in the presence of a high weed burden. In addition to the standard herbide treatments used to control grasses in wheat (nominated as 'low' input), a 'high' input wheat treatment was included in the design along with various broadleaf crops grown for grain or brown manure (Bm), and a fallow treatment. It was found that using the latest and most effective ryegrass control options in wheat was very expensive relative to those used in the other treatments. See Table below to compare the costs of the herbicides alone used to control ryegrass.

Ryegrass Herbicide Costs at Eurongilly Exp 1 in 2012

Crop & Input Year 1	**Ryegrass Control Costs** ($/ha)
Wheat (Low)	$56
Wheat (High)	$142
Lupin (Grain)	$65
TT Canola (Grain)	$62
RR Canola (Grain)	$46
Pea Bm	$66
Fallow	$35

For more trial information (including methods) CLICK here

Q.1 Eurongilly Exp 2

In 2013 a second trial was established on another farm with a herbicide-resistant AGR population (Eurongilly Experiment 2). The wheat yield in wheat high input treatment represented about twice the canola yield, but was considerably lower in the wheat low input treatment due to competition with ARG. The lupin-grain crop proved to be the most profitable crop with a profit/cost ratio of 2.5 (profit of $2.50 for each $1 spent). Nitrogen was applied to the wheat at rates of 174 and 49 kgN/ha (high and low inputs; respectively) and to the canola at 196 and 98 kgN/ha (high and low inputs; respectively). The high rates of N reduced the gross margin in both the canola and wheat high input treatments compared to lupin in Experiment 2, or the canola and wheat treatments described above in Experiment 1. As the canola price was similar between 2012 and 2013 ($490/t and $476/t), the main difference in gross margin related to a lower crop yield in Experiment 2. In this case, a break crop (lupins) were still more profitable than wheat.

Comparisons of grain yield, income, variable costs, and gross margins of wheat and break crops grown for grain or brown manure (Bm) or fallow from Year 1 of Eurongilly Expt 2.

Crops arranged in order of descending gross margin.

Crop & input	Grain yield 2013 (t/ha)	Gross income[a] 2013 ($/ha)	Variable costs 2013 ($/ha)	Gross margin 2013 ($/ha)	Profit / cost ratio
Lupin - grain	2.6	$1040	$299	$741	2.5
Wheat - high	4.0 (14.5)	$1110	$756	$354	0.5
Canola - low	1.6	$781	$442	$339	0.8
Wheat - low	2.2 (12.2)	$556	$289	$300	1.1
Canola - high	1.9	$872	$711	$161	0.2
Fallow	0	$0	$72	-$72	-1.0
Peas Bm	0	$0	$204	-$204	-1.0

[a]***Note***: Grain prices used in the calculations were current at the around the time of harvest and assumed delivery to Junee except RR canola to Stockinbingal (extra freight cost = $5/t).
() brackets indicate grain % protein.

For more trial information (including methods) CLICK here

Q.1 Wagga Wagga Exp 1

Experiment 1 at Wagga Wagga focused on examining the N benefits of break crops for subsequent crops. There were 3 sets of treatments phased across years with single breaks (break crop was used once over 4 years) and double breaks (break crop was used twice over 4 years) with a range of combinations of crop rotation sequences (Table 3). The break crops tested included canola, lupins, field peas, vetch and high density legume pasture species. Continuous wheat with and without N were used as controls. Field peas were harvested for grain or brown manured at peak Dry Matter (DM) prior to grain-filling, vetch and legume pasture were either cut for hay or brown manured, lupins and canola were harvested for grain.

Table 3 Outline of treatments at the Graham Centre site in Wagga Wagga Exp 1.

	2011	2012	2013	2014
Single break	Break crops	Wheat	Wheat	Wheat
	Wheat+N	Break crops	Wheat	Wheat
Double breaks	Canola+N	Break crops	Wheat	Wheat
	Break crops	Canola	Wheat	Wheat
Control	Wheat+N	Wheat+N	Wheat+N	Wheat+N
	Wheat+N	Wheat-N	Wheat-N	Wheat-N

For more trial information (including Methods) CLICK HERE

Table 4 Gross margin analysis for break crops in comparison with wheat crops in 2013 at the Graham Centre site in Wagga Wagga Exp 1.

Crop Management	Break crops	Income	Variable cost	Gross margin	Profit/cost ratio
Brown Manure	Pea	$0	$207	-$207	0.0
	Vetch	$0	$213	-$213	0.0
	Pasture	$0	$182	-$182	0.0
Hay	Vetch	$884	$472	$412	1.9
	Pasture	$791	$415	$376	1.9
Grain	Pea	$339	$299	$41	1.1
	Lupin	$345	$277	$68	1.2
	Canola	$761	$291	$470	2.6
Continuous cereals					
Wheat+N		$787	$355	$432	2.2
Wheat -N		$533	$269	$264	2.0

Results showed that canola was the most profitable crop as a break crop, whereas brown manured treatments for pulses and legume pastures lost one year production without any income (Table 4). However, brown manured treatments greatly increased available soil N to the subsequent crops as discussed in Q4. Hay cut treatments for vetch and pastures had comparable gross margins to a wheat crop with 75 kg/ha of N fertiliser (Table 4), while still left an N benefit for following crops as discussed in Q4.

Q.1 Wagga Wagga Exp 2

Research in the second experiment at Wagga Wagga explored the effects of weed competition and management on crop performance. Annual ryegrass was pre-sown at 1.5 kg/ha at the whole site prior to commencing experimentation. Unlike the studies undertaken at Eurongilly, the ryegrass was not herbicide resistant, and the grass in the 'weed free' treatments were largely controlled with pre- and post-emergent herbicides. No herbicides were applied on the 'weed present' treatments (Table 1).

Table 1 Outline of treatments at the Agricultural Institute in Wagga Wagga Exp 2.

2012	Weed management		2013	2014	2015
Break crops	Weed free		Wheat	Wheat	Wheat
			Canola	Wheat	Wheat
	Weed present	Crop desiccated	Wheat	Wheat	Wheat
			Canola	Wheat	Wheat
		Brown manured	Wheat	Wheat	Wheat
			Canola	Wheat	Wheat
Control	Wheat+N	Wheat+N	Wheat+N	Wheat+N	Wheat+N
	Wheat-N	Wheat-N	Wheat-N	Wheat-N	Wheat-N

Table 2 Gross margin analysis for break crops in comparison with wheat crops in 2013 at Agricultural Institute in Wagga Wagga Exp 2.

Weed management		Crop management	Yield (t/ha)	Gross income	Total variable cost	Gross margin
Weeds present	Canola	Crop desiccated	2.5	$1,123	$398	$725
	Lupin	Brown manured	5.4	$0	$200	**-$200**
	Lupin	Crop desiccated	0.6	$198	$272	**-$73**
	Pea	Brown manured	4.3	$0	$207	**-$207**
	Pea	Crop desiccated	0.7	$196	$303	**-$107**
	Pasture	Brown manured	5.5	$0	$182	**-$182**
	Pasture	Hay cut	5.4	$933	$478	$455
Weeds free	Canola	Grain harvested	2.8	$1,288	$439	$849
	Lupin	Grain harvested	1.7	$536	$378	$158
	Pea	Grain harvested	1.5	$399	$378	$21
	Wheat+N	Grain harvested	4.6	$1,041	$423	$618
	Wheat-N	Grain harvested	4.5	$1,014	$345	$669

Gross margin analysis showed that canola was the most profitable crop as a break crop, even when weeds were present, although crop desiccation increased herbicide input costs and reduced the gross margin slightly (Table 2). When weeds were present, pasture cut for hay was the only other treatment with a positive gross margin apart from canola. For grain harvested treatments, canola had the highest gross margin and pea had the lowest gross margin (Table 2). It was noted that there was no N response to wheat crops probably due to the dry finish in 2013.

Q2. Are sequences including break crops more profitable than continuous wheat?

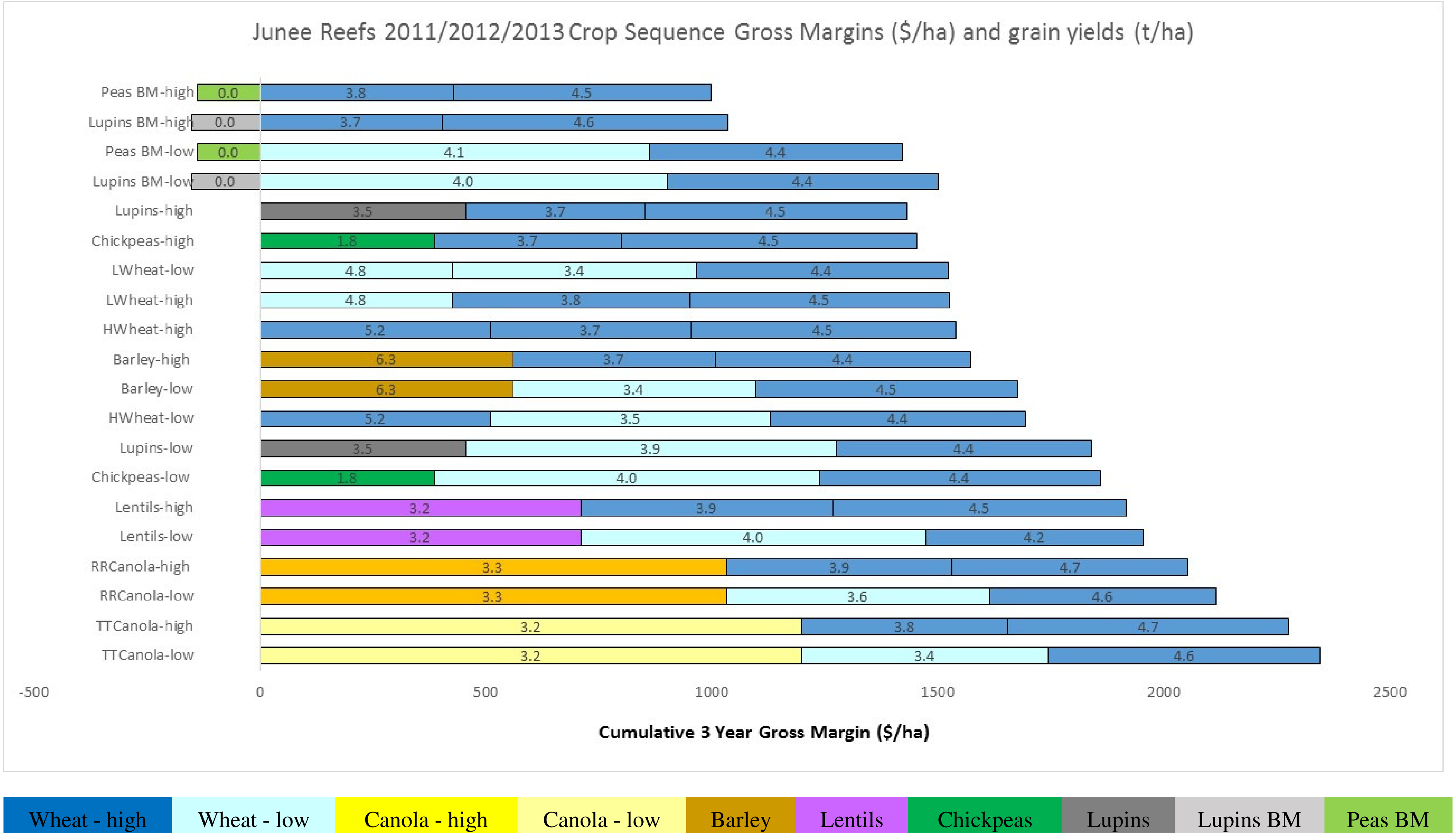
- Junee Reefs
- Eurongilly Exp 1
- Eurongilly Exp 2
- Wagga Wagga Exp 1
- Wagga Wagga Exp 2

Q.2 Junee Reefs

Wheat following break crops were consistently more profitable than wheat on wheat. Calculated 3 year cumulative gross margins of 8 out of 10 treatments where break crops were grown for grain in the first year ranged from $1,944-$2,433/ha compared to $1,608-$1,782/ha for continuous wheat (see the figure and Table below for detailed breakdown). This in part reflected the relatively low wheat grain prices experienced during experimentation, and the high returns for canola. Crop sequences involving legumes were found to be profitable either due to their high value (e.g. lentil) or as a result of increased wheat yields and lower costs of production for following wheat crops.

Growing pulses for brown manure (Bm) lost money in the year that they were grown, but achieved excellent weed control, provided high inputs of N and a residual carry-over of soil water, and more ground cover than if they had been cut for hay. The low input wheat crops grown immediately following Bm had the highest grain yields and profit, but the increased grain yields were insufficient to fully compensate for the loss of income in the first year. The high available soil N following Bm caused the high input wheat which received additional fertiliser N to 'hay off' during the 2012 growing season. On the other hand, the Bm low input wheat sequence provided a lower risk adverse option over dry years. The net result was that the 3 year cumulative gross margin using Bm was the least profitable of any break crop treatment where there was no major weed problem ($1,044-$1,533/ha) (see Table below).

It was concluded that break crop choice and selection should be based on individual farm management and ability to manage the various break crops options in the rotation. If growers remain flexible in break crop and end-use decisions, and make suitable choices, risks associated with producing them can be greatly reduced. It was concluded that a cropping program that includes break crops is likely to be more sustainable in terms of N inputs and risk of build-up of root diseases than continuous wheat, and provided cheaper, more effective strategies for controlling herbicide resistant grass weeds.


Junee Reefs 2011/2012/2013 Crop Sequence Gross Margins ($/ha) and grain yields (t/ha)
Peas BM-high
Lupins BM-high
Peas BM-low
Lupins BM-low
Lupins-high
Chickpeas-high
LWheat-low
LWheat-high
HWheat-high
Barley-high
Barley-low
HWheat-low
Lupins-low
Chickpeas-low
Lentils-high
Lentils-low
RRCanola-high
RRCanola-low
TTCanola-high
TTCanola-low
-500
0
500
1000
1500
2000
2500
Cumulative 3 Year Gross Margin ($/ha)
Wheat - high
Wheat - low
Canola - high
Canola - low
Barley
Lentils
Chickpeas
Lupins
Lupins BM
Peas BM

Comparisons of the mean annual gross margins ($/ha/yr) calculated for different crop sequences from three years of experimental data at years 1-3 at Junee Reefs 2011-2013.

Crop sequences are arranged in order of descending average annual gross margin.

Crop & input in 2011	Input in 2012	Gross margin in 2011[a] ($/ha)	Gross margin in 2012[b] ($/ha)	Gross margin in 2013[c] ($/ha)	Average annual gross margin (3 yrs) ($/ha/yr)	Average profit/cost ratio (3 yrs)
					>$600/ha	
Canola – low	low	$1,199	$545	$690	$811	2.0
Canola – low	high	$1,199	$456	$712	$789	1.6
Canola - high	Low	$1,033	$581	$690	$768	1.6
Canola - high	high	$1,033	$498	$715	$749	1.3
Chickpeas	low	$386	$851	$708	$648	1.7
Lentils	low	$710	$764	$651	$708	1.9
Lentils	high	$710	$558	$737	$668	1.3
Lupins	low	$455	$821	$745	$674	1.6
					$400-$600/ha	
Wheat – high	low	$511	$617	$653	$594	1.3
Wheat – high	high	$511	$442	$676	$543	1.0
Wheat – low	high	$425	$527	$660	$537	1.2
Wheat – low	low	$425	$540	$643	$536	1.1
Chickpeas	high	$386	$414	$742	$514	1.4
Lupins	high	$455	$396	$767	$539	1.1
Lupins Bm	low	-$150	$902	$780	$511	1.7
Field pea Bm	low	-$139	$861	$740	$487	1.6
					<$400	
Lupins Bm	high	-$150	$404	$819	$358	1.0
Field pea Bm	high	-$139	$428	$755	$348	0.9

For more trial information (including methods) CLICK here

Q.2 Eurongilly Exp 1

In the presence of a high weed burden herbicide-resistant annual ryegrass (ARG), sequence profitability was closely related to the efficacy of weed control. Herbicides used to control the ryegrass population were a major input cost and the effectiveness of the management decisions used for the different sequences impacted the year-to-year profitability. One of the key questions addressed was:

Do crop sequences that include a break crop improve the profitability of subsequent cereal crops in the presence of herbicide resistant ARG?

In year 1 the most profitable crops were RR and TT canola which returned gross margins of =$1259/ha (yield = 3.5t/ha), and $1166/ha (3t/ha), respectively. The next most profitable crops were lupins at $683/ha (3.1t/ha), high input wheat at $257/ha (3.2t/ha), the low input wheat at $250/ha (2.0 t/ha), with the brown manure or fallow treatments all having negative returns (-$45 to -$250/ha). In year 2, the treatments with the highest gross margin were canola following fallow or brown manure treatments (> $1000/ha, grain yield avg = 3.5t/ha) with canola following wheat (H) or lupins returning ~$900/ha (3.2t/ha). Over the 3 years, the most profitable sequence was RR canola - wheat (H) - wheat, with an average GM of $883/ha/yr. Sequences with the highest average annual gross margins >$800/ha/yr were treatments that had canola (RR or TT) in year 1, with the next most profitable group having grain lupins in year 1 or canola year 2 (> $600/ha). The third group included sequences of fallow, combinations of wheat (H or L) or lentils in year 1 (soil pH at Eurongilly site was much lower than at the Junee Reefs site), with the final group involving sequences with Bm crops followed by wheat (H or L).

Grain yield, annual Gross Margin and 3-year average Gross Margin at Eurongilly Exp 1.

Break Type	Crop x Input 2012	Crop x Input 2013	Grain Yield 2012	Gross Margin 2012	Grain Yield 2013	Gross Margin 2013	Grain Yield 2014	Gross Margin 2014	**Average 3 yr Gross Margin**
			(t/ha)	($/ha)	(t/ha)	($/ha)	(t/ha)	($/ha)	**($/ha/yr)**
S	RR Canola	Wheat (H)	3.5	$1,259	4.7	$533	4.5	$858	**$883**
S	RR Canola	Wheat (L)	3.5	$1,259	2.8	$489	4.1	$788	**$845**
S	TT Canola	Wheat (L)	3.0	$1,166	4.7	$537	3.8	$828	**$844**
D	RR Canola	Wheat (Hay)	3.5	$1,259	7.4DM	$533	3.7	$709	**$834**
D	Lupin grain	RR Canola	3.1	$683	3.2	$967	4.1	$721	**$790**
S	Lupin grain	Wheat (H)	3.1	$683	5.1	$726	3.9	$863	**$757**
D	Fallow	RR Canola	nil	**-$45**	3.6	$1,159	3.7	$696	**$603**
Nil	Wheat (H)	Wheat (H)	3.2	$257	5.0	$642	4.2	$855	**$585**
D	Lupin Bm	RR Canola	nil	**-169**	3.6	$1,146	4.1	$680	**$552**
S	Pea Bm	Wheat (H)	5.2DM	**-$160**	5.0	$707	4.3	$911	**$486**
S	Pea Bm	Wheat (L)	5.2DM	**-$160**	3.0	$525	3.8	$826	**$397**
Nil	Wheat (L)	Wheat (L)	2.0	$250	1.5	$170	3.3	$745	**$388**

Overall it was found that sequences that involved either canola or a spray topped lupin grain crop in year 1 followed by cereal hay or RoundupReady (RR) canola in year 2 provided the highest gross margins and significantly reduced ARG seed bank over the 3 year crop sequence. Cheaper double break combinations using a fallow or pulse Bm in year 1 followed by RR canola in year 2 resulted in lower gross margins, but were the most effective in reducing the seed bank. Continous low input wheat had the lowest gross margin and the least ryegrass control.

Q.2 Eurongilly Exp 2

The lupin grain yield in 2013 of 2.6/ha resulted in the highest gross margin with a profit: cost ratio of 2.5:1. The wheat (H) grain yield in 2013 was approximately double the wheat (L) yields due to reduced competition from ARG and also double the canola (H) grain yield. However, the wheat (H) and canola (H) grain yields were lower than expected due to the dry October (14mm) and November (7mm) rainfall and high nitrogen inputs. These lower yields combined with the high inputs of nitrogen of 196kgN/ha in both the wheat (H) and canola (H) significantly reduced their respective gross margins in 2013.

The wheat-hay treatment was significantly the most profitable in 2014 with gross margins being two to three times higher than any other treatment. Wheat yield in both the high and low treatments in 2014 were similar at 2.7 and 2.6 t/ha respectively but the protein concentrations were significantly higher in the wheat (H) treatment, 16.4% compared to 14.8% in the wheat (L). Wheat yields were significantly lower than observed in Exp 1 in 2013. The low wheat yields and high protein concentrations were due to the crop suffering from stem frost (40% stems affected) and head frost (10%), which reduced water and carbohydrate transportation and reduced the plant's ability to fill grain. This resulted in screenings of between 14% to 19% in the wheat (L) and wheat (H) treatments respectively. This had a significant negative effect on the wheat gross margins in 2014, especially in the wheat (H) treatment due to the high nitrogen inputs. The RR canola grain yields in 2014 were also lower than in Exp 1 in 2013 (1.7-1.9t/ha *c.f*. 3t/ha in Exp 1) resulting in low gross margins due to high input costs of herbicides and nitrogen.

At Eurongilly Exp 2, the top six sequences in terms of average annual 3 year gross margins included either the hay treatment in 2014 or lupin-grain in 2013 (due to their yearly high gross margins). If we compare the average three year gross margin in experiment 1 and 2, the first main difference is that the canola grain yields and associated gross margins were significantly lower in both the first and second year in crop sequences at Eurongilly experiment 2. The second difference is that the average 3 year gross margin in any sequence that included a wheat (H) treatment, especially in 2014 was very unprofitable. The performance of the low input wheat sequence (Wheat (L) – Wheat (L)) relative to the other sequences in experiment 2 was due to the high costs associated with unused N fertiliser used in high input wheat and canola treatments. The brown manure treatments followed by wheat (H) were the least profitable sequences in both experiments.

Grain yield, annual gross margin and Average 3 year Gross Margin 2013-15 at Eurongilly Exp 2.

Crop x Input 2013	Crop x Input 2014	Grain yield 2013	Gross Margin 2013	Grain yield 2014	Gross Margin 2014	Grain yield 2015	Gross Margin 2015	Average 3 yr GM
		(t/ha)	($/ha)	(t/ha)	($/ha)	(t/ha)	($/ha)	($/ha/yr)
TT canola	Hay	1.6	$348	7.9	$933	3.7	$638	**$640**
RT canola	Hay	1.6	$40	8.1	$962	3.9	$708	**$568**
RR canola	Hay	1.9	$171	7.9	$937	4.3	$587	**$564**
Lupins	Wheat (L)	2.6	$724	2.1	$222	3.4	$696	**$550**
Lupins	Canola	2.6	$724	1.7	$157	4.6	$753	**$543**
Lupins	Wheat (H)	2.6	$724	2.6	$42	4.1	$697	**$487**
Wheat (H)	Wheat (L)	4.0	$359	2.7	$369	3.9	$631	**$455**
TT canola	Wheat (L)	1.6	$348	2.5	$274	4.0	$605	**$408**
Wheat (H)	Canola	4.0	$359	1.7	$163	4.1	$663	**$393**
Wheat (H)	Wheat (H)	4.0	$359	2.8	$118	4.3	$612	**$362**
RT canola	Wheat (L)	1.6	$40	2.5	$307	4.2	$733	**$362**
TT canola	Wheat (H)	1.6	$348	2.7	$23	4.4	$681	**$351**
RR canola	Wheat (L)	1.9	$171	2.5	$309	4.5	$566	**$350**
Wheat (L)	Wheat (L)	2.2	$318	2.1	$129	4.1	$547	**$331**
Wheat (L)	Canola	2.2	$318	1.7	$82	4.4	$550	**$316**
Fallow	Canola	Nil DM	-$72	1.9	$285	4.8	$705	**$305**
Pea Bm	Wheat (L)	5.7DM	-$204	2.9	$421	3.9	$695	**$305**
Fallow	Wheat (L)	Nil DM	-$72	3.0	$442	4.3	$519	**$298**
Wheat (L)	Wheat (H)	2.2	$318	2.7	-$18	3.6	$586	**$297**
RT canola	Wheat (H)	1.6	$40	2.7	$53	4.5	$745	**$279**
RR canola	Wheat (H)	1.9	$171	2.6	$36	4.1	$609	**$271**
Fallow	Wheat (H)	Nil DM	-$72	2.7	$115	4.0	$715	**$253**
Pea Bm	Canola	5.7DM	-$204	1.9	$242	4.7	$634	**$223**
Pea Bm	Wheat (H)	5.7DM	-$204	2.8	$114	4.2	$654	**$188**

For more trial information (including methods) CLICK here

Q.2 Wagga Wagga Exp 1

Gross margin analysis showed that averaged across two phases, the rotation with canola as a single break crop (canola-wheat-wheat rotation) had the highest average gross margin ($529/year) across 3 years (Table 1). Cutting for hay significantly improved the financial returns for the rotations including vetch ($482/year) or pasture ($453/year) as a break crop compared to the brown manure option, which was higher than the continuous wheat with additional N fertiliser. When break crops were brown manured, the gross margin was lower than where grain was harvested due to the loss of income as a result of the brown manuring. The profit/cost ratio was the highest when canola was used as a single break crop (2.8) and the lowest for all brown manured treatments as well as continuous cereal without N input (Table 1). Results indicated that the benefit for subsequent crops from the additional N supplied by the brown manured treatments could not offset the cost of establishment of the break crops and loss of income. Nevertheless, the brown manure option would offer great opportunity to reduce herbicide costs if the paddock contained a high population of difficult to control herbicide-resistant weeds.

In general, double break crop options improved gross margins for all crop management options, particularly for the brown manured options. The gross margin increased more than $100/year when canola was used as a break crop in combination with a brown manure option of pasture or field pea compared with a single break crop rotation (Table 1). Pasture cut for hay followed by one canola crop as a double break crop had the highest gross margin ($524/year), which was much higher than continuous cereals with N fertiliser. Double break crops offer more opportunity to reduce disease incidence as well as more options to control difficult weeds. The improved profitability of the double breaks over the single breaks was largely driven by the higher gross margins received for canola in year 1 versus the wheat treatments. Favourable growing conditions and good prices for canola in the first year of the trial had a large effect on the average gross margins for the various crop sequences.

Table 1. Averaged gross margin analysis under different crop sequences at the Graham Centre site in Wagga Wagga Exp 1.

Treatment	Crop Management	Income	Variable cost	Gross margin	Profit/cost ratio
		Single break			
Pea	Brown Manure	$558	$255	$303	2.2
Vetch		$553	$257	$296	2.2
Pasture		$530	$246	$284	2.2
Vetch	Hay	$825	$342	$482	2.4
Pasture		$776	$323	$453	2.4
Pea	Grain	$695	$287	$407	2.4
Lupin		$682	$279	$403	2.4
Canola		$826	$297	$529	2.8
		Double break			
Pasture	Brown Manure	$664	$271	$393	2.5
Pea		$678	$277	$401	2.4
Pasture	Hay	$853	$328	$524	2.6
Lupin	Grain	$781	$295	$486	2.6
Pea	Grain	$770	$301	$469	2.6
		Continuous cereals			
Wheat +N	Grain	$875	$415	$460	2.1
Wheat –N	Grain	$663	$274	$390	2.4

Crop management had a great impact on the grain yield of the following cereal crops. The pasture brown manure treatment increased grain yield significantly for the first subsequent crops compared to the hay cut treatment (Table 2), but no differences were found between brown manured and hay cut treatments for the second and third crops. However, the residual effect from the pasture could last 2-3 years as evidenced by achieving comparable grain yields with the continuous cereal treatments with N applied (75 kg N/ha). No difference was found in protein under different crop management for wheat and canola following pasture treatments (Table 2). The significant increase in grain yield for the 1st crop was most likely due to extra input of N from N_2 fixation in the brown manured treatment. The hay cut treatment however, improved on-farm profitability.

For the pea crop, the brown manure treatment increased yield of the 1st wheat crop (P = 0.055) compared to responses to the pea harvested grain treatment, but no similar trend was apparent for canola (Table 2). Similar to responses to the pasture treatment, the grain yields from the 2nd and 3rd crops following pea under either brown manured or grain harvested treatment were comparable to the continuous cereal treatments with N applied, although grain protein content was significantly higher after brown manured than the grain harvested treatments. There were no significant differences in grain yield between vetch brown manured and hay cut treatments, but protein contents were significantly higher for the brown manured treatment than on the hay cut treatment for the 2nd and 3rd crops following vetch (Table 2). When lupin was harvested for grain, the rotation with lupin-canola-wheat was more profitable than the lupin-wheat-wheat rotation (Table 2). For the continuous cereal treatment, grain yields were significantly higher on the N applied treatment than that with N applied in the 2nd and 3rd year, but no difference was found in year 4.

Table 2. Crop yield (t/ha) and grain protein content (%) for different crops under different crop management at the Graham Centre site in Wagga Wagga Exp 1.

2011	2012	2013&2014	2011 Crop	Grain (t/ha)				Protein (%)		
Year 1	Year 2	Years 3&4	Management	Year 1	Year 2	Year 3	Year4	Year 1	Year 2	Year 3
Pea	Wheat	Wheat	Grain	2.5	3.5	3.5	3.5	22.2	7.1	6.6
		Wheat	Bm		3.7	4.2	3.5		9.6	8.4
			Significance		*P*= 0.055	*n.s.*	*n.s.*		*P*< 0.01	*P*= 0.066
	Canola	Wheat	Grain	2.5	2.0	3.7	3.5	22.2	38.1	8.3
		Wheat	Bm		2.3	3.7	3.4		39.4	9.6
			Significance		*n.s.*	*n.s.*	*n.s.*		*n.s.*	*P*= 0.069
Vetch	Wheat	Wheat	Hay cut		3.4	3.6	3.5		6.9	6.8
		Wheat	Bm		3.7	3.8	3.6		8.6	8.0
			Significance		*n.s.*	*n.s.*	*n.s.*		*P*< 0.05	*P*= 0.054
Pasture	Wheat	Wheat	Hay cut		3.0	3.4	3.4		6.9	7.0
		Wheat	Bm		3.6	3.7	3.3		8.2	7.5
			Significance		*P*= 0.01	*n.s.*	*n.s.*		*n.s.*	*n.s.*
	Canola	Wheat	Hay cut		1.8	3.7	3.4		37.5	7.7
		Wheat	Bm		2.3	3.7	3.4		38.2	8.4
			Significance		*P*< 0.05	*n.s.*	*n.s.*		*n.s.*	*n.s.*
Lupin	Wheat	Wheat	Grain	2	3.4	3.6	3.5	26.5	7.4	7.4
	Canola	Wheat	Grain		2.1	3.9	3.4		37.3	7.7
			Significance		*N.A.*	*P*< 0.05	*n.s.*	*n.s.*	*N.A.*	*n.s.*
Wheat+N	Wheat+N	Wheat+N	Grain	5.2	3.5	3.6	3.4	10.0	8.3	10.5
	Wheat-N	Wheat-N	Grain		2.4	3.1	3.4		5.9	6.5
			Significance		*P*< 0.05	*P*< 0.05	*n.s.*		*P*< 0.01	*P*< 0.01

n.s., not significant; N.A., not applicable

Q.2 Wagga Wagga Exp 2

Gross margin analysis showed that crop sequences including canola boost gross margins greatly on both weed free and weed present treatments simply due to its high grain price. The average grain prices over 5 years were canola $452/tonne; wheat $225/tonne; lupin $310/tonne and field pea $271/tonne at the farm gate.

When break crops were brown manured, average rotation gross margins ranged from $326/ha to $411/ha per year, which was much lower than those on weed free treatments. However, pasture cut for hay boosted profit with an annual average gross margin was up to $610/ha, which was higher than the continuous cereal treatment with N fertiliser ($576/ha)

Desiccating break crops in general was not a good option to manage weeds at this site apart for canola, possibly due to the high weed pressure competing with crops for water and nutrients during the growing season. The gross margins for desiccated lupin and field peas were under $388/ha, similar to brown manured treatments (see Table below).

Averaged gross margin analysis under different crop rotation sequence undertaken in Wagga Wagga Exp 2.

Crop1	CropMgmt1	WeedMgmt	Crop2	Gross income	Total variable cost	Gross margin	Profit/cost ratio
Canola	Grain	WeedFree	Wheat	$1,078	$375	$703	2.9
Lupin	Grain	WeedFree	Wheat	$847	$356	$491	2.4
Pea	Grain	WeedFree	Wheat	$812	$356	$456	2.3
Lupin	Bmanure	WeedPresent	Wheat	$600	$254	$346	2.4
Pea	Bmanure	WeedPresent	Wheat	$670	$259	$411	2.6
Pea	Bmanure	WeedPresent	Canola	$587	$261	$326	2.2
Pasture	Bmanure	WeedPresent	Wheat	$612	$249	$363	2.5
Pasture	Bmanure	WeedPresent	Canola	$559	$252	$307	2.2
Pasture	Hay	WeedPresent	Wheat	$958	$348	$610	2.7
Pasture	Hay	WeedPresent	Canola	$864	$350	$514	2.5
Canola	Desic	WeedPresent	Wheat	$988	$321	$667	3.1
Lupin	Desic	WeedPresent	Wheat	$660	$278	$382	2.4
Pea	Desic	WeedPresent	Wheat	$677	$289	$388	2.3
Pea	Desic	WeedPresent	Canola	$585	$291	$294	2.0
Wheat+N	Grain	WeedFree	Wheat+N	$971	$395	$576	2.5
Wheat	Grain	WeedFree	Wheat-N	$887	$341	$547	2.6

Q.3 Can a weed problem be managed more cost effectively with break crops than in a continuous cereal system?

- Eurongilly Exp 1
- Eurongilly Exp 2
- Wagga Wagga Exp 2

Q.3 Eurongilly Exp 1

This experiment investigated the effectiveness at reducing seed banks of herbicide resistant annual ryegrass (ARG) through the use of different inputs and herbicides applied to canola, pulse legumes, or wheat crops to answer the question:

Can herbicide resistant ARG be managed more cost-effectively under break crops than cereals?

The seed bank at the site changed from 1815 seeds/m² prior to the commencement of experimentation to between 56 and 3140 seeds/m² at the conclusion of the experiment depending on crop sequence. RR canola in year 1 followed by high input wheat (Sakura® pre-em & post emergent Boxer Gold®) in year 2, and wheat (Sakura®) in year 3 was the most profitable sequence, but was less effective at reducing the seed bank (219 seeds/m²) compared to most double break options (56-142 seeds/m²) with the exception of triazine tolerant (TT) canola followed by cereal hay (300 seeds/m²).

Interaction between crop treatments and ryegrass plant populations.

ARG panicles per m² in the spring year 1 in untreated areas were 1042 (with each panicle containing in the order of 30 seeds), significantly more than the low input wheat with 534 panicles/m². All other treatments in year 1 had significantly fewer panicles than observed in the low input wheat. The most effective ARG control was achieved by fallow, pulse Bm or RR canola (see Table below). By spring in year 2, there were significant differences in panicles/m² with four distinct categories (0-8, 14-71, 192-388 & >643 panicles/m²). Main year 2 treatment effects continued into year 3 with panicles numbers from fewest to most in order of: canola < hay = wheat (H) < wheat (L), and year 1 effects: fallow < pulses < canola = wheat (H) < wheat (L). Interactions were categorised into groups of (0-30, 60-166, 199-370, >536 panicles/m²). Generally, double break sequences or those where high input (H) wheat treatments were grown following treatments with bare soil or less stubble from year 1 had significantly fewer panicles.

By the autumn of year 2, there was a significant three-fold increase in ARG seed bank populations (5492 seeds/m²) following low input wheat (L) and by autumn year 3 a further significant 2.5 fold increase (13148 seed/m²) after a second wheat (L) treatment. Comparatively, seed bank numbers were reduced to 124 seeds/m² where canola (H) 2012 was followed by wheat hay (2013), and double breaks involving legumes, canola, fallow or hay resulted in the lowest seed banks following the 3 year sequences (see Table below). Main effects from year 1 and year 2 treatments were still apparent after the conclusion of the experiment in March 2015, with the year 2 treatments having a greater effect with significantly lower seed bank numbers remaining in order of: canola < wheat (hay) < wheat (H) < wheat (L) (meaned data not shown). The expensive herbicide costs ($142/ha) associated with consecutive high input wheat treatments resulted in a significant reduction in seed bank by November 2014 (366 plants/m²), but was not as effective as sequences involving break crops or a fallow.

In the presence of a high population of herbicide-resistant ARG, sequences that included a break crop were more profitable compared to continuous wheat (H or L). Canola was consistently the most profitable break crop, largely due to the high returns from canola itself, but legume grain crops were profitable and provided additional N for crops in year 2. Although the TT canola / wheat (H) sequence was profitable, it was not as effective at reducing the ARG seed bank and any sequence with wheat (L) resulted in an increase in ryegrass numbers. Break crops or fallow provided cheaper and more effective ARG control options. Two consecutive years of complete ARG control were required to reduce seed banks to managable levels. The most profitable double break sequences were RR canola followed by a cereal hay or grain lupins followed by RR canola with these sequences also very effective at reducing the seed bank. Sequences involving fallows and brown manures reduced production risk in subsequent years due to enhanced yield in the following wheat crops, but were not as profitable as continuous cropping (see also weeds rules-of-thumb in Appendix E).

Average annual gross margin over 3 years compared to ryegrass seedbank (April 2013, 2014, 2015) and ryegrass panicle number (November 2012-2014) in Exp 1 at Eurongilly, NSW.

Crop 2012 pre-treatments are arranged in order of descending SEEDBANK March 2015 seed counts.

Crop x Input 2012	Crop x Input 2013	Ryegrass panicles Nov 2012	SEEDBANK March 2013	Ryegrass panicles Nov 2013	SEEDBANK March 2014	Ryegrass panicles Nov 2014	SEEDBANK March 2015	Average Annual 3yr GM
(Year 1)	(Year 2)	(panicles/m^2)	(seeds/m^2)	(panicles/m^2)	(seeds/m^2)	(panicles/m^2)	(seeds/m^2)	($/ha/yr)
Fallow	Canola	0 (NM)^	290	0	NM	2	56	$603
Lupin grain	Canola	43*	748	0	196	6	63	$790
Lupin BM	Canola	0 (NM)^	152	0	NM	1	110	$552
Fallow	Wheat (H)	0 (NM)^	290	2	NM	10	118	$539
RR Canola	Wheat (Hay)	0	208	0 (537)^	124	23	122	$834
Pea BM	Canola	0 (NM)^	464	0	210	4	142	$513
Lupin grain	Wheat (H)	43*	748	8	312	19	148	$757
Pea BM	Wheat (H)	0 (NM)^	464	2	496	14	162	$486
RR Canola	Wheat (H)	0	208	15	381	29	219	$883
TT Canola	Wheat (H)	32	505	14	NM	82	252	$844
Wheat (H)	Canola	78	777	0	259	20	267	$636
Lupin BM	Wheat (H)	0 (NM)	152	2	NM	11	279	$463
TT Canola	Wheat (Hay)	32	505	0 (790)^	NM	23	300	$844
Wheat (L)	Canola	504	5492	0	797	22	332	$582
Wheat (H)	Wheat (H)	78	777	29	1379	60	366	$585
Wheat (L)	Wheat (H)	504	5492	71	3412	121	523	$537
Fallow	Wheat (L)	0 (NM)^	290	56	NM	100	970	$530
Lupin BM	Wheat (L)	0 (NM)^	152	192	NM	308	1105	$419
Lupin grain	Wheat (L)	43*	748	200	6614	122	1167	$715
Wheat (H)	Wheat (L)	78	777	294	5508	147	2158	$513
TT Canola	Wheat (L)	32	505	383	NM	229	2222	$800
RR Canola	Wheat (L)	0	208	388	7770	200	2387	$845
Pea BM	Wheat (L)	0 (NM)^	464	237	7413	157	3118	$397
Wheat (L)	Wheat (L)	504	5492	898	13148	943	3140	$388
P value (2012)		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
P value (2013)			NA	<0.001	<0.001	<0.001	<0.001	
P value (interaction)			NA	0.004	0.105	<0.001	0.699	

*Lupins spray topped in Nov 2012 prior to ryegrass seed maturity
^Ryegrass panicles estimated at zero in 2012 and 2013 due to either spraying or cutting of hay prior to seed set
NM Not measured

For more trial information (including methods) CLICK here

Q.3 Eurongilly Exp 2

The effect of the various sequences and associated herbicides and competition on ARG control were similar in both of the Eurongilly experiments. The RR and RT canola, brown manures or fallow were very effective at reducing ryegrass plant numbers and associated seedbank. In experiment 2, where wheat (H) was sown before or after an effective break crop, the results were similar to a double break crop. The main exception in experiment 2 was the lupin (grown for grain) treatment which had more ryegrass panicles and dry matter production than in experiment 1. The main reason for this was that the lupins in experiment 1 were spray-topped whereas the lupins in experiment 2 were not, emphasising the value of spray-topping pulses in the presence of a high ryegrass burden (in particular a herbicide resistant population that is not resistant to paraquat).

Ryegrass seedbank and panicle numbers for Eurongilly Exp 2.

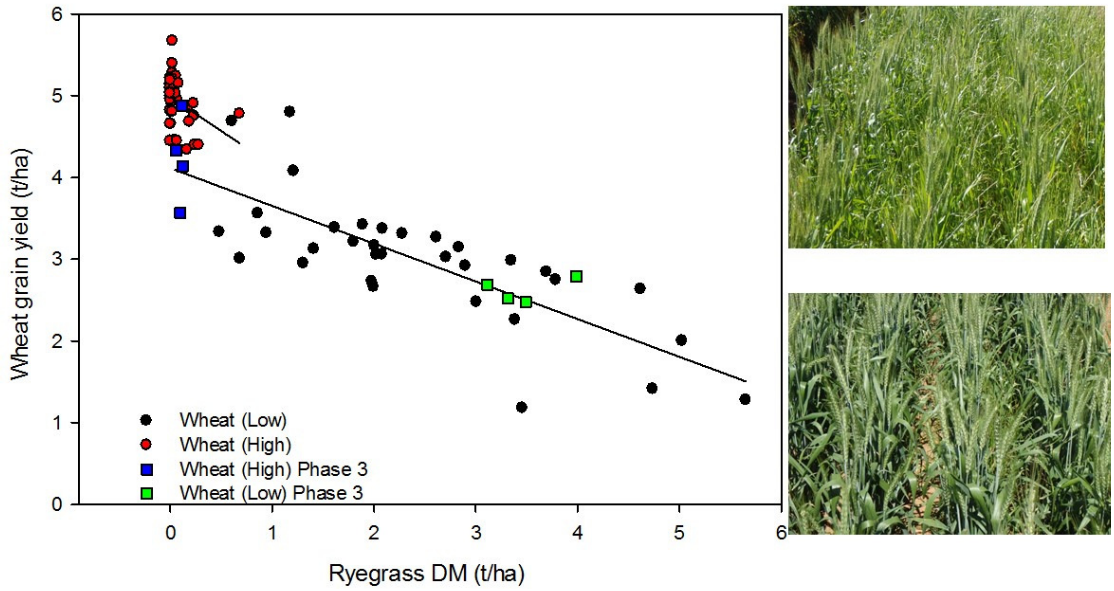
Crop x Input 2013	Crop x Input 2014	Seedbank March 2013	Ryegrass panicles Nov 2013	Seedbank March 2014	Ryegrass panicles Nov 2014	Seedbank March 2015	Ryegrass panicles Nov 2015	Seedbank Feb 2016
Year 1	Year 2	seeds/m^2	panicles/m^2	seeds/m^2	panicles/m^2	seeds/m^2	panicles/m^2	seeds/m^2
Fallow	Canola	2775	0	649	1	408	22	37
RT Canola	Wheat (H)	2775	0	900	2	375	4	58
RR Canola	Wheat (H)	2775	1	670	2	350	3	59
Peas Bm	Canola	2775	108*	897	1	104	10	106
Wheat (H)	Canola	2775	30	1337	1	212	5	115
RR Canola	Hay	2775	1	670	99^	457	15	132
RT Canola	Hay	2775	0	900	78^	197	11	145
Peas Bm	Wheat (H)	2775	108*	897	3	309	8	218
Fallow	Wheat (H)	2775	0	649	2	226	5	223
TT Canola	Hay	2775	193	3358	631^	1004	47	347
Wheat (H)	Wheat (H)	2775	30	1337	6	593	23	363
Peas Bm	Wheat (L)	2775	108*	897	52	729	26	437
RT Canola	Wheat (L)	2775	0	900	23	593	20	520
RR Canola	Wheat (L)	2775	1	670	20	819	10	597
Lupins	Canola	2775	462	4505	1	892	46	638
Fallow	Wheat (L)	2775	0	649	44	1112	39	653
Lupins	Wheat (H)	2775	462	4505	47	1129	61	711
TT Canola	Wheat (H)	2775	193	3358	70	1019	51	826
Wheat (H)	Wheat (L)	2775	30	1337	173	2722	104	1316
Wheat (H)	Canola	2775	534	6748	1	1507	133	1477
Wheat (H)	Wheat (H)	2775	534	6748	130	3216	126	1567
Wheat (L)	Wheat (L)	2775	534	6748	532	4930	167	1693
TT Canola	Wheat (L)	2775	193	3358	166	3415	108	1720
Lupins	Wheat (L)	2775	462	4505	537	4251	152	1951
P value (2013)			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
P value (2014)			NA	NA	<0.001	<0.001	<0.001	<0.001
P value (interaction)			NA	NA	<0.001	0.025	0.037	0.005

* Brown manure treatment was killed prior to ARG setting seed. Effectively zero ryegrass seedset.

^ Hay treatment was cut for hay prior to ARG setting seed. Followup spray with glyphosate.

Lupins were not spray topped in 2013

In both Eurongilly Experiments in 2013, pre- and post-emergent herbicide treatments combined with higher N and P nutrition and increased wheat density (150 plants/m^2 *cf* 75 plants/m^2) in the high input wheat treatments resulted in good control of the annual ryegrass compared to the low input wheat treatment (30 panicles/m^2 *cf* 534 panicles/m^2 and 0.1 t/ha *cf* 3.5 t/ha ryegrass DM). The effect of the high and low input treatments on ryegrass control and ultimately wheat grain yield can be seen in Figure 4. The high input treatment (open symbols) significantly reduced ryegrass DM and increased wheat grain yield. By contrast there was higher ryegrass DM under the low input treatments (closed symbols) resulting in a reduction in wheat grain yield of 450 kg/ha for every 1 t/ha of ryegrass DM regardless of whether the 2013 wheat followed a break crop, brown manure, fallow or wheat in 2012 (see Figure below and weeds rules-of-thumb in Appendix E).



Relationship between ryegrass dry matter (DM) and wheat grain yield following high and low input treatments in wheat at two locations at Eurongilly, NSW

For more trial information (including methods) CLICK here

Q.3 Wagga Wagga Exp 2

The site was established in 2012. All crops were established satisfactorily (Table 1). The ryegrass population was 10-25 plants/m^2 for the weed free treatments, and 71-94 plants/m^2 for the weed present treatments. This result indicated the efficacy of pre-emergent herbicide on ryegrass where there was not a high population of individuals with herbicide-resistance. The ryegrass was further controlled by post-emergent herbicides for the weed free treatments during the seedling stage. The presence of weeds in crops had a great impact on crop DM at anthesis; especially for lupin and pea crops. The crop DM at anthesis was reduced by 35-36% for both lupin and pea when weeds were present compared to the weed free treatments. The weed burden represented 2.2 and 1.5 t/ha in lupin and pea crops; reaspectively. For the more competitive crop, canola, the impact of weeds was much smaller. At harvest, 63% of the lupin and 54% of the grain yield of the pea crop was lost when weeds were present compared with the weed free treatments. Canola yield was also reduced by 19% in the weed present treatment compared to the weed free treatment. There was little response to N by the wheat crop due to a lack of moisture late in the growing season. Neither was there much difference in grain protein between wheat crops with or without N fertiliser application (data not shown).

Table 1. Crop establishment, anthesis DM and grain yield for canola, lupin, pea and wheat crops with and without weed control in Wagga Wagga Exp 2 in 2012

Crop	Weed Mgmt	Establishment			Anthesis DM			Grain yield	
		Crop (Plants/m^2)	Weed impact	Ryegrass (Plants/m^2)	Crop (t/ha)	Weed impact	Ryegrass (t/ha)	Crop (t/ha)	Weed impact
Canola	WeedFree	97		25	7.6		0.3	2.9	
	WeedPresent	103	6%	71	6.5	-14%	0.9	2.3	-19%
Lupin	WeedFree	95		29	8.4		0.0	1.7	
	WeedPresent	76	-20%	71	5.4	-35%	2.2	0.6	-63%
Pea	WeedFree	50		24	6.9		0.0	1.5	
	WeedPresent	52	4%	94	4.4	-36%	1.5	0.7	-54%
Wheat	Wheat+N	141		10	11.9		0.0	4.6	
	Wheat-N	154	9%	10	10.6	-11%	0.0	4.5	-3%

The crop grain yield was variable under different weed and crop management (Table 2). For wheat crops following lupin the weed free treatment had the highest grain yield, whereas the weed present treatment with crop desiccated had the lowest grain yield. By contrast, canola crops following pea with brown manured or crop desiccated treatments had higher yield than weed free treatments. Canola following the pasture brown manured treatment had higher grain yield than the hay cut treatment due to extra N input into soil, but wheat following the pasture brown manured treatment did not show any advantage compared to the hay cut treatment. No N response was detected in 2013.

Table 2. Effects of weed management under different break crops on grain yield of the first crops following break crops in Wagga Wagga Exp 2.

2012	2013	Weed Mgmt	Crop Mgmt	Year 1 Grain Yield (t/ha)	Year 2 Grain Yield (t/ha)	Yield increase
Lupin	Wheat	WeedPresent	Bm		4.2	-7.7%
			Desic	0.6	4.1	-10.9%
		WeedFree	Grain	1.7	4.6	
Pea	Canola	WeedPresent	Bm		1.9	15.6%
			Desic	0.6	1.8	12.9%
		WeedFree	Grain	1.5	1.6	
	Wheat	WeedPresent	Bm		5.0	1.7%
			Desic	0.7	4.6	-5.5%
		WeedFree	Grain	1.5	4.9	
Pasture	Canola	WeedPresent	Bm		1.9	12.9%
			Hay		1.7	
	Wheat	WeedPresent	Bm		4.5	-2.7%
			Hay		4.6	
Canola	Wheat	WeedPresent	Desic	2.5	4.5	-4.2%
		WeedFree	Grain	2.9	4.7	
Wheat +N	Wheat +N	WeedFree	Grain	4.6	4.5	-6.2%
Wheat-N	Wheat-N	WeedFree	Grain	4.5	4.8	

Q.4 What effects do break crops have on soil nitrogen availability?

- Junee Reefs
- Eurongilly Exp 1
- Eurongilly Exp 2
- Wagga Wagga Exp 1
- Ariah Park vetch termination trial

Q.4 Junee Reefs

Even though elevated concentrations of soil mineral nitrogen (N) (i.e. nitrate+ammonium) are frequently observed after legume crops and pastures (Angus *et al* 2015), only a fraction of the N in legume residues remaining at the end of a growing season becomes available immediately for the benefit of subsequent cereal crops (Peoples *et al* 2009). The microbial-mediated decomposition and mineralisation of the N in legume organic residues into plant-available inorganic forms is influenced by three main factors: (i) rainfall to stimulate microbial activity, (ii) the amount of legume residues present, and (iii) the N content (and "quality") of the residues. Field data are utilised to estimate the apparent mineralisation of N from legume stubble, or brown manure (Bm; where a legume is killed with "knock-down" herbicide prior to maturity to provide a boost in available soil N and/or to control difficult to manage weeds). The rate of mineralisation is expressed per mm of summer fallow rainfall, per tonne (t) of above-ground legume residue dry matter (DM), and kg total residue N (i.e. above-ground N + N estimated to be associated with the nodulated roots).

Results from experimentation undertaken in southern NSW indicated that total soil mineral (inorganic) nitrogen (N) measured just prior to sowing wheat in 2012 (0-1.6m) was 42 or 92 kg N/ha greater following lupin grown for either grain or Bm respectively, than following wheat or canola in 2011. The apparent net mineralisation of lupin organic N over the 2011/12 summer fallow was equivalent to 0.11- 0.18 kg N/ha per mm rainfall and 7-11 kg mineral N per tonne lupin shoot residue dry matter (DM). This represented 22-32% of the total estimated lupin residue N at the end of the 2011 growing season. By the autumn of 2013, there was still 18-34 kg more N/ha after the 2011 lupin treatments than non-legumes. This represented an apparent mineralisation of a further 3-4 kg N per tonne of 2011 lupin's residue biomass and 10-12% of its N two years after the lupin had been grown.

Crop growth in 2011

The 2011 growing season rainfall (GSR: April-October) was 216 mm which was lower than the 311 mm long-term average, but heavy rainfall in February 2011 (226 mm) resulted in an annual total of 639 mm, around 130 mm wetter than the long-term average (506 mm). The soil moisture profile at the beginning of the growing season was close to full which contributed to good crop establishment and growth, and respectable grain yields (Table 9). The lupin treatments were calculated to have accumulated a total of 290 kg N/ha (lupin Bm) and 398 kg N/ha (lupin grain crop) of which 241 kg N/ha (83%) and 338 kg N/ha (85%) were estimated to have been derived from N_2 fixation, respectively.

The crop harvest indices (i.e. grain as % of above-ground DM) were 35% for lupin, 43% for wheat and 30% for canola. The N content of the stubble remaining after grain harvest was higher for the lupin crop (1.4%N; C:N ratio=28) than either canola (0.7%N; C:N=60) or wheat (0.3%N; C:N=130), but the shoot material in the lupin Bm treatment had the highest "quality" (2.6%N; C:N=15). The total amounts of N calculated to be remaining in the vegetative residues and roots of the lupin treatments at the end of the 2011 growing season were between 3- to 5-fold higher than where wheat had been grown (Table 1).

Table 1. Above-ground dry matter (DM), crop N accumulation, grain yield and the amount of N estimated to be remaining in vegetative and root residues at the end of the growing season where wheat, canola, or lupin was grown for either grain or brown manure (Bm) at Junee, NSW in 2011[a]

Crop grown in 2011	Peak biomass (t DM/ha)	Shoot N (kg N/ha)	Total crop N[b] (kg N/ha)	Grain yield (t/ha)	Grain N harvested (kg N/ha)	N remaining in residues (kg N/ha)
Lupins Bm	8.4	218	290	0	0	290
Lupins	9.9	300	398	3.5	210	188
Wheat +N[a]	11.1	106	151	4.8 (10.5% protein)	87	64
Canola +N[a]	10.6	164	207	3.2 (46% oil)	94	113
LSD (P<0.05)	1.3				11	22

[a] N fertiliser was applied to wheat @ 49 kg N/ha and canola @ 66 kg N/ha.
[b] Shoot data adjusted to include an estimate of below-ground N (Unkovich *et al.* 2010).

Trends in available soil mineral N, and estimates of N mineralisation in 2012 and 2013

Soil mineral N measured in April 2012 were similar following the 2011 wheat and canola crops (76-77 kg N/ha), but were 42 or 92 kg N/ha greater than after wheat where lupin had been grown for grain or Bm, respectively (Table 2). Apparent net mineralisation over the wet 2011/12 summer fallow (515 mm Sept 2011-April 2012 after Bm, or 386 mm Nov 2011-April 2012 for grain crops *cf* 214 mm long-term average) represented the equivalent of 0.11-0.18 kg N/ha per mm rainfall, 7-11 kg N per tonne residue DM, and 22-32% of the 2011 lupin residue N. Soil mineral N was still 18 or 34 kg N/ha higher in soil in the lupin-wheat sequences than continuous wheat in April 2013 (Table 2), which was equivalent to a further 3-4 kg N per tonne of the 2011 residue DM and 10-12% of the residue N subsequently becoming available. The estimates of apparent mineralisation of legume N calculated from these data in Table 2 represent the net effect of growing legumes for Bm or grain on plant-available soil N regardless of whether the mineral N was derived directly from above- and below-ground legume residues, arose from “spared” nitrate due to a lower efficiency of legume roots in the recovery of soil mineral N, and/or an additional release of N from the soil organic pool (Peoples *et al.* 2009). Although soil mineral N was not determined following grain harvest at the end of the 2011 growing season at Junee Reefs, given that lupin assimilated only 49-60 kg N/ha from the soil (calculated as: total lupin N - N fixed) while 151 kg N/ha was taken up by wheat from the soil and fertiliser, it is likely that some of the additional available soil N measured after lupin could have been unutilised nitrate carried over from the previous season.

Table 2. Concentrations of soil mineral N (0-1.6m) measured in autumn 2012 and 2013 following either wheat, canola and lupin grown for grain or brown manure (Bm) at Junee, NSW in 2011, and calculations of the apparent net mineralisation of lupin N from 2011 expressed per tonne shoot residue dry matter (DM), or as a % of total residue (above+below-ground) N.

Crop grown in 2011	Soil mineral N autumn 2012	Apparent mineralisation of legume N		Soil mineral N autumn 2013	Apparent net mineralisation of legume N	
	(kg N/ha)	(kgN/t DM)	(% residue N)	(kg N/ha)	(kgN/t DM)	(% residue N)
Lupins Bm	169	11	32%	167	3	12%
Lupins	119	7	22%	151	4	10%
Wheat	77	-	-	133	-	-
Canola	76	-	-	115	-	-
LSD (P<0.05)	35			20		

In common with the experiment at Junee Reefs and many previous field experiments where the accumulation of soil mineral after legumes has been compared with wheat (Angus *et al* 2015), legumes grown at five other locations across south-eastern Australia were also found to increase concentrations of available soil N (Table 3).

The measured improvements in soil mineral N, and the derived estimates of apparent mineralisation of legume N, were similar across all five studies (Table 3). As might be expected from the higher N content and lower C:N ratio of the Bm residues and the longer period available for mineralisation to occur (Peoples *et al* 2009), soil mineral N tended to be higher, and the calculated estimates of mineralisation were greater, for Bm treatments than where pulses were grown for grain in the two studies where such comparisons were available (Junee Reefs and Hopetoun; Tables 2 and 3). However, the average measures of mineralisation calculated for the two Bm treatments (0.21 kg N/mm; 11 kg N/t shoot residue DM; 28% residue total N), did not differ greatly from the mean determinations for eight pulse crops harvested for grain (0.18 kg N/mm; 10 kg N/t shoot residue DM; 26% residue total N).

Table 3. Examples of the impact of prior legume crops on additional autumn soil mineral N compared to following wheat, and estimates of the apparent net mineralisation of legume N at different locations in NSW, Vic and SA.

Location and year	Legumes grown for grain or Bm in previous year	Additional soil mineral N	Apparent net mineralisation of legume N		
		(kg N/ha)	(kg N/mm)	(kgN/t DM)	(% residue N)
Breeza, NSW	Chickpea	38	0.14	12	30
1998	Faba bean	47	0.17	18	36
Hopetoun, Vic	Field pea	47	0.17	6	17
2010	Vetch Bm	88	0.24	10	24
Culcairn, NSW	Lupin	61	0.10	11	30
2011	Faba bean	88	0.15	11	27
Naracoorte, SA	Field pea	28	0.23	6	18
2012	Faba bean	42	0.34	10	31
mean		55	0.19	11	27

The relationships between summer fallow rainfall, legume residue DM, or total N, and the subsequent additional soil mineral N measured the following autumn, were generally similar across five different experiments. It was concluded that the average estimates of apparent mineralisation calculated for the pulse grain crops from these five studies could represent useful 'rules-of-thumb' to predict the likely effects of legumes on the N dynamics of dryland cropping systems, although more experimental data should be collated and analysed to ensure the reliability of such determinations. Many more Bm studies are required before an equivalent approach can be recommended for legume Bm treatments as the timing of crop termination will have a large influence on the end result.

Of the three different measures of apparent mineralisation examined here, perhaps the estimate of the additional soil mineral N per tonne shoot residue DM might be the most useful for farmers and their advisors to apply. When data were collated from all the different legume treatments imposed at Junee Reefs and other trials undertaken elsewhere in NSW, in Victoria and SA, there appeared to be a fairly consistent relationship between pulse grain yields and additional soil mineral N the following autumn (see figure below). In this case grain production provided a surrogate measure of overall growth crop productivity during the growing season and would be directly related to the likely amount of crop residues remaining after harvest. Since most pulse crops have a harvest index of around 30-35%, in other words around one-third of the total above-ground biomass is commonly harvested in grain and two-thirds remains in stubble residues. In other words stubble DM can be calculated directly from harvested grain yields (i.e. shoot residue DM [t/ha] = 2 x grain yield [t/ha]). The relationship between pulse grain yield and additional mineral N indicated in the figure below was equivalent to around 15 kg of additional mineral N (compared to the scenario if wheat had been grown rather than a legume crop) for every tonne of legume grain produced. Therefore, the additional soil mineral N (kg N/ha) that on average might be expected to be detected in autumn following a pulse crop could approximate as 15 x harvested legume grain yield (t/ha).

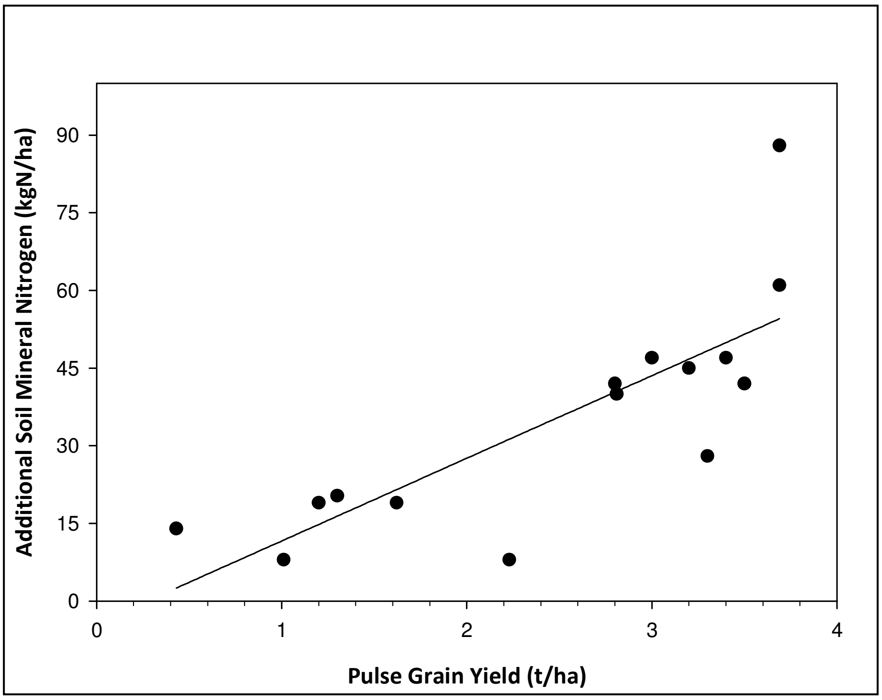


Figure 1 Additional Soil Mineral N (kg N/ha) following pulse crops harvested for grain

For more trial information (including methods) [CLICK here]

Q.4 Eurongilly Exp. 1

Soil mineral N (kg N/ha) values were higher following fallow and legume treatments than where wheat or canola treatments had been grown. Wheat and canola treatments were top-dressed with N fertiliser in Year 1.

Grain yield and soil mineral N at Eurongilly Exp. 1 in the autumn of Year 2

Crop & input Year 1	Grain yield 2012 (t/ha)	Soil Mineral N in April 2013 (kgN/ha)
Fallow	0	250
Peas Bm	0	231
Lupin	3.1	204
Wheat (H)	3.2 (11.5)	172
Wheat (L)	2.0 (11.6)	169
Canola (L)	3	155
Canola (H)	3.5	144

For more trial information (including methods) CLICK here

Q.4 Eurongilly Exp. 2

At the second Eurongilly site, the soil mineral N values were similar to those seen at the Experiment 1 site in that the highest mineral N was found following the fallow and brown manure treatment whilst the lowest mineral N occurred after the canola and wheat treatments. The difference between the two sites occurred with the high input wheat and canola. As previously mentioned (see Eurongilly Exp 2, Q3), there was most likely N fertiliser remaining that the crop didn't have the opportunity to translate into yield in 2013 which may have contributed to the elevated mineral N values.

Grain yield and soil mineral N at Eurongilly Exp. 2 in the autumn of Year 2

Crop & input	Soil Mineral N in April 2014 (kgN/ha)
Fallow	179
Peas Bm	169
Wheat - high	162
Lupin - grain	141
Canola - high	141
Canola - low	118
Wheat - low	82

For more trial information (including methods) CLICK here

Q.4 Wagga Wagga Exp 1

All treatments started with 95 kg N/ha of soil mineral N at sowing. At the end of the growing season, the N balance on the brown manured treatment for all break crops was significantly higher than those harvested for grain (pea) or cut for hay. In the brown manured treatments, the N balance was up to 150 kg N/ha (under vetch). In contrast, the N balance was the lowest with hay cut under vetch and pastures. The N balance of the pea and lupins grain harvested treatments were intermediate (see Table below).

At sowing in year 2, the soil mineral N tended to be higher on the brown manured treatments compared to treatments with product removal for all break crops, but no statistically significant differences were detected except for pea where an additional 42 kg N/ha was measured after the brown manured treatment. At the end of the 2nd crop, the N balance of the canola crop was negative due to more N being removed in the grain that was calculated N inputs, whereas the N balance of wheat following the pea brown manured treatment was estimated to be +62 kg N/ha. The continuous cereal treatment with applied N was calculated to have the highest N balance, but since the supplied fertiliser N would have been more susceptible to loss processes than equivalent N inputs in legumes residues, it is likely that some of the apparent surplus N would have been lost from the system.

At sowing in year 3, the soil mineral N was similar to those at sowing in year 2 regardless of preceding crop treatments. It appeared that the soil mineralisation rate under the canola crop was much faster than under the wheat crop. The soil mineral N was higher for the vetch and pasture brown manured treatments than the hay cut treatments. At harvest of the 3rd crop, the N benefit had been diminished regardless of different crop management. The continuous cereal treatment without N applied had the lowest N balance.

Nitrogen balance over 3 years for different crops under different crop management at the Graham Centre site of Wagga Wagga Exp 1.

2011 Year 1	2012 Year 2	2013 Year 3	Crop Management	Soil MN at sowing	Fertiliser N	N fixed	N removed	N balance at harvest	Soil MN at sowing	Fertiliser N	N removed	N balance at harvest	Soil MN at sowing	Fertiliser N	N removed	N balance at harvest
						Year 1				Year 2				Year 3		
Pea	Wheat	Wheat	Grain	94.7		44.6	83.7	55.6	83.0		43.7	39.3	50.4		41.0	9.4
		Wheat	Bm	94.7		44.6	0.0	139.3	125.1		62.9	62.2	73.9		60.4	13.4
			Signif	N.A.		N.A.	$P<0.01$	$P<0.01$	$P<0.05$		$P<0.01$	*n.s.*	*n.s.*		$P=0.01$	*n.s.*
	Canola	Wheat	Grain	94.7		43.5	94.7	43.6	84.3		123.7	-39.3	108.3		54.7	53.5
		Wheat	Bm	94.7		43.5	0.0	138.2	105.4		148.0	-42.5	99.6		63.8	35.9
			Signif	N.A.		N.A.	$P<0.01$	$P<0.01$	*n.s.*		$P=0.093$	*n.s.*	*n.s.*		$P<0.05$	*n.s.*
Vetch	Wheat	Wheat	Hay cut	94.7		55.7	142.0	8.4	67.2		41.1	26.2	60.9		42.9	18.0
		Wheat	Bm	94.7		55.7	0.0	150.4	114.8		56.2	58.6	106.9		53.5	53.4
			Signif	N.A.		N.A.	$P<0.01$	$P<0.01$	*n.s.*		$P<0.05$	*n.s*	$P<0.05$		$P=0.056$	$P=0.069$
Pasture	Wheat	Wheat	Hay cut	94.7		41.3	103.9	32.1	67.7		37.0	30.7	60.8		42.1	18.7
		Wheat	Bm	94.7		41.3	0.0	136.0	83.5		51.6	31.9	63.2		47.9	15.3
			Signif	N.A.		N.A.	$P<0.01$	$P<0.01$	*n.s.*		$P<0.05$	*n.s.*	*n.s.*		*n.s.*	*n.s.*
	Canola	Wheat	Hay cut	94.7		41.9	106.3	30.3	71.1		107.4	-36.3	63.2		49.9	13.3
		Wheat	Bm	94.7		41.9	0.0	136.6	102.1		143.0	-40.9	117.2		54.9	62.3
			Signif	N.A.		N.A.	$P<0.01$	$P<0.01$	*n.s.*		$P<0.05$	*n.s.*	$P=0.088$		$P=0.062$	*n.s.*
Lupin	Wheat	Wheat	Grain	94.7		47.7	88.7	53.6	81.0		43.3	37.7	79.2		46.5	32.7
	Canola	Wheat	Grain	94.7		40.4	82.9	52.2	72.1		122.7	-50.6	77.6		52.5	25.1
			Signif	N.A.		N.A.	*n.s.*	*n.s.*	*n.s.*		$P<0.01$	$P<0.01$	*n.s.*		*n.s.*	*n.s.*
Wheat +N	Wheat +N	Wheat +N	Grain	94.7	75.0	0.0	90.2	79.5	73.6	75.0	51.0	97.6	89.5	75.0	66.2	98.2
	Wheat -N	Wheat -N	Grain						73.6	0.0	24.7	48.9	43.4	0.0	35.7	7.7
			Signif						N.A.	N.A.	$P<0.01$	$P<0.01$	$P<0.01$	N.A.	$P<0.01$	$P<0.01$

n.s., not significant; N.A., not applicable

Q.4 Ariah Park vetch termination trial

A vetch trial was established in 2014 at Ariah Park to investigate the impact of different end uses of vetch on subsequent wheat crops. Vetch was either harvested for grain, brown manured (Bm) or cut for hay. Grain and Bm plots were then split in two for grazed and ungrazed treatments. In year 1, despite the vetch accumulating between 3-4 t above-ground DM per ha, grain yields were low at ~0.5 t/ha in both grazed and ungrazed treatments. A later than optimum sowing date (May 24th) and a dry end to the growing season contributed to the poor yields. In this case, there was no yield penalty from grazing (200-300 kg vetch DM removed/ha) in either the vetch (Year 1) or the wheat (Year 2).

In year 2 (2015), soil and plant measurements were taken to assess the differences treatments had on the subsequent wheat crop. There were no significant differences in soil mineral N (0-160 cm), plant establishment numbers or NDVI measures. However, there were significant differences in grain yield and protein at harvest (see Table below). Where the vetch was cut for hay there was a reduced wheat grain yield and protein. Conversely, higher grain yields and protein were seen in the Bm treatments. Similar results were seen for hay treatments in a vetch end use trial conducted at Birchip in 2012.

Wheat attributes measured at Ariah Park in 2015 after different vetch end use treatments in 2014

Treat	**Grain Yield** (t/ha)		**Protein** (%)		**Heads/m^2**		**Tiller wt** (g DM)
Bm Only	4.97	*a*	11.4	*a*	423	ab	3.0
Grain Only	4.95	*a*	9.73	*b*	394	bc	3.1
Graze & Bm	5.04	*a*	11.8	*a*	461	a	2.7
Graze & Grain	4.78	*ab*	10.6	*b*	352	c	3.4
Hay Cut	4.56	*b*	9.90	*b*	367	bc	3.1
P value	0.017		<0.001		0.025		0.22
lsd (P=0.05)	0.2723		0.931		66.35		NS

Simulation Case Study

Lockhart simulation modelling example

Comparisons of the long-term financial outcomes of crop sequences with and without break crops

The results of crop sequencing experiments are strongly affected by season type. For instance, in the experiments conducted at Hopetoun, Junee and Eurongilly, crop sequences featuring canola have been particularly profitable due to the seasons over which these experiments were conducted being particularly suited to canola (large amounts of stored soil water at sowing and sowing opportunities in April). Also, crop sequence experiments are unable to capture the long-term dynamics of weed seed banks and soil N, factors which drive break crop selection and profitability. In order to overcome this limitation, we have established a simulation framework to extend our experimental results over multiple seasons and long term sequences. A description of this is presented below based on an example from Lockhart in southern NSW.

Several continuous croppers in the Lockhart district have started using field pea brown manures (Bm) on large areas of their farms (up to 25%) in order to reduce the weed seed bank of wild oats and ryegrass, to improve soil N availability, and to accumulate soil water to reduce the production risk of canola. Whilst they have adopted this practice with conviction (Rural Management Strategies clients had 5,000 ha under field pea brown manure in 2012), questions remain as to the relative economics of the strategy compared to continuous canola-wheat rotations. Simulation over multiple seasons using locally relevant crop management and financial data provides a useful means for answering these questions.

APSIM 7.4 was used to simulate the different crop sequences over a 16 year period based on local soil types, climate data, and regionally relevant management rules developed in consultation with local advisors and growers (Table 1). Simulations were phased such that each crop type was grown in every year of the simulation. Outputs from these simulations provide a quantification of seasonal variability in crop yield and crop sequence response. APSIM outputs were then used to parameterise the stochastic version of the Land Use Sequence Optimiser (LUSO), which is able to simulate grass weed dynamics under the different crop sequences. LUSO was also run with each crop type grown in every year, and output was analysed over a 16 year sequence.

In the Lockhart example, a crop sequence of brown manure field peas followed by canola and then 2 wheat crops (Bm-C-W-W) was compared to the conventional sequence of canola followed by 2 wheat crops (C-W-W) with all N provided by fertiliser. Growers in the Lockhart district wished to know whether the extra N fixed by the field peas, and the grass weed control afforded by brown manuring and a double break were able to compensate for the loss of income for 1 year.

Results of the APSIM-LUSO simulation indicate that C-W-W is only marginally more profitable over a 16 year sequence compared to Bm-C-W-W ($3,100/ha vs $3,273/ha; Fig. 1). The loss of income from one quarter of cropped land being in brown manure is compensated for by a higher average canola yield (1.8 t/ha vs. 1.6 t/ha), higher average wheat grain quality (APW vs. ASW) and lower average annual N fertiliser costs ($109/ha vs. $159/ha). Perhaps counter-intuitively, the brown manure system is more profitable in higher yielding seasons (e.g. 2005, 2010) because the N provided allows canola, and to a lesser extent wheat crops, to yield closer to their water limited potential, without the risk incurred by applying N as fertiliser.

Table 1. Management inputs for the different crop types used in the Lockhart APSIM-LUSO analysis. It was assumed N that fertiliser price = $1.4 per kg N for all crop types.

Parameter	Field pea brown manure	Canola	Wheat
Sow date	20-May	15-Apr to 1-Jun following 25 mm of rain over 3 days	1-May to 1-Jun following 15 mm of rain over 3 days
Variety	Morgan	Mid (e.g. Gem)	Mid (e.g. Gregory)
Density (plants/m²)	40	40	100
N fertilizer	Nil	28 kg/ha N at sowing in Bm-C-W-W sequence and 60 kg/ha N in C-W-W sequence	Top-up to 90 kg/ha on 15 July
Costs excluding N, interest and tax ($/ha)	$153	$246	$253
Grass weed survival (%)	0. 006	0.3	0.55

Grain price	NA	$500	$280 (APW) in Bm-C-W-W and $250 (ASW) in C-W-W reflecting higher protein from APSIM simulations

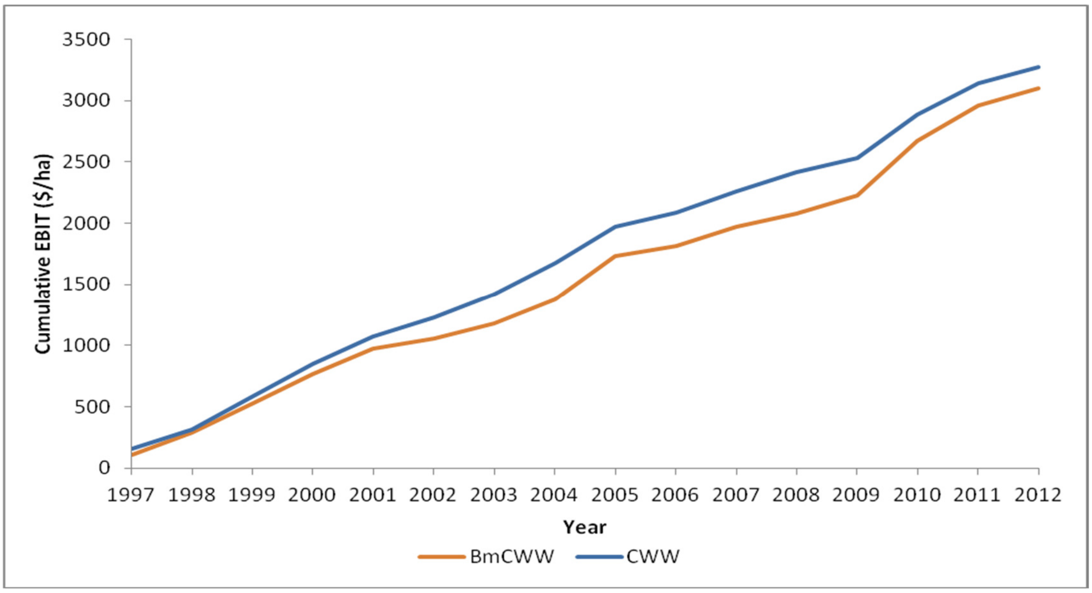


Figure 1. Cumulative earnings before interest and tax (EBIT) from 1997-2012 under the different crop sequences.

The Bm-C-W-W sequence is also much more sustainable than the C-W-W sequence, being able to keep grass weed seed banks at a low level. Grass weed pressure begins to reduce the profitability of the C-W-W sequence at the end of the 16 year period (Fig. 2).

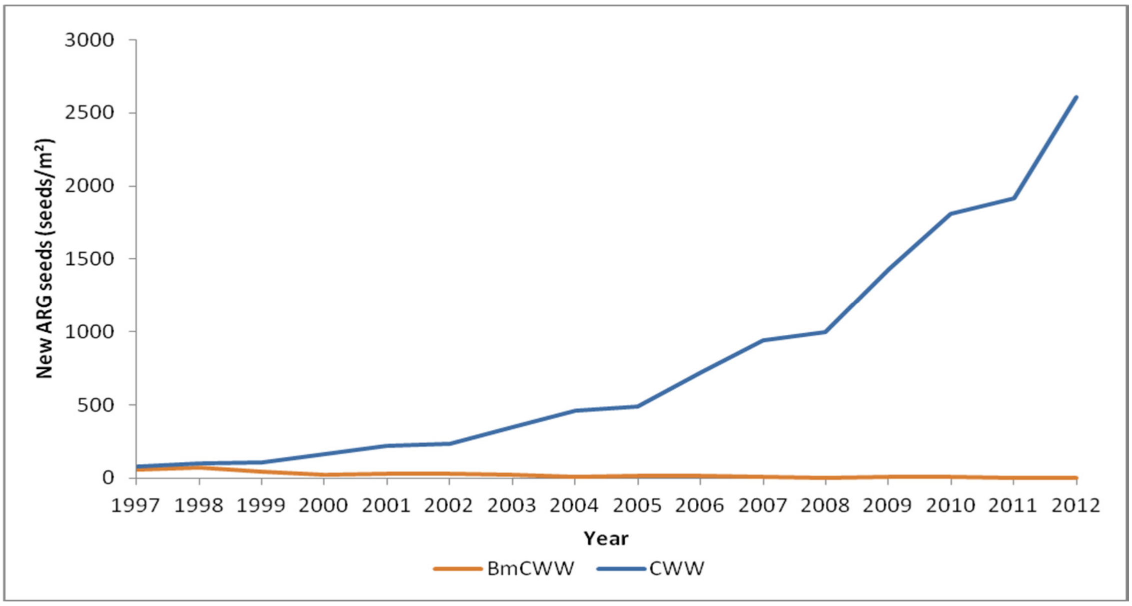


Figure 2. New annual ryegrass seeds contributed to the soil seed bank in each year from 1997-2012 under the different crop sequences.

Lockhart and Ariah Park residue incorporation experiment

Increasing adoption of brown manuring is being driven by the emergence of herbicide-resistant weeds on continuous cropping farms. Paddock-scale replicated strips of fallow *vs* field pea brown manure, or standing vs incorporated brown manure treatments were imposed by farmers on properties at Lockhart and Ariah Park, NSW in 2012. At the time of spray-out at Lockhart only 2.6 t/ha of pea shoot biomass had accumulated, representing a total N input (shoot + nodulated root) of ~117 kg N/ha, of which 69 kg N/ha was fixed. By comparison the field pea at Ariah Park had accumulated 4.4 t/ha of shoot biomass, representing a total N input of 200 kg N/ha, of which 88 kg N/ha was fixed. Subsequent measurements were confounded due to summer weed escapes 2012/13.

The brown manure treatment reduced grass weed incidence compared to long fallow at Lockhart in 2013 and increased soil mineral N by ~30 kg N/ha, but yield maps suggested 0.26 t/ha higher canola grain yields following long fallow as a result of an additional 20-30 mm stored moisture under the long fallow treatment in the drier than average 2013 growing season.

Irrigated Cropping Council

Q1. Can a break crop be as profitable as a cereal?

- Kerang

Q.1 Kerang

A total of 160 different rotational combinations between wheat, barley, canola, faba bean and fallow have now been assessed in the irrigated trial run by ICC at Kerang between 2010 and 2013. Gross margins have been calculated on all crops using the cash price at harvest, and taking into consideration the varied input costs resulting from the previous rotation. Irrigated break crops proved to be profitable in their own right. Faba beans were the most profitable crop in 2013 ($1797/ha) and canola in 2010 ($1500/ha).

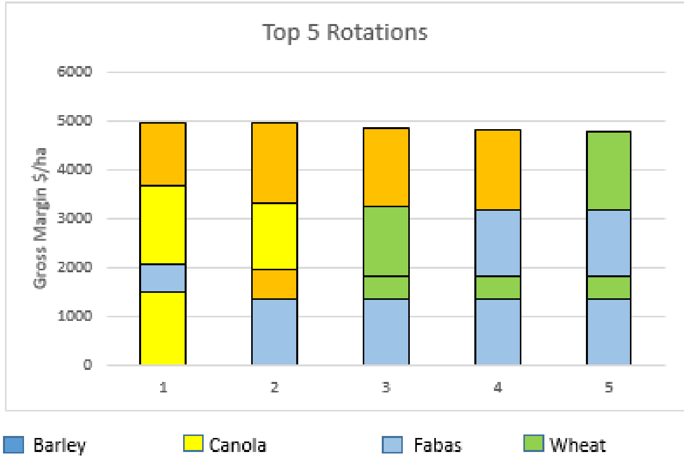
Q2. Are sequences including break crops more profitable than continuous wheat?

- Kerang

Q.2 Kerang

The top 5 cumulative gross margins over 4 years ($4,783-$4,964) have involved at least one break crop in the sequence. The best performing rotation was barley on canola on faba beans on canola. Three of the top 5 rotations featured 2 break crops in the sequence. One major influence on profit has been in the amount of fertiliser N required to meet target yield budgets in the cereals. The trend has been a savings in N required after faba beans, as well as sometimes achieving a higher quality (and hence price) in wheat after fabas. The other major influence has been the fluctuation in grain prices. Comparing 2011 and 2013, average barley gross margins were $640/ha and $1174/ha respectively.

Worst performing crops were wheat after 4 years of cereals on cereals. Rotations involving wheat after barley (3.2 t/ha) or wheat (3.5 t/ha) suffered from reduced grain yields as a result of crown rot. This compares to an average yield in the wheat plots, following either canola or faba bean of 6.9 t/ha.



Of course $/ha is only one consideration for selecting a rotation – N balance, weeds, herbicide rotation, commodity price, irrigation allocations and layouts all play a part in the final decision.

Q.3 Can a weed problem be managed more cost effectively with break crops than in a continuous cereal system?

- Kerang

Q.3 Kerang

Broadleaf weeds in break crops - While grass weeds became increasingly difficult to control in continuous cereal treatments with many of the experimental plots having large resistant ryegrass burdens, broadleaf weeds were also difficult to manage within break crops. The herbicide tolerant canola varieties certainly provide in-crop control options (watering up canola almost excludes the use of pre-emergents), but broadleaf weed control is more problematic with pulses. This is particularly obvious in the faba plots where the build-up of prickly lettuce has highlighted concerns about the limited in-crop broadleaf weed control options in faba beans.

Q.4 What effects do break crops have on soil nitrogen availability?

- Kerang

Q.4 Kerang

At the ICC trial site at Kerang Vic, an irrigated faba bean crops accumulated an estimated 20 t DM/ha and yielded 5.6 t/ha of beans in 2010. Despite the site being flooded post-harvest, the pre-sowing measurements in 2011 indicated concentrations of soil mineral N around 100 kg N/ha higher following faba bean than where wheat or canola had been grown in 2010. The increased N availability after the large 2010 faba bean crop did not appear to persist into the 2nd year since pre-sowing soil mineral N in 2012 was found to be similar following both the faba bean-wheat and canola-wheat sequences (88 and 80 kg N/ha, respectively).

Similar results were observed in 2014 where soil mineral N (0-60cm) was higher where faba bean had either been brown manured in September (153 kg N/ha) or October (153 kg N/ha) or harvested for grain (84 kg N/ha) compared to after cereals (37 kg N/ha).

Deep Soil N Results (0-60 cm) - Soil Nitrate (kg N/ha)

	After Canola	After Fabas	After Wheat	After Barley	After Fallow
2011	69	160	45		
2012		126	81	79	99
2013	47	156	55	47	
2014		84	37		

Case Studies

- Numurkah and Ardmona

Numurkah and Ardmona

Full paddock analyses of two farms at Numurkah and Ardmona were monitored. Although having different philosophies regarding rotation, both farmers include oilseeds, cereals and legumes in their crop sequences. Both are maintaining profitable systems and paddock soil N analyses show elevated mineral N after legumes, resulting in decreased N fertiliser applications in following crops. After initial problems with disease susceptibility and unreliable yields, faba beans have become more popular in the irrigation rotation, with many of the other traditional dryland legume crops unable to tolerate the waterlogging irrigation brings. Local areas of irrigated faba bean have increased from 1,000 to ~10,000 ha over the course of the project. Grain yield, averaged across 60 paddocks of commercial faba bean in 2014, was 4.4 t/ha with a gross margin value of around $475/t.

As the figures are supplied by the case study irrigators, the values for each operation varied and the treatment of cash costs and non-cash cost (e.g. an allowance for repairs and maintenance). The gross margin analysis at Ardmona only considered the cash costs.

Rotations and Gross Margins -Presented below are summaries from irrigator's paddocks at Numurkah and Ardmona in Northern Victoria.

The Numurkah rotation is Fabas – Canola – Wheat – Barley. As discussed in the Kerang trial results, the faba beans and canola, while break crops, can be quite profitable in their own right. By having the two break crops together, there is also a good opportunity to manage the weeds (i.e. two years of grass control in the broadleaf crops then two years of broadleaf weed control in the cereals). The inclusion of fallow at Numurkah due to the paddock requiring laser grading and a failed crop of faba beans was due to late pre-irrigation and hence late sowing and poor establishment leading to a crop not worth harvesting (and a negative gross margin in reality).

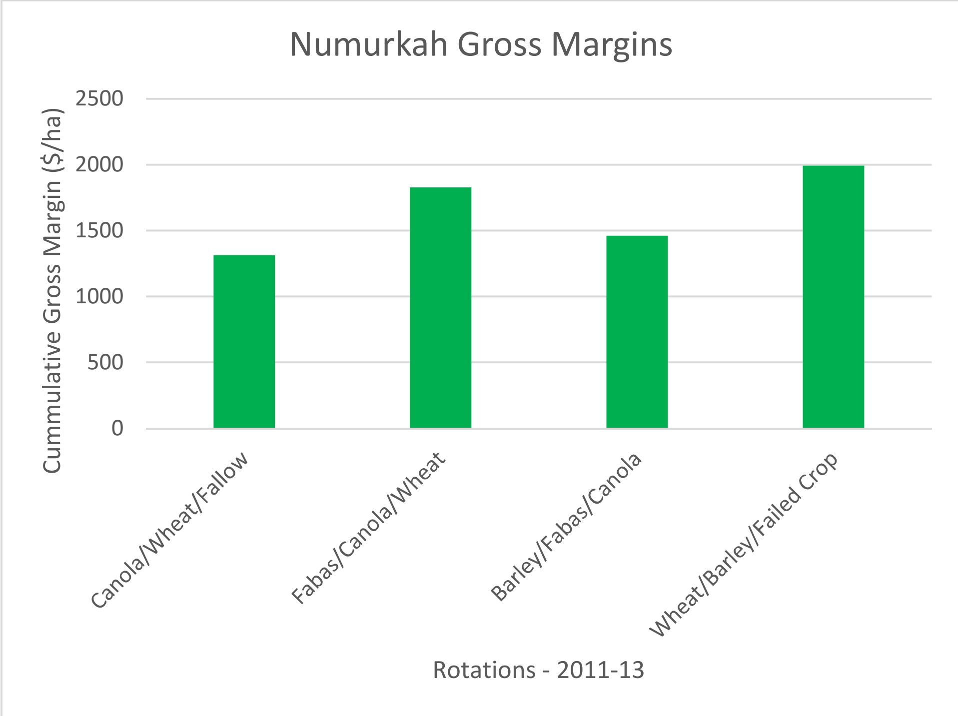


Figure 1 Cumulative Gross Margins for Rotations at Numurkah (2011-2013)

One major difference between the two farms was the inclusion of summer cropping at Ardmona. This added a substantial amount to the per hectare return over the monitored period. Soybeans in 2012/13 returned $737/ha and maize in 2011/12 returned $1400/ha.

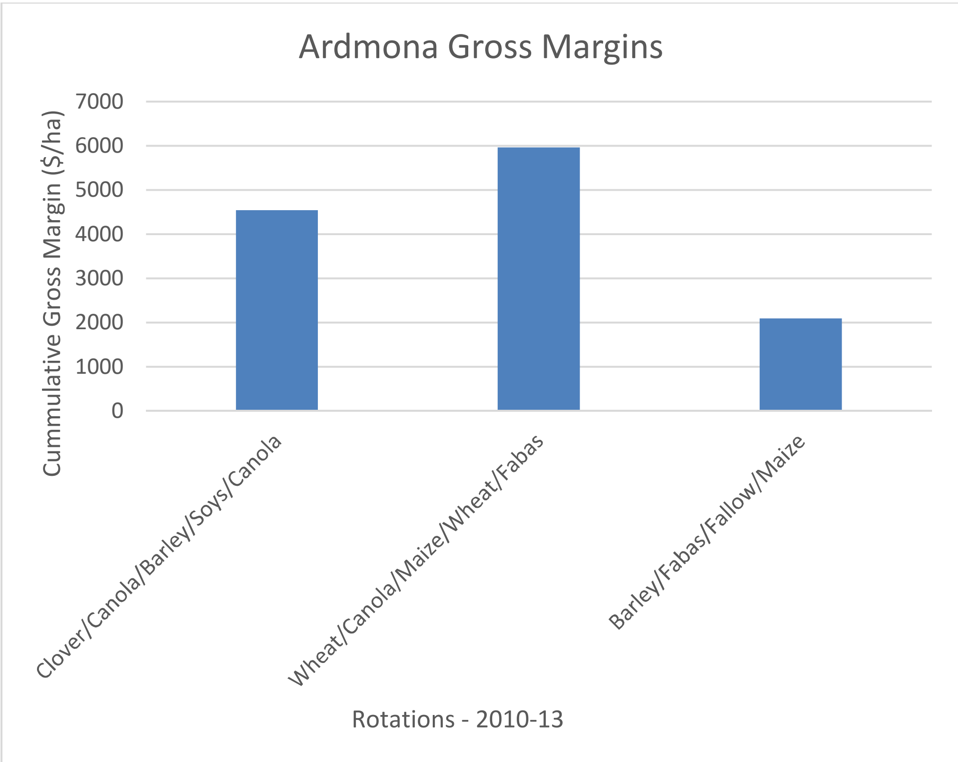


Figure 2 Cumulative Gross Margins for Rotations at Ardmona (2011-2013)

Nitrogen - As well as following the gross margin, the project tracked N under the crops. The starting soil mineral N at the beginning of the season (0-60cm) for different rotations at Ardmona is indicated below.

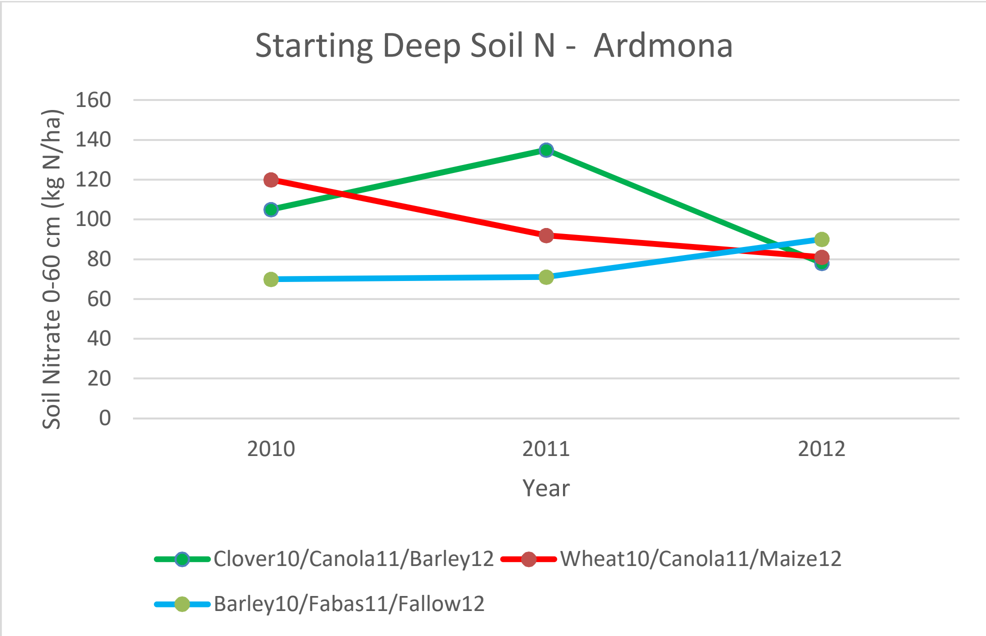


Figure 3 Starting soil mineral N at Ardmona (2010-2012)

While the general trend of what legumes can do for soil N is illustrated above, there are seasons where the expected increase in soil N prior to sowing is not realised. This is because the faba bean stubble from the previous season needs to be broken down or mineralised before the N for the next crop is available. In summers with low rainfall, mineral N levels prior to sowing can be quite low but will improve in-crop as moisture becomes available and the soil microbes can start to breakdown the stubble.

The Ardmona rotations work on building soil N and then using it with crops of decreasing N requirement. The Ardmona crop choice has used pasture, faba beans, fallow and fertiliser (with the maize crop) to manage soil N availability.

The Numurkah rotations follow a similar sequence to those at Ardmona in that the system builds up soil N levels and then use crops of decreasing N requirement. Numurkah rotations follow a simpler sequence – Fabas then Canola, then Wheat then Barley. This system effectively builds up the soil N with fabas then runs it down over time with what is considered an N hungry canola crop (although this assumption will be challenged below) and finishing with a lower N requirement crop in barley.

Using the paddock yields from 2012 (a better year with less complications from late sowing and waterlogging), each crop's N demand can be calculated from the actual yield by the N requirement per tonne. From this we get:

Canola	2.7 t/ha x 60 kg N/t	= 162 kg N/ha
Wheat	6 t/ha x 40 kg N/t	= 240 kg N/ha
Barley	6 t/ha x 30 kg N/t	= 180 kg N/ha

While canola is the crop with the highest N requirement **per tonne of grain**, the overall requirement **per hectare** is less than the other cereals. Even if we use 80 kg N/t for canola, the demand per hectare is still below that of wheat. There are other benefits of having two “break crops” in a row associated with weed control and disease suppression, but from an N perspective, perhaps wheat should be first in line in an irrigated cropping environment.

MacKillop Farm Management Group

A three phased experiment was run in Naracoorte SA, with a series of break options and cereal treatments sown in Year 1 of each phase. The first phase (Experiment 1), established in 2011 and the second phase (Experiment 2), established in 2013 are shown here to illustrate the key learnings from the trials.

In Year 2 for each of the trials, break crop and cereal treatments were all sown to wheat. The first phase (Experiment 1) had two times of sowing and four different N rates and the second phase (Experiment 2) had one time of sowing and eight different N rates. In the third and final year of each of the phases barley was sown and managed the same across all Experiments and plots.

The reason for the repeatability of the trial over three years was to capture variations in seasonal conditions and markets. It must be noted that 2014 and 2015 seasons experienced below average rainfall from July to October. August and September 2014 and September 2015 were in the 10th percentile for rainfall and October 2015 was the driest on record.

Monthly rainfall (mm), long-term rainfall (LTR) (mm) and growing season rainfall (GSR) March to October (mm), for 2011-15 at the Lochaber trial site.

(Naracoorte (View Bank) Station 26104 (36.85°S, 140.56°E, 42 m elevation) accessed online from Australia Bureau of Meteorology (http://www.bom.gov.au)).

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual	GSR March-October
2011	64.8	67.4	83.0	22.0	38.4	58.8	95.6	64.6	53.8	30.8	29.0	28.0	636.2	447.0
2012	4.2	1.6	27.4	18.2	36.8	94.2	66.0	80.8	33.6	26.0	11.8	17.4	418.0	383.0
2013	0.6	10.4	16.6	18.2	50.4	60.4	102.0	101.2	61.2	55.8	18.0	13.6	508.4	465.8
2014	26.2	0.8	14.0	38.4	38.0	84.0	68.8	21.0	16.4	11.0	20.0	10.8	349.4	291.6
2015	62.0	2.0	9.0	26.6	48.2	28.4	49.0	35.4	25.2	3.4	23.7	-	-	225.2
LTR	26.5	18.5	24.9	28.5	39.8	58.3	74.2	63.1	43.6	30.0	32.7	38.1	433.3	362.4

Q1. Can a break crop be as profitable as a cereal?

This research project has shown that various break crops can be as profitable as wheat. In all three years of experiments subclover (hay) returned a higher gross margin than wheat (grain) and in two of the three years this increase in financial return was significant (see Tables below). Beans and winter sown peas also had significantly higher returns compared to wheat grain in two of the three years. Safflower tended to have similar returns as the wheat grain treatment.

The canola treatment returns were variable over the three years. In Experiment 1, canola grain had a significantly higher return then wheat grain. In the other two years wheat grain had a higher (although not significant) return compared to canola grain. In Experiment 1, canola grain had a higher yield, 2.3 t/ha, compared to Experiment 2, which was 1.7 t/ha (see Tables below). A big difference between Experimental years was the commodity price for canola grain, ranging from $500/t (2011), $540/t (2012) and $490/t (2013). Therefore the variation in canola returns was in part driven by the volatility of the commodity price. Variations in input costs, due to seasonal factors also contributed to differences in returns between years.

Over the life of the project the spring sown barley and pea crops were not as profitable as wheat.

- Naracoorte Experiment 1
- Naracoorte Experiment 2

Q.1 Naracoorte Experiment 1

The results from the first year (2011) of Experiment 1 (see Table below) show that there were many treatments that were more profitable than wheat in a single year. In fact, the only treatments that were less profitable than wheat were those that were spring sown instead of winter sown. Subclover was by far the most profitable treatment, with a gross margin three times that of the wheat treatments.

Experiment 1, YEAR 1 (2011) break crop yield/dry matter (t/ha) and Gross Margin ($/ha).

Arranged in descending order of Gross Margin

Break Crop Sown 2011	YEAR 1 2011 Yield t/ha	YEAR 1 2011 biomass t/ha	YEAR 1 2011 Gross Margin ($/ha)
Subclover (hay)	-	7.6	1051
Canola (grain and graze)	2.2	1.1	690
Canola (grain)	2.3	-	678
Peas (winter sown)	3.3	-	635
Beans	2.8	-	528
Canola (hay)	-	8.4	343
Wheat (grain)	3.8	-	336
Wheat (grain and graze)	3.7	0.5	336
Safflower (spring sown)	1.4	-	307
Wheat (0.3 m rows)	3.4	-	301
Barley (spring sown)	3.0	-	198
Peas (spring sown)	1.6	-	86
P value	<0.001	-	<0.001
l.s.d (P<0.05)	0.7	-	145

Q.1 Naracoorte Experiment 2

Table 3 highlights that in a different growing season (2013) (compared to 2011 in Experiment 1), there were again many treatments that were more profitable than wheat in a single year. In 2013, the trends in profitability were similar to that in 2011 except for the canola treatment. The canola treatment was less profitable than the wheat due to different seasonal conditions. The canola yields were lower and input costs were higher due to greater weed and insect pressure than in 2011. However, it remained more profitable than the spring sown options. These differences highlight the importance of multi-year comparisons to capture seasonal variability.

Experiment 2 YEAR 1 (2013) break crop yield/dry matter (t/ha) and gross margin ($/ha)

Break Crop Sown 2013	YEAR 1 2013 Yield t/ha	YEAR 1 2013 DM t/ha	YEAR 1 2013 Gross Margin ($/ha)
Subclover	-	10.4	1097
Beans	3.8	-	934
Peas (winter sown)	4.5	-	922
Wheat (grain)	3.9	-	419
Canola (grain)	1.7	-	180
Peas (spring sown)	1.7	-	178
Barley (spring sown)	1.8	-	69
P value	<.001	-	<.001
l.s.d (P<0.05)	0.9	-	447

Q2. Are sequences including break crops more profitable than continuous wheat?

Across all seasons (over a three-year period) the most profitable rotations tended to be those where initially a break crop was utilised, compared to continuous cereals. The sequences that included winter legume species as break crops were more profitable than continuous wheat across all years.

Based on 75 kg N/ha being applied on the year 2 wheat crop, subclover (hay) was the most profitable break crop option over the life of the project, being the most profitable rotation across all Phases. Peas - winter sown and beans were the next most profitable, followed by canola grain, all more profitable than continuous cereal rotations. The spring sown break crops were not as profitable as continuous cereals.

The benefit of a break crop was emphasized when the following wheat crop was sown early (before wheat on wheat rotation) in the seeding program.

When evaluated the canola and wheat 'grain and graze' treatments suffered no yield penalty post grazing when grazed within the 'safe' period. Grazing of these crops should follow best management guidelines.

Overall disease levels were low during the trials, but the results highlight the potential for cereal on cereal rotations to have an increased risk of take all, root rot and crown rot.

Of the break crops safflower had the highest plant available water capacity, giving it a greater ability to extract soil water moisture from the profile. This capacity tended to have a negative effect on subsequent yields and quality.

Water use efficiency of the wheat crop tended to be greater following a winter sown pea, bean and subclover break crop, although post break crop harvest soil moisture levels tended not to vary between break crops.

- Naracoorte Experiment 1
- Naracoorte Experiment 2

Q.2 Naracoorte Experiment 1

Cumulative gross margins, for Experiment 1, are presented in the Table below, with a significant interaction between 2011 break crop and gross margin recorded. The highest gross margin on average was $2278 with the break crop subclover hay, which is significantly higher than all other gross margin averages. Peas - winter sown and canola - grain were the next best performing treatments on average. The wheat on wheat treatments performed between $1245/ha - $1127/ha, similar to the safflower and spring sown barley treatments.

Over the two year rotation, at the 75 kg N/ha treatment, the sub clover cut for hay returned the highest gross margin - $2264/ha; this was higher than all other treatments. Peas – winter sown, and canola – grain, had the second highest gross margins. Peas – winter sown had an increase of $549/ha in gross margin compared to spring sown peas. The lowest gross margins tended to be the cereal on cereal treatments.

Cumulative gross margin ($/ha): Experiment 1 YEAR 1 (2011) break crop + YEAR 2 (2012) wheat TOS 1 (2012 N application rate x 2011 break crop).

Cumulative gross margin ($/ha) – YEAR 1 2011 break crop + YEAR 2 2012 wheat TOS 1					
Break Crop	YEAR 2 2012 wheat N application rate				
Sown 2011	25	50	75	100	
Sub clover (hay)	2248	2357	2264	2243	**2278**
Peas (winter sown)	1952	1871	1902	1736	**1865**
Canola (grain)	1827	1850	1881	1834	**1848**
Canola (grain and graze)	1758	1795	1739	1808	**1775**
Beans	1638	1593	1609	1614	**1614**
Canola (hay)	1484	1403	1384	1423	**1424**
Peas (spring sown)	1422	1258	1353	1293	**1332**
Wheat (0.3 m rows)	1159	1329	1362	1129	**1245**
Barley (spring sown)	1187	1236	1152	1220	**1199**
Wheat (grain and graze)	1178	1147	1202	1183	**1178**
Wheat (grain)	1156	1134	1087	1129	**1127**
Safflower (spring sown)	1201	1124	1082	1092	**1125**
	1518	**1508**	**1501**	**1475**	
	P value	l.s.d (P<0.05)			
2012 N Treatment	0.189	NS			
2011 Break Crop	<0.001	96			
N Treatment X Break Crop	1.000	NS			

Over the three-year rotation, on average the TOS 1 gross margins were significantly greater than TOS 2, $2857/ha compared to $2720/ha. The 2011 break crop had a significant interaction with the cumulative gross margin, with the most profitable break crop on average being sub clover at $3608/ha over the three year rotation, and the least profitable was wheat - grain at $2354/ha. Nitrogen application rate did not significantly interact with the cumulative gross margin. The most profitable rotation was - subclover X wheat + TOS 1 + 50 kg N/ha X barley, $3827/ha.

Q.2 Naracoorte Experiment 2

In the second year of Experiment 1 (2012) and Experiment 2 (2014) there was no significant interaction between wheat yield and N rate application; therefore applying additional N didn't increase yields in these Experimental years (data in full report). The higher rates of N are likely to have required more and better timed growing season rainfall to have had a greater N response. In Experiment 2, this was reflected in the gross margins, with the added input cost of N and no increase in wheat yields significantly decreasing returns.

Local farm practice considers 75 kg N/ha (i.e. Year 2 wheat treatment) as standard management and as such the three year cumulative gross margins for these treatments only are shown in the table below. There was a strong trend to indicate that the 3 winter sown legume treatments had a much higher cumulative 3-year gross margin than all other treatments. As there were no differences in Year 2 and Year 3 gross margins the large variation is attributed to the large differences in Year 1 gross margins.

Experiment 2 YEAR 3 (2015) barley yield (t/ha), gross margin ($/ha) and cumulative gross margin (2013 + 2014 + 2015) – results from wheat plots with treatment 75 kg N/ha only.

Break Crop Sown 2013	YEAR 3 2015 Barley yield (t/ha)	YEAR 3 2015 Gross Margin ($/ha)	Cumulative Gross Margin ($/ha) 2013 + 2014 + 2015
Sub clover (hay)	1.7	-148	1109
Beans	1.8	-112	1084
Peas (Winter Sown)	1.8	-122	1025
Wheat	1.8	-117	586
Peas (Spring Sown)	2.1	-44	387
Canola	1.9	-97	353
Barley (Spring Sown)	1.6	-154	79
P value	0.542	0.542	0.036
l.s.d (P<0.05)	NS	NS	698

Q.4 What effects do break crops have on soil nitrogen availability?

On average across all break crop seasons beans had the highest level of N_2 fixation, averaging 13 kgN/tDM produced. Post-harvest, legume break crops had higher residual mineral N when compared to wheat and canola grain crops. This trend was observed after both the wheat and barley rotations, suggesting the benefits of a legume break crop residual mineral N can last more than one season.

Under favourable seasonal conditions break crop treatments resulted in significantly higher subsequent wheat yields, regardless of the N treatment applied. In dry spring conditions (Experiment 2, Year 2 (2014)) and subsequent lower wheat yield the impact of the legume break crop was not significant, although the rotations including beans and peas out-yielded the wheat on wheat rotation. Under these conditions there was no interaction between wheat yields and N treatment applied.

Across all seasons on average the wheat on wheat rotation had lower protein % and plump grain (>2.0 mm) %, compared to the legume break crop rotations. In Year 3 of each of the Experiments there was a significant interaction between barley yields X previous year wheat N application rate X initial break crop, again supporting the finding that the break crop influence can last more than one season.

- Naracoorte Experiment 1
- Naracoorte Experiment 2

Q.4 Naracoorte Experiment 1

Soil mineral N following all legume break crops grown in Year 1 of Experiment 1 (2011) were all significantly higher than after the wheat (grain) treatment.

Experiment 1 Mineral N (kg N/ha) 0-60 cm pre-sowing YEAR 2 2012 wheat crop.
Arranged in descending order of Mineral N.

Break Crop Sown 2011	Mineral N 2012 (kg N/ha) 0-60cm
Peas (spring sown)	139
Subclover (hay)	134
Beans	125
Peas (winter sown)	111
Wheat (grain and graze)	109
Canola (grain and graze)	106
Barley (spring sown)	103
Wheat (0.3 m rows)	98
Canola (grain)	93
Safflower (spring sown)	87
Wheat (grain)	81
Canola (hay)	55
P value	<0.001
l.s.d (P<0.05)	20

Q.4 Naracoorte Experiment 2

The soil mineral N results from the three year period for selected treatments in Experiment 2 highlight that after two subsequent cereal crops the bean treatment still had significantly higher soil mineral N than any of the other treatments.

Table 7. Mineral N post-harvest (kg N/ha) 0-60 cm, Year 1 all treatments, Year 2 and Year 3 from treatments with 75 kg N/ha applied in 2014.
Arranged in descending order of 2015 Mineral N.

Break Crop	Mineral N (kg N/ha) 0-60 cm		
Sown 2013	May-14	Dec-14	Dec-15
Beans	175	94	116
Peas (winter sown)	148	84	69
Canola	123	110	64
Subclover (hay)	144	110	61
Peas (spring sown)	148	86	57
Barley (spring sown)	84	66	54
Wheat	105	50	45
P value	0.028	0.002	<0.001

l.s.d (P<0.05)	47	25	18

Simulation Case Study

Summary

- Increasing legume content of the crop and pasture sequence increased gross margin by increasing animal productivity and reducing N fertiliser costs.
- Maintaining a high legume content of pastures doubled animal gross margins and also improved the cropping phase gross margin.
- Including faba bean in the crop sequence maximised gross margin of the cropping phase at current crop prices.

Introduction

A simulation study was conducted comparing the value of canola, faba bean and wheat crops in rotation with either grass- or legume-based pastures. The study was based on a case study of a typical farm in the Naracoorte region of South Australia. Simulations were conducted using the AusFarm simulation software to link various APSIM crop and soil models (v 7.7) and GRAZPLAN pasture and animal management models together (Holzworth et al. 2014; Moore et al 2014). Weather data was taken from the SILO database (Jeffery et al. 2001) and soil was parameterised with local soil characteristics.

The case study

The system consisted of a self-replacing merino flock on a 1000 ha farm where clover-medic based annual pastures were established but became annual grass dominant as the pasture aged. Based on the representative farm, the ratio of pasture to crop was set at 63:37 by simulating a sequence with 5 years of pasture followed by 3 years of cropping. Eight paddocks of equal size (125 ha) were allocated to the 8-year rotation, each one year out of phase.

Crops were sown based on a rainfall rule (>15mm over 5 days after 25 April for canola, after 1 May for wheat and after 15 May for faba bean). Crops were fertilised so that available soil N at sowing was 100 kg N/ha in the case of wheat and 120 kg N/ha in the case of canola. A further topdressing of 40 or 50 kg N/ha was applied at stem elongation in wheat and canola, respectively. Faba beans were not fertilised. In some comparisons faba beans were brown-manured by spraying out during early grainfilling stage.

Legume pastures were sown after the last crop and as occurred in the case-study farm, were simulated to become grass-dominant (>90%) in the last 2-3 years. Pasture was removed in mid-October of the 5th year of pasture.

The simulation analysis represented a self-replacing merino flock grazing the pastures and stubbles. A constant stocking rate was maintained from year to year and fluctuations in forage supply were handled through supplementary feeding. Stocking rate was set at 3.5 breeding ewes per farm hectare (5.6 ewes per pasture hectare) according to the description supplied in the case study. The sheep enterprise was based on large-framed Merino ewes producing a mixture of Merino and first-cross lambs. Joining commenced on 20 December and lasted for 6 weeks. Lambs were sold from 15 January after they reached a target weight of 50kg or on 30 April. Ewes were cast for age at 6 years.

This resulted in an average stocking rate of 10.5 DSE/pasture hectare. Livestock were moved around the pasture and stubble paddocks regularly (paddocks assessed every 7 days), with the best feed being assigned in the following priority order: weaners, lactating ewes, ewes in late pregnancy, other ewes. Stock were fed a grain supplement (30:70 lupin:barley) to maintain their body condition above class-specific thresholds. Maintenance feeding was carried out in the paddocks (i.e. feedlotting was not used).

Simulations were run from 1960 to 2015 inclusive using weather data from Naracoorte. The first 8 years were discarded to minimise the effect of initial conditions on the results. The remaining years (1969 to 2015) included 8 continuous cycles of the 8-year rotation.

Simulated scenarios – modifications to the base case study

Scenarios were set up to assess the value of different crops in the cropping sequence. Specifically the break crops faba bean and/or canola were replaced with wheat. In addition, the value of brown manuring a faba bean crop compared to producing grain was also tested to assess the differing N benefits to the subsequent wheat or canola crop.

In a separate set of comparisons the value of maintaining the legume content of a pasture was tested, assessing the benefit to both the animal production and subsequent crops through N fertiliser savings. In the case of the clover pasture, 5-year average legume proportion was >50% compared to <10% in the grassy pasture.

Results reported

To make comparisons between the above scenarios a gross margin analysis was undertaken. Model outputs included grain yield, N-fertiliser application, clean wool production, number and weight of lamb and ewe sales. Economic values for meat, wool, grain, fertiliser, variable costs associated with crop, pasture and sheep production and management were taken from the 2015 PIRSA Farm Gross Margin Guide. The additional cost of maintaining a legume pasture included winter cleaning with herbicide, insecticide application and additional P fertiliser. Other costs were assumed to be the same in all scenarios and consequently would not affect the comparison.

Discussion / Analysis

Yields of pasture and crops are typical of average yields which are reported in the region. Although seasonal variability was accounted for in the analysis only long-term averages are reported here.

The analysis showed that where the pasture became grass dominant, the faba bean-canola-wheat cropping sequence was the most profitable rotation option. Removing faba bean from the system increased average annual N fertiliser costs by $24,000 (Table 2a).

Excluding faba beans from the rotation reduced both cropping and animal enterprise gross margin. The effect on animal production was associated with lack of faba bean stubble and spilt grain for animal feed and generally lower N content of the soil which affected both subsequent crop and pasture production.

Modifying the system to brown manure faba bean rather than harvesting grain provided only a small fertiliser saving in subsequent crops. Brown-manuring faba bean reduced average gross margin of the whole farm by $225,000/year. The small fertiliser saving ($3-5000/year) was offset significantly by loss in income from faba bean grain (worth over $400/tonne), but also a loss in animal production due to lack of faba bean stubble and spilt grain.

Substituting canola with wheat made only a small difference to the gross margins of the enterprise.

The only systems that were predicted to achieve significantly higher average gross margins than farmer practice required maintenance of a high legume component in the pastures and inclusion of faba bean in the crop sequence. Improving pastures approximately doubled gross margin from animal production and slightly increased gross margin of the cropping component through N fertiliser savings. These systems increased gross margin by $138,000 to 150,000 across the farm, depending on the crops included in the sequence (not shown).

Further simulation analyses suggest that small additional profits could be gained from clover dominant pasture by increasing stocking rate from 3.5 ewes/ farm ha to 4.0 ewes/ha, but long-term average gross margin declined with any further increases in stocking rate.

Table 1: Simulated long-term mean annual pasture and grain yields, average fertiliser application, total clean fleece weight, number of animals sold per year (lambs plus ewes) and total live weight sold per year and supplementary feed supplied.

(a) Simulated comparison of the Farmer Practice case study with other cropping phase options.

		Farmer Practice (base case)	Without Faba	Double break With BM	Single break with Faba	Single break with BM
Pasture		Grassy	Grassy	Grassy	Grassy	Grassy
Crop 1		Fababean	Wheat	Fababean(BM)	Fababean	Fababean(BM)
Crop 2		Canola	Canola	Canola	Wheat	Wheat
Crop 3		Wheat	Wheat	Wheat	Wheat	Wheat
Yield						
Pasture	t/ha/yr	4.23	4.19	4.10	4.20	4.04
Crop 1	t/ha	5.03	4.11	0.00	5.03	0.00
Crop 2	t/ha	2.77	2.21	2.86	5.20	5.47
Crop 3	t/ha	4.66	4.45	4.62	4.15	3.99
Fertiliser						
Crop 1	kg N/ha	-	85	-	-	-
Crop 2	kg N/ha	80	145	55	54	41
Crop 3	kg N/ha	92	107	98	92	96
Animal Production						
Fleece Weight	kg/year	8643	8433	8791	8493	8689
Number Sold	head/yr	2195	2161	2163	2129	2130
Live Weight Sold	tonnes/yr	110	101	106	106	103
Supplementary Feeding	kg/ewe/yr	77	79	81	79	82

(b) Simulated comparisons between a grassy and legume based pasture followed by 3 crop sequence options. The third comparison also modifies the base case crop sequence.

Pasture	Grassy	Legume	Grassy	Legume	Grassy	Legume

Crop 1		Wheat	Wheat	Wheat	Wheat	Fababean	Wheat
Crop 2		Wheat	Wheat	Canola	Canola	Canola	Fababean
Crop 3		Wheat	Wheat	Wheat	Wheat	Wheat	Canola
Yield							
Pasture	t/ha	4.16	7.16	4.19	7.18	4.23	7.47
Crop 1	t/ha	4.11	4.75	4.11	4.75	5.03	4.84
Crop 2	t/ha	3.60	3.96	2.21	2.31	2.77	4.91
Crop 3	t/ha	4.17	4.43	4.45	4.77	4.66	2.82
Fertiliser							
Crop 1	kg N/ha	84	49	85	49	-	48
Crop 2	kg N/ha	115	110	145	141	80	-
Crop 3	kg N/ha	101	96	107	98	92	70
Animal Production							
Fleece Weight	kg/year	8303	10596	8433	10588	8643	10678
Number Sold	head/yr	2117	2398	2161	2428	2195	2444
Live Weight Sold	tonnes/yr	101	140	101	141	110	143
Supplementary Feeding	kg/ewe/yr	86	25	79	25	77	21

Table 2: Simulated long-term average annual farm gross margins from a 1000ha farm ($'000) received from the cropping, animal and total enterprise. Fertiliser and supplementary feed cost savings associated with modified cropping sequence or pasture type are also shown. Other differences are associated with crop yield and wool and meat production.

(a) Simulated comparison of the Farmer Practice case study with other cropping phase options.

	Farmer Practice (base case)	Without Faba	Double break With BM	Single break with Faba	Single break with BM
Pasture	Grassy	Grassy	Grassy	Grassy	Grassy
Crop 1	Fababean	Wheat	Fababean (BM)	Fababean	Fababean (BM)
Crop 2	Canola	Canola	Canola	Wheat	Wheat
Crop 3	Wheat	Wheat	Wheat	Wheat	Wheat
Farm Gross Margin ($'000/yr)					
Cropping	402	240	188	407	191
Animal	136	112	126	126	118
Total	**538**	**351**	**313**	**533**	**309**
Benefit of modified sequence		-187	-225	-5	-230
Cost saving relative to base case ($'000/yr)					
Crop Fertiliser		-24	3	4	5
Supplementary feed		-2	-4	-2	-4

(b) Simulated comparisons between a grassy and legume based pasture followed by 3 crop sequence options. The third comparison also modifies the crop order.

Pasture	Grassy	Legume	Grassy	Legume	Grassy	Legume

Crop 1	Wheat	Wheat	Wheat	Wheat	Fababean	Wheat
Crop 2	Wheat	Wheat	Canola	Canola	Canola	Fababean
Crop 3	Wheat	Wheat	Wheat	Wheat	Wheat	Canola
Farm Gross Margin ($'000/yr)						
Cropping	234	281	240	283	402	413
Animal	107	247	112	249	136	259
Total	**341**	**528**	**351**	**533**	**538**	**672**
Benefit of legume pasture		**187**		**181**		**144**
Cost saving relative to grassy pasture ($'000/yr)						
Crop Fertiliser		7		8		8
Supplementary feed		62		56		58

Mallee Sustainable Farming Systems

Q1. Can a break crop be as profitable as a cereal?

- Mildura Low Rainfall Crop Sequence Site
- Mildura Break Crop Comparison Trials
- Loxton and Waikerie break crop comparison trials (SAGIT)

Q.1 Mildura Low Rainfall Crop Sequence Site

In paddocks such as the location of the Mildura Low Rainfall Crop Sequencing site where cereal crop yields are impaired by the presence of agronomic constraints (e.g. grass weeds, soil borne disease and low soil fertility) break crops production and profitability can match or even exceed that of maintaining a poor performing cereal in that paddock. In 2011, field peas out yielded wheat (1.78 v 1.47 t/ha respectively) and also had a gross margin of approximately 2.5 times greater (~$320 vs ~$120/ha). While canola (0.7 t/ha) and chickpea (0.83 t/ha) produced less grain yield than the continuous wheat treatment, the gross margins of these crops were similar (Canola: ~$130/ha) or better (Chickpea ~$200/ha) than wheat.

In 2012, seasonal conditions were poor, however the productivity of field pea relative to wheat was similar. Field pea following canola yielded 1.17 t/ha while wheat following canola yielded 1.05 t/ha (see Table below). Where both these crops were grown following a chemical fallow, yields were about 1.25 t/ha. On average, field pea was also slightly more profitable (by ~$30/ha) than wheat in these treatments. The poor productivity of canola and chickpea in 2012 led the break even or slightly better (<$50/ha) gross margins in 2012.

Non-grain break crops also showed potential at the Mildura site. In 2011, dry matter (DM) production was high across all non-grain break crops with oats producing 4.8 t/ha, vetch producing 2.7 t/ha and medic producing 3.2 t/ha. A late break and low in-crop rainfall in 2012 constrained the DM production of vetch (0.99 t/ha). However, the volunteer medic pasture which was able to germinate after 64 mm of rainfall in March accumulated very high DM yields (7.1 t/ha) despite the poor growing season rainfall. Generally, the low stocking rates (2 DSE/winter grazed ha) used in the Mallee prevented capture of additional profit from excess biomass production, but profit could be captured from conserving this DM for hay. For example, the cumulative gross margin of the oaten hay sequence ($255/ha) was nearly twice as profitable as the continuous wheat treatment at the site (data not shown).

Treatment Grain yields over four years (2011-2014) at the Mallee Crop Sequencing Trial site, Mildura, VIC

2011 Crop	Yield t/ha	[b]2012 Crop	Yield t/ha	[b]2013 Crop	Yield t/ha	[b]2014 Crop	Yield t/ha
Canola (TT)	0.93	Chickpea	0.30	Wheat	2.57	[lx]Wheat CL	1.41
Canola (TT)	0.62	Field peas	1.17	Wheat	2.44	[lx]Wheat CL	1.43
Canola (TT)	0.66	Vetch (Brown Manure)	NA	Wheat	2.54	[lx]Wheat CL	1.54
Chickpea	0.83	Canola (TT)	0.39	Wheat	2.31	[lx]Wheat CL	1.61
Chemical Fallow	NA	Canola (Clearfield)	0.27	Wheat	2.27	[lx]Wheat CL	1.52
Chemical Fallow	NA	Chemical Fallow	NA	Wheat	2.42	[lx]Wheat CL	1.20
Chemical Fallow	NA	Field peas	1.24	Wheat	2.50	[lx]Wheat CL	1.60

Medic (high seed rate)	NA	Medic (volunteer)	NA	Wheat	1.96	[Ix]Wheat CL	1.43
Medic (low seed rate)	NA	Medic (volunteer)	NA	Wheat	2.19	[Ix]Wheat CL	1.54
Field pea	1.35	Canola (TT)	0.39	Wheat	2.32	[Ix]Wheat CL	1.33
Field pea	1.93	Vetch (Brown Manure)	NA	Wheat	2.67	[Ix]Wheat CL	1.57
Vetch (Brown Manure)	NA	Canola (TT)	0.25	Wheat	2.58	[Ix]Wheat CL	1.84
Vetch (Brown Manure)	NA	Field pea	0.77	Wheat	2.60	[Ix]Wheat CL	1.83
Barley	2.2	Wheat	0.76	[Ix]Wheat CL	1.04	[Ix]Wheat CL	1.78
Canola (Clearfield)	0.59	[Ix]Wheat CL	1.05	Wheat CL	1.44	[Ix]Wheat CL	1.17
Canola/Field pea mix	1.17	Wheat	0.87	[Ix]Wheat CL	1.00	[Ix]Wheat CL	1.69
Oaten hay	NA	Wheat	0.82	[Ix]Wheat CL	1.22	[Ix]Wheat CL	1.69
Field peas	2.05	Wheat	1.26	[Ix]Wheat CL	1.12	[Ix]Wheat CL	1.69
Chemical Fallow	NA	Wheat	1.26	[Ix]Wheat CL	1.30	[Ix]Wheat CL	1.65
Wheat	1.47	[Ix]Wheat CL	0.93	Wheat CL	1.42	[Ix]Wheat CL	1.31
LSD (Grain Yield Only)	0.44		0.25		0.20		0.20

[b]Wheat CL is Clearfield wheat

[Ix]Intervix applied to the Clearfield wheat

Q.1 Mildura Break Crop Comparison Trials

Recent break crop comparison trials have highlighted the potential for grain legume crops to be productive and profitable in the Northern Victorian and South Australian Mallee (Table 2). Trials were conducted on a similar sandy loam soil type at Mildura (2013 and 2014) and Waikerie (2015). Growing season rainfall for 2013-2015 was 130mm, 132mm (Mildura) and 145mm (Waikerie) which was below average, although stored soil moisture was available in 2014 and 2015 from summer storms. Potentially yield limiting factors such as frost, heat or biological constraints such as pest or disease did not appear to significantly impact these trial sites.

2013

The three field pea varieties were the highest yielders, with Twilight the highest yielding treatment at Mildura (1.3 t/ha) in 2013 (Table 1). Mandelup lupins and Striker and Genesis 090 chickpeas also performed well (> 0.8 t/ha). In most cases, selecting the best suited crop type had a greater impact on yield than selecting the best variety within a pulse crop type. Despite grain yields of less than one tonne per hectare, chickpeas were the most profitable break crop at the site due to the relativity high grain prices. Field pea treatments were also a profitable break crop option with a gross margin of ~$100 to 200/ha depending on the variety. In trials located at the same site in 2013, there were high returns for wheat ($368/ha), but this level of profitability did not continue into subsequent years.

Table 1. Mean grain yield and gross margins of different pulse options evaluated at Mildura in 2013. GSR (April – October) = 130 mm

Arranged in order of descending gross margin

Crop	Variety	Grain Yield (t/ha)	Gross Margin ($/ha)
Chickpea (Kabuli)	Genesis 090	0.91	254
Chickpea (Desi)	PBA Striker	0.94	194
Field Pea	PBA Twilight	1.31	187
Field Pea	PBA Wharton	1.11	130
Field Pea	PBA Pearl	1.04	96
Lupin (Narrow)	Mandelup	1.02	75

Vetch	Volga	0.53	38
Faba Bean	Farah	0.57	2
Vetch	Rasina	0.43	-4
Chickpea (Kabuli)	Genesis 079	0.36	-8
Lupin (Albus)	Luxor	0.75	-24
LSD		0.20	

2014

Field peas were the stand out crop in terms of both DM production (5.8-6.5 t/ha) and grain yield (1.7-2.3 t/ha) at the Mildura site in 2014, however good grain yields were generally achieved for all pulse crop options; chickpea (1.5-1.6 t/ha), lentil (1.5 t/ha), faba bean (1.4 t/ha) and lupins (0.9-1.2) (Table 2). Based on long-term prices, all treatments at the site in 2014 had a positive gross margin. PBA Bolt lentils were the most profitable at $650/ha followed by Kabuli chickpea's which had an average return of around $550/ha. The profit achieved for both field pea's and faba beans was around $300/ha with the exception of the high yielding PBA Wharton field pea's with a gross margin of $457/ha. Lupin profitability was worst with Luxor lupins only breaking even.

This trial was located alongside the Mildura low rainfall crop sequencing trial which had an average wheat yield of 1.54 t/ha (+/- 0.3 t/ha) across all treatments. These yield produced gross margins of $145 – $300/ha with an average of $237/ha. Therefore, this trial has demonstrated that break crops have the potential to significantly exceed the profitability of cereal in the low rainfall zone when reasonable production is achieved.

Table 2. Mean dry matter production, grain yield and gross margins of various pulse options evaluated at Mildura in 2014.

Arranged in order of descending gross margin

Treatments with the same letter in the Sig. Diff column are not significantly different (p<0.05)

Crop	**Variety**	**Dry Matter** (kg/ha)	Sig. Diff.	**Grain Yield** (t/ha)	Sig. Diff.	**Gross Margin** ($/ha)
Lentil	PBA Bolt	4881	bcd	1.46	bc	650
Chickpea (Kabuli)	PBA Monarch	3960	defg	1.62	b	585
Chickpea (Kabuli)	Genesis 090	3848	efg	1.47	bc	528
Field Pea	PBA Wharton	5768	abc	2.25	a	457
Chickpea (Desi)	PBA Striker	4162	def	1.57	bc	455
Faba Bean	PBA Simara	5654	abc	1.41	bc	318
Faba Bean	Farah	4836	cde	1.39	bc	310
Field Pea	PBA Pearl	5850	ab	1.69	b	294
Field Pea	PBA Twilight	6455	a	1.67	b	290
Lupin (Narrowleaf)	Mandelup	4096	def	1.23	cd	124
Lupin (Narrowleaf)	PBA Barlock	3818	fg	0.94	d	50
Lupin (Albus)	Luxor	2990	g	0.87	d	4

Q.1 Loxton and Waikerie break crop comparison trials (SAGIT)

Across two locations (Loxton and Waikerie) and four soil types in the South Australian Mallee in 2015 (see Table below), lentils had both the most consistent and the highest average grain yield (0.73 t/ha). Field peas only averaged 0.64 t/ha despite having the highest individual yield at any one site of 1.2

t/ha at the Waikerie sand. Field pea yields were particularly affected by frost on the Loxton and Waikerie flat sites. Vetch grain yields were also good with 0.63 t/ha while narrow-leaf lupins, canola and faba bean yielded similarly at 0.5 – 0.53 t/ha. The later maturing crops, chickpeas and albus lupins, performed the worst in 2015 with average yields below 0.5 t/ha. Very low yields were obtained from these crops on the soils with the lowest water holding capacity at each site; Loxton sand and Waikerie flat.

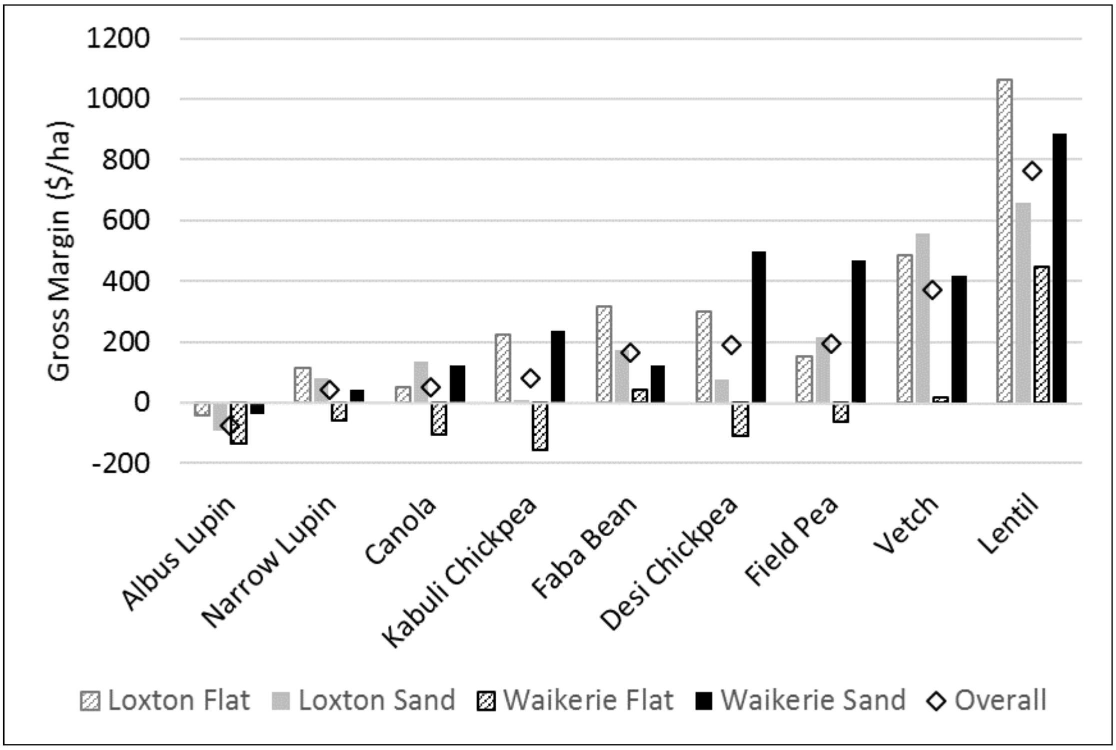
An interesting finding was the relatively high and consistent biomass production of the break crops across soil types compared to the high between site variability for grain yield. This could provide a useful fall-back position for farmers growing break crops as they could elect to use the biomass for livestock forage or hay if grain yield is uncertain due to constraints such as frost, heat shock or drought. Field pea produced the greatest biomass with an average of 3.1 t DM/ha across all four trial sites and no less than 2.7 t DM/ha at any one. Canola, vetch and lentil produced similar levels of biomass with 2.5 – 2.7 t DM/ha on average while desi chickpea, narrow leaved lupin and faba bean produced 2.1 – 2.3 t DM/ha across all sites. The lowest levels of biomass were produced by kabuli chickpea and albus lupins (1.6 and 1.4 t DM/ha respectively).

Lentils were the most profitable break crop option on all soil types in 2015, and averaged nearly $800/ha profit across all sites (see Figure below). This is a reflection of the extremely high price of $1340/t and high and constant yields across all sites relative to the other break crops. Vetch grain which also had a relatively high price was also a profitable option on all soils except the Waikerie flat. Field pea, faba bean and chickpeas returned $75 - $200/ha across all sites while canola and narrow leaf lupins usually broke even. Albus lupins was not a profitable option at any site.

A wheat variety trial located at the Waikerie site produced an average yield of 0.9 t/ha while a nearby commercial paddock where wheat was grown following vetch yielded 1.55 t/ha.

Grain yield (kg/ha) for each trial site and as an overall average across all sites.

Treatment	Loxton Flat	Loxton Sand	Waikerie Flat	Waikerie Sand	Overall
Albus Lupin	0.28	0.14	0.02	0.30	0.18
Kabuli Chickpea	0.43	0.22	0.05	0.45	0.29
Desi Chickpea	0.55	0.30	0.09	0.77	0.43
Narrow-leaved Lupin	0.71	0.60	0.20	0.49	0.50
Canola	0.52	0.69	0.20	0.66	0.52
Faba bean	0.83	0.55	0.29	0.46	0.53
Vetch	0.77	0.86	0.19	0.69	0.63
Field Pea	0.58	0.71	0.16	1.21	0.66
Lentils	0.96	0.64	0.48	0.82	0.72
p value	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*0.001*
lsd (5%)	*0.12*	*0.19*	*0.09*	*0.09*	*0.23*



Gross margin for each break crop at the four trial sites and for the overall average yield across all sites.

For more trial information (including methods) CLICK HERE

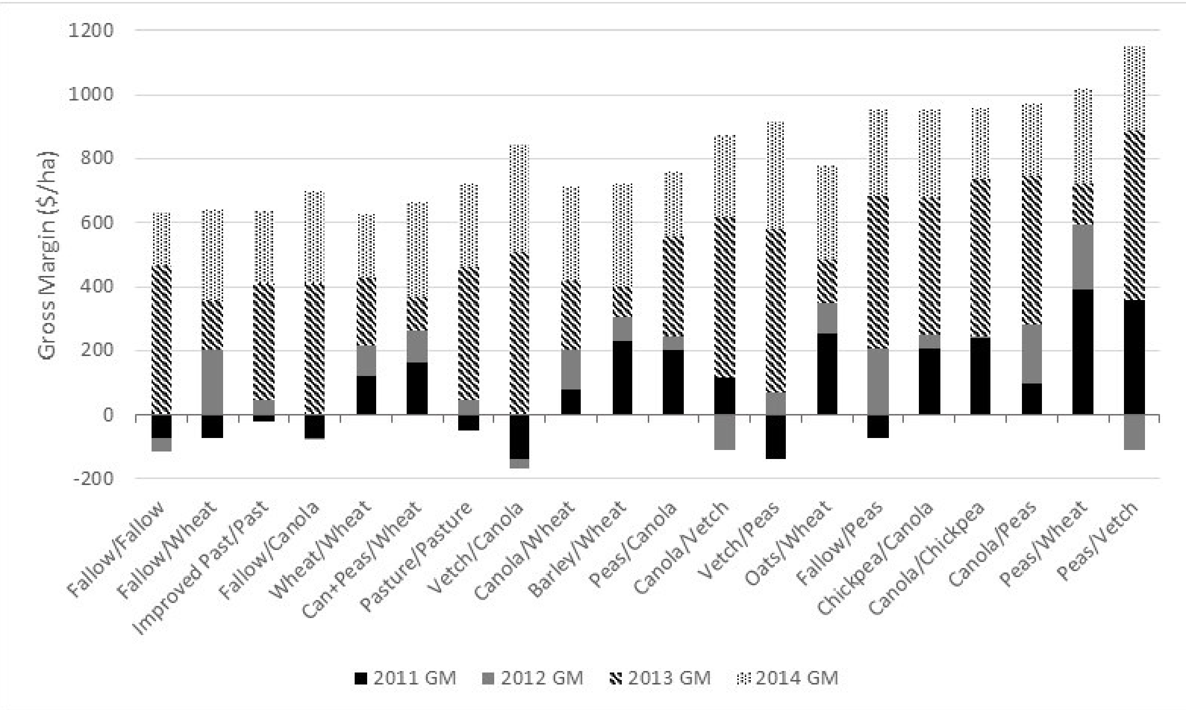
Q2. Are sequences including break crops more profitable than continuous wheat?

- Mildura
- Karoonda WUE site

Q.2 Mildura

At the Mildura Low Rainfall Crop Sequencing site including break phases in the rotation significantly increased the productivity of subsequent cereal crops relative to maintaining continuous wheat. A single year break phase of field pea or fallow in 2011 increased wheat yield in the following year by 0.3 t/ha and a canola crop resulted in a 0.1 t/ha yield benefit in the 2012 wheat crop. In 2013, the benefit of having a two year beak prior to 2013 was 0.5-1.25 t/ha. However, the benefit of the single break crop option from 2011 only lasted a single season. Break crop benefits were also observed in 2014 with selected rotations having up to a 0.4 t/ha greater yield than the continuous wheat treatment.

Over the four seasons, 15 of the 19 rotations compared were more profitable than maintaining continuous wheat (see Figure below). On average, the top five most profitable rotations were $360/ha (or $90/ha per year) more profitable than the continuous wheat. Furthermore, four of the top five most profitable rotations included a two year break crop phase.



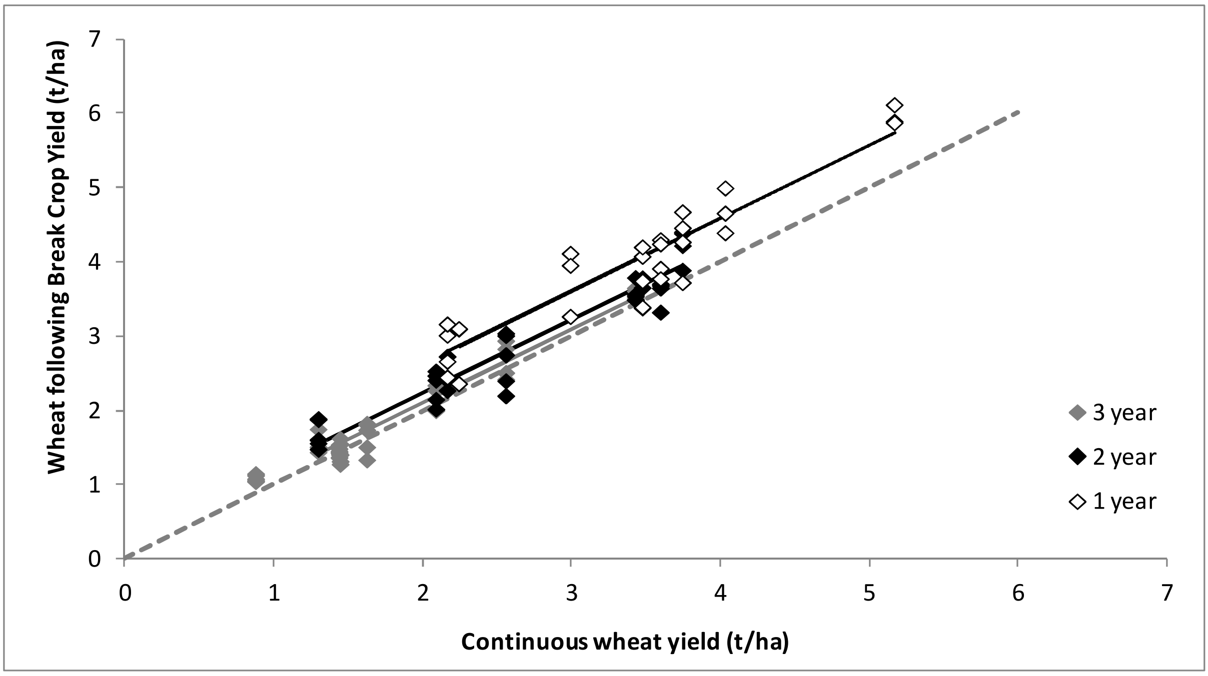
Seasonal gross margins (2011-2014) for each treatment in the low rainfall crop sequencing trial site at Mildura.

Key characteristics of the most profitable rotations were the inclusion of at least one profitable break crop in the sequence and the alleviation of agronomic constraints resulting in increased profitability in the wheat crops following the break phase. Of the rotations that were less profitable than wheat, three of the four included at least one fallow phase. The other rotation was a two year pasture, which had high a brome grass population and spray topping as the only weed control tactic. However, the absolute difference in gross margin between these treatments and the continuous wheat treatment was small (on average less than $40/ha).

For more trial information (including methods) CLICK HERE

Q.2 Karoonda WUE site

Yield data from three years of wheat crops following breaks (in either 2009 or 2010) at the Karoonda WUE site were combined to analyse the cereal yield gain from including the break crops in Mallee paddock rotations (see Figure below). Across all soil, season and break crop types, an additional 1 t/ha of grain was produced in the three subsequent wheat crops following the break phase. The yield benefit was approximately 0.6 t/ha in the first year after the break (wheat after break yield= 0.99 continuous wheat yield +0.65 t/ha), 0.3 t/ha in the second year after the break (wheat after break yield =0.99 continuous wheat yield + 0.27 t/ha) and 0.1 t/ha in the third year after the break (wheat after break yield= 0.99 continuous wheat yield +0.14 t/ha).



Wheat yields following a break (1 year after break; 2 years after break and 3 years after break) plotted against wheat following wheat. Data is from 4 soil types over 3 seasons (2010-13) and legume, brassica and pasture breaks.

The cumulative gross margins for three years of wheat grown following a break in either 2009 or 2010 were calculated for each soil type × crop sequence combination and are presented relative to the gross margin for continuous wheat (see Table below). Break crops generally had a positive impact on the profitability of subsequent cereal crop and generally grain legume, brassica and pasture break phases increased profitability more than cereal break phases (cereal rye).

Difference in cumulative gross margin of three years of wheat grown following a break crop compared with continuous wheat.

	Rotation				Swale	Mid-Bottom	Mid-Top	Hill
2009	2010	2011	2012	2013	$/ha	$/ha	$/ha	$/ha
peas	wheat	wheat	wheat		464	429	368	363
mustard*	wheat	wheat	wheat		484	328	36	363
rye grain	wheat	wheat	wheat		265	134	191	142
DP rye*	wheat	wheat	wheat		502	70	262	-33

pasture	wheat	wheat	wheat		388	363	522	449
	lupins	wheat	wheat	wheat	288	357	450	290
	canola	wheat	wheat	wheat	329	63	212	202
	rye grain	wheat	wheat	wheat	25	-102	288	290
	DP rye	wheat	wheat	wheat	-12	-178	193	52
	pasture	wheat	wheat	wheat	188	379	513	-19

*Mustard failed to establish across Mid and Hill soils, DP rye is dual purpose rye for hay and grain. Costs calculated using the Rural Solutions Farm Gross Margin Guide, grain prices are 5 year averages (note that the 5 year average lupin price was $305/t), pasture biomass valued at $35/t/ha. For 2009-2012 the continuous wheat three year cumulative gross margin was: swale $2751/ha, mid-bottom $2116/ha, mid-top $895/ha and hill $1728/ha and for 2010-2013 the continuous wheat three year cumulative gross margin was: swale $1687/ha, mid-bottom $1485/ha, mid-top $493/ha and hill $1275/ha.

For more trial information (including methods) CLICK HERE

Q.3 Can a weed problem be managed more cost effectively with break crops than in a continuous cereal system?

- Mildura

Q.3 Mildura

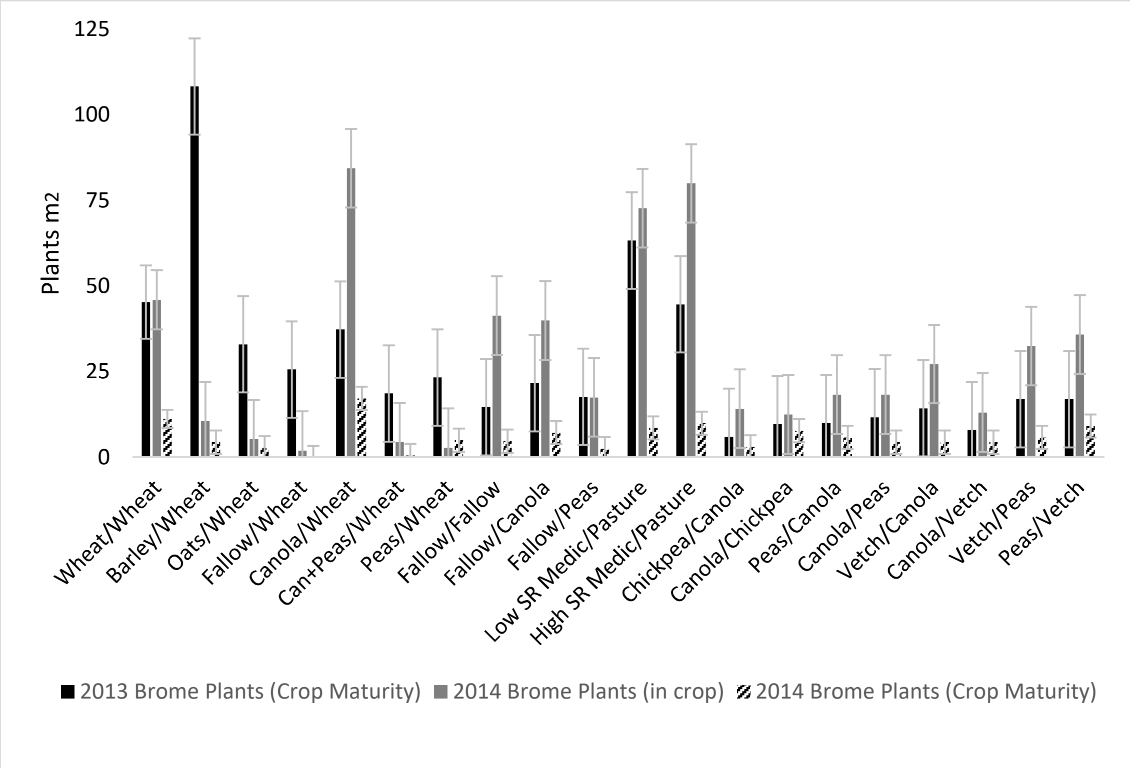
Two year break treatments generally reduced the brome grass population in the cereal phase; however, all rotations relied on Clearfield herbicides for brome grass control by the end of the trial.

Brome Grass

At the Mildura low rainfall crop sequencing site, treatments that included two year break phases generally had fewer grass weeds in 2013 and 2014 when all rotations were sown to wheat (see Figure below). The exceptions were the pasture treatments where brome grass control relied only on 'spray topping'. Winter cleaning pastures with group 'A' herbicides, such as were applied to the other break crop options, would likely have prevented the proliferation of brome in the pasture treatments.

Crop sequences that included a one year break phase failed to reduce the brome grass numbers for longer than one season relative to the continuous wheat treatment. As a consequence both the one year break and continuous cereal rotations relied on the application of Clearfield herbicides to manage the brome grass population. The weed population in these rotation was minimised by the 2014 harvest following two applications of Intervix, however at this intensity of application, the onset of resistance to Clearfield herbicides is likely to be rapid.

The two year break treatments also required an application Clearfield herbicide in 2014 as a brome grass population of 10-40 plants m^2 had established in the second wheat crop. This shows that where a high weed population is present (a seedbank of 150 brome plants m^2 was present at the beginning of the trial) a longer break crop phase of three or more years may be required to adequately reduce the weed seed bank. Alternatively, break phases need to be implemented before weed numbers reach high levels and or integrated weed management tactics in the cereal phase (e.g. harvest weeds seed control) needs to be combined with the use break phases over the cropping sequence.



Brome grass (plants m^2) measured at crop maturity in 2013 and in crop and at crop maturity in 2014.

For more trial information (including methods) CLICK HERE

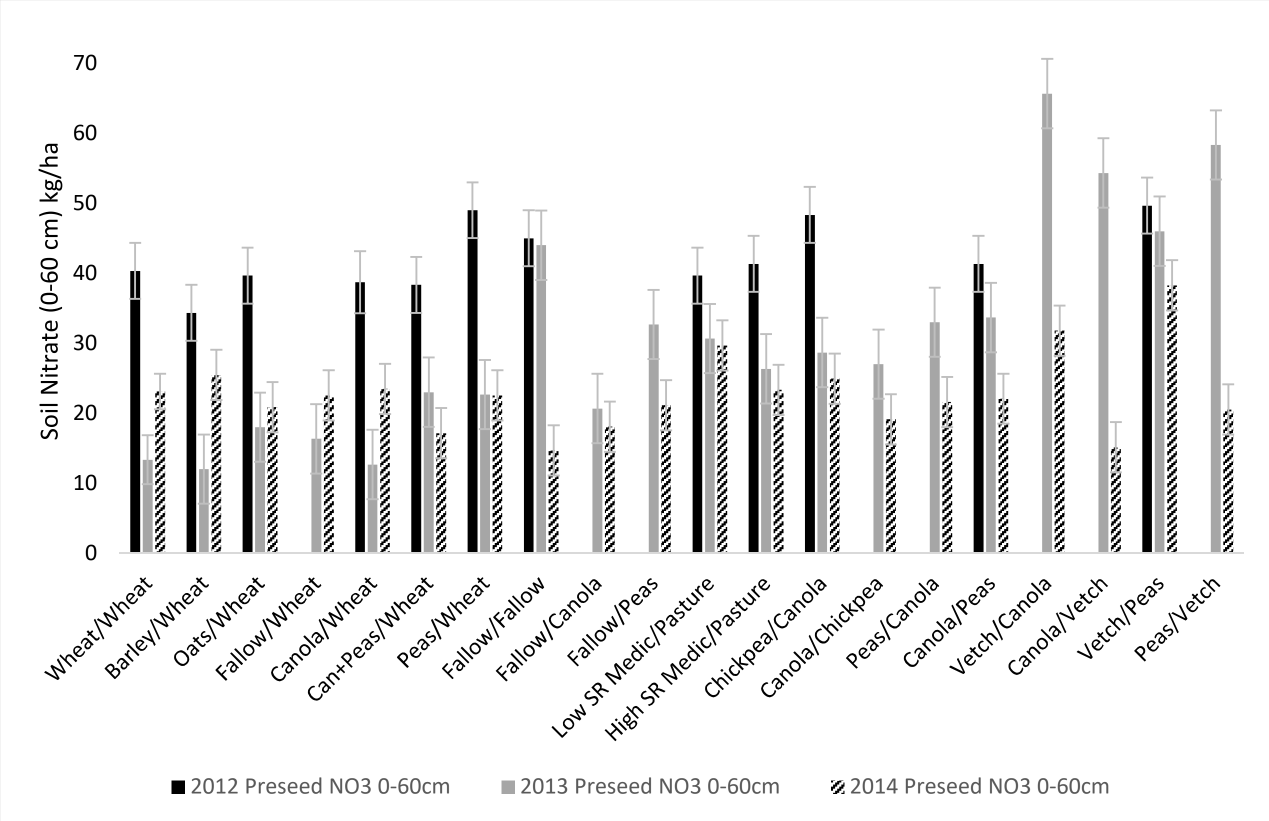
Q.4 What effects do break crops have on soil nitrogen availability?

- Mildura
- Karoonda WUE site

Q.4 Mildura

Legumes crops consistently increased pre-sowing soil N in the year following the break, although the benefits of soil water following break phases were variable.

Including legume crops and pastures at the Mildura low rainfall cropping sequencing site provided soil nitrogen benefits to the following wheat crop (see Figure below). Soil nitrate (0-60 cm) levels measured pre-seeding in 2012 were about 50 kg/ha where vetch, chickpea and field pea had been grown in 2011 while for other treatments levels were 30 to 40 kg/ha. The biggest differences in pre-sowing N was measured in 2013 where levels varied between 12 and 66 kg/ha. The two-year break treatments which included vetch in the rotation had the highest amount of pre-sowing N with at least 30 kg/ha more soil nitrate measured in these treatments than following continuous wheat. Smaller nitrogen differences between treatments were observed at sowing in 2014 when all treatments had a wheat phase the year before. The vetch/canola and vetch/field pea rotations had significantly higher N levels than most other treatments.



Soil nitrate (0-60 cm) measured prior to seeding in in 2012, 2013 and 2014. Error bars represent the standard error of each treatment.

Note: soil nitrate was only measured for each crop type in 2012 and not for each treatment.

For more trial information (including methods) CLICK HERE

Q.4 Karoonda WUE site

At the Karoonda WUE site, soil nitrate measured at sowing in 2010 following break crops grown in 2009 indicated increases in available soil N following pasture and peas compared to wheat in most trial locations (Table 1). Nitrate levels following cereal rye were typically lower than after wheat; particularly on the lighter soil types.

In 2011, there was a significant N benefit from the 2010 legumes (lupins or pasture) and cereal rye in the mid-bottom and hill landscape positions, but there was little evidence of statistically significant carry-over N benefits from break crops grown in 2009 (Table 2).

Table 1. Soil nitrate and moisture content (0-100cm) measured at four landscape positions at the time of sowing in 2010 following different crops grown in 2009

2009 Crop	Wheat		Peas		Pasture		Rye (grain)		Mustard	
	Nitrogen kg/ha	Moisture Vol mm	Nitrogen kg/ha	Moisture Vol mm	Nitrogen kg/ha	Moisture Vol mm	Nitrogen kg/ha	Moisture Vol mm	Nitrogen kg/ha	Moisture Vol mm
hill	72	113	82	113	95	132	54	121		
mid-top	58	136	75	141	82	166	32	143		
mid-bottom	87	209	87	227	118	205	86	200		
swale	134	278	146	239	164	230	128	242	146	233

Table 2. Soil nitrate concentration (0-100cm) measured at the time of sowing in 2011 indicating the difference from continuous wheat (shown in brackets) following 2009 or 2010 break crops.

Preceding crop	**Swale**	**Mid-Bottom**	**Mid-Top**	**Hill**
		Sowing mineral N (kg/ha)		
2009 Break Crop				
Legume (peas)	103 (-20)	95 (+19)	80 (-2)	90 (+19)
Brassica (mustard)	110 (-13)	100 (+25)	-	-
Cereal Rye Grain	108 (-16)	96 (+20)	70 (-11)	102 (+31)
Pasture	115 (-9)	99 (+24)	69 (-13)	91 (+20)
2010 Break Crop				
Legume (lupins)	151 (+28)	155 (+79)	108 (+26)	117 (+46)
Brassica (canola)	106 (-17)	89 (+14)	88 (+7)	92 (+21)
Cereal Rye Grain	106 (-17)	111 (+36)	68 (-13)	106 (+35)
Cereal Rye 'Grazed'	104 (-19)	102 (+27)	73 (-8)	92 (+21)
Pasture	132 (+9)	120 (+44)	99 (+18)	135 (+63)
LSD within soil zone P<0.05	ns	30	ns	23

For more trial information (including methods) CLICK HERE

Riverine Plains

Q1. Can a break crop be as profitable as a cereal?

- Yarrawonga

Q.1 Yarrawonga

Data collected from two research experiments between 2012 and 2013, and on-farm data collected in 2014 indicated that pasture legume hay, faba bean and canola can be as profitable, and often more profitable, than wheat.

In 2012, the arrowleaf clover hay provided the highest gross margin due to the combination of high yields and high prices (Table 1). This was followed by the subclover hay treatment. The clover hay treatments have multiple advantages for the average two year gross margins as they potentially provide higher available soil N, better weed control and higher soil moisture due to an early termination.

The wheat, canola, faba beans and chickpeas were harvested for grain. Wheat yields showed an N response with a significant difference between the + N fertiliser treatment (4.84 t/ha) and the nil treatment (4.07 t/ha). There was no significant difference between canola yields +/- N. Above average prices and yields were achieved for most grains; in particular wheat, faba beans and canola in 2012.

Table 1. Comparisons of grain yield, hay production, income, variable costs and gross margins at Yarrawonga South in 2012.

Crops arranged in order of descending gross margin.

Treatment	Grain or hay yield (t/ha)	Gross income ($/ha)	Total variable costs ($/ha)	Gross margin ($/ha)
Arrow-leaf clover hay	4.3	1,324	229	1,095
Subclover hay	4.0	1,252	229	1,023
Wheat + N	4.8	1,310	323	987
Wheat - N	4.1	1,066	215	851
Faba bean	3.0	1,170	347	823
Canola + N	2.2	1,206	415	791
Canola - N	1.8	965	307	658
Vetch hay cut	3.5	815	224	571
Chickpea	1.7	799	265	534
Field pea hay	2.8	614	244	371

Note: Grain and hay prices used in the calculations were current at the time of harvest. Variable costs were based on local practice and prices and are estimated as a guide only.

The 2013 season had a dry start and finish, but rain fell at just the right time resulting in an excellent growing season with average GSR (296mm; decile 5). An exceptionally late and severe frost on the 18th of October devastated some cropping areas in the region, and while the trial site was affected, the extent of damage was not as bad as other local crops.

Subclover hay again provided the highest gross margin which was buoyed by good hay prices. Wheat + N fertiliser provided the second highest gross margin, followed by wheat without additional N. The canola and faba bean yields may have been more affected by the frost than the wheat.

Table 2. Comparisons of grain yield, hay production, income, variable costs and gross margins at Yarrawonga South in 2013.

Crops arranged in order of descending gross margin.

Treatment	Grain or hay yield (t/ha)	Gross income ($/ha)	Total variable costs ($/ha)	Gross margin ($/ha)
Subclover hay	3.8	1,064	221	843
Wheat + N	4.6	1,164	323	841
Wheat - N	4.0	1,012	215	797
Canola + N	2.4	1,200	415	785
Faba bean	2.9	1,160	377	783
Canola - N	2.0	1,000	307	693

Note: Grain and hay prices used in the calculations were current at the time of harvest. Variable costs were based on local practice and prices. These figures are estimated as a guide only.

Q.4 What effects do break crops have on soil nitrogen availability?

- Yarrawonga
- Culcairn

Q.4 Yarrawonga

Peak biomass sampling results (see Table below), show a clear relationship between plant DM and total nitrogen (N) fixed. In most cases, more DM accumulation resulted in an increased amount of N_2 fixed. Previous studies have shown that the percentage of N_2 fixed by most legumes in south-eastern Australia appears to range between 60–90% of total plant N and the amount of N_2 fixed tends to be related to biomass production (15–25 kg N fixed/ tonne of shoot DM). Provided there are adequate numbers of effective rhizobia in the soil and the concentrations of soil mineral N are not too high, the amount of N_2 fixed will largely be regulated by legume growth rather than by the % of the legume derived from N_2 fixation.

Vetch produced the most total plant fixed nitrogen (141 kg N/ha) followed by the arrowleaf clover (138 kg N/ha), faba beans (129kg N/ha) and sub-clover (118 kg N/ha). These results were significantly higher than the field peas (86 kg N/ha) and chickpeas (50 kg N/ha). The data in the table below suggested that the clovers and chickpeas did not fix N as efficiently as the other legumes with only 12–13 kg fixed N/t shoot DM compared with 19 kg fixed N/t shoot DM for the vetch and 15–16 kg fixed N/t shoot DM for the faba beans and field peas. This may have been the result of a later than ideal timing of peak biomass sampling in the clovers (sampling closer to senescence can result in reduced N in the leaf as N is exported for seed production).

Yarrawonga Vic (2012), estimates of nitrogen fixation

Treatment	Mean Shoot DM (t/ha)	Legume N fixed (%)	Shoot N fixed (kg N/ha)
Faba Beans	5.2	82	85
Field Peas	4.0	64	58
Vetch	5.1	79	95
Chickpeas	2.0	65	24
Subclover	5.8	69	69
P-value (<0.05)	<.001	NS	<.001
LSD	1.2		17

Q.4 Culcairn

The effect of rhizobial inoculation

A study was undertaken in 2010 in collaboration with Vic DPI and the GRDC National Rhizobium Program (GRDC project UMU00032) on an acid soil site at Culcairn in southern NSW which had a history of >10 years cereals. Inoculation increased plant reliance upon N fixation for growth (from 23% to 64% for faba bean; 26% to 58% for lupin), kg of shoot N fixed per tonne of shoot DM accumulated (from 4 to 18 kg N/tDM for faba bean; 5 to 18 kg N/tDM for lupin), and the amounts of shoot N fixed by faba bean 9-fold from 24 to 208 kg N/ha, and almost 5-fold from 37 to 169 kg N/ha by lupin. There was no significant effect of inoculation on lupin grain yield (3.5 to 3.7 t/ha), but there was a spectacular impact of inoculation on grain yield by faba bean which increased from 1.8 to 2.7 t/ha – i.e. an extra tonne of grain worth ~$300/ha for the cost of $7/ha in inoculant.

Concentrations of soil mineral N at Culcairn in 2011 were 50-100 kg N/ha higher following inoculated faba bean and lupin than either the uninoculated treatments or following canola or wheat. But while the grain yields of wheat grown after either faba bean or lupin (5.4 t/ha) were significantly higher than wheat after wheat (4.5 t/ha), there was no interaction with added N fertiliser suggesting that the improvements in yield were not necessarily associated with enhanced N supply.

Case Studies

Wilby

Three paddocks on the Glover family farm at Wilby (South of Yarrawonga), were sown as a commercial case study of faba beans (Rana), lupins (Mandelup) and clover (mix of Mintaro clover and Balansa subclover for hay). Soil tests taken during February in the lupin and faba bean paddock showed that soil pH in the top 10 cm ranged from 5 – 5.1, Colwell P ranged 69 – 110 mg/kg and soil nitrate 19 – 22mg N/kg. Each paddock had 1t/ha lime applied during March. The clover mix was sown @ 8kg/ha during mid April and the lupins were sown @ 80kg/ha in late April. Both were sown using an RFM airseeder with MAP @ 90kg/ha on nine-inch spacings. The faba beans were broadcast (which is not recommended) at 160kg/ha during late April and worked in with MAP @ 90kg/ha. Although broadcasting seed is not ideal, good germination was still achieved due to excellent rainfall after sowing. However, lack of seeding depth did contribute to plants lodging during the season which subsequently caused issues at harvest. All pulses were inoculated with standard peat inoculant just prior to sowing. Grain yield and biomass was recorded for each faba bean, lupin and clover paddock, and grain yields were collated across the whole farm for wheat and canola. The costs of production were determined from the farmer's own records and the value of grain or hay at the time of harvest were used to calculate gross margins.

Comparisons of on-farm grain yield, hay production, income, variable costs and gross margins for commercial crops grown at Wilby in 2014. *Crops arranged in order of descending gross margin.*

Treatment	Grain or hay yield (t/ha)	Gross income ($/ha)	Total variable costs ($/ha)	Gross margin ($/ha)
Faba bean	3.5	1,715	453	1,262
Wheat + N	4.3	1,161	323	838
Canola + N	2.8	1,232	415	817
Subclover hay	4.3	1,075	292	783
Lupin	2.5	1,025	297	728

Note: Grain and hay prices used in the calculations were current at the time of harvest. Variable costs were based on farmer records. These figures are estimated as a guide only.

For the more details in the full report CLICK HERE

Southern Farming Systems

Two crop competition sites were established at Inverleigh and Lake Bolac in south west Victoria, commencing in 2011 and finishing in 2013. At each site 4 x 40 m plots were established for each competing team to grow and manage their respective sequences of crops over the three year period. Each plot was allocated a team, which consisted of either farmers, advisers, researchers or academics, who competed against one another to achieve the highest yearly and rotational (3 years) gross margin. The choice of pulse and crop cultivar, sowing and in-crop management and grain marketing were at the discretion of each team, although a pulse had to be grown in 2011, all teams chose to grow canola in 2012, followed by a compulsory wheat crop in 2013.

For more information about the 'Methods' for the trials CLICK HERE

Q1. Can a break crop be as profitable as a cereal?

Crop competitions showed large variations in returns, despite all teams growing identical sequences of crops on the same soil types and receiving the same amounts of rainfall at the respective Inverleigh and Lake Bolac sites. The teams achieving the highest financial returns were those that produced high yielding crops whilst minimising their costs of production, reducing weed pressures through effective herbicide programs, combined with conservative in-crop N fertiliser applications and choice of longer seasoned wheat cultivar suited to above average spring rainfall received in 2013.

- Inverleigh Crop Competition
- Lake Bolac Crop Competition

Yearly grain yield (GY) and yearly and rotational (3 years) total cost (TC) and gross margin (GM) for each team at Inverleigh and Lake Bolac from 2011 to 2013, in south west Victoria.

Team	2011 Pulse				2012 Canola				2013 Wheat				3 Year	
	Crop	GY t/ha	TC $/ha	GM $/ha	Variety	GY t/ha	TC $/ha	GM $/ha	Variety	GY t/ha	TC $/ha	GM $/ha	TC $/ha	GM $/ha
							Inverleigh							
A	Faba Bean	2.77	526	277	Hyola 555TT	3.05	472	1295	Bolac	7.06	405	1403	1403	2975
B	Faba Bean	0.00[A]	376	-376	Hyola 971CL	3.44	452	1460	Elmore CL+	5.64	554	1124	1382	2208
C	Faba Bean	4.11	569	653	Hyola 575CL	3.10	456	1308	Phantom	5.7	398	1038	1423	2999
D	Lupin	3.46	374	543	Hyola 575CL	2.83	559	1003	Revenue	7.38	396	1853	1329	3399
E	Field Pea	2.28	415	332	Hyola 555TT	2.47	474	914	Beaufort	5.37	499	774	1388	2020
F	Field Pea	2.26	426	191	Hyola 575CL	2.88	481	1105	Phantom	5.97	451	1120	1358	2416
							Lake Bolac							
G	Faba Bean	2.06	573	24	Hyola 505RR	2.45	443	960	Scout	6.30	402	1338	1418	2322
H	Faba Bean	0.00[B]	368	-368	Thumper TT	2.39	629	628	Beaufort	3.70	413	462	1410	722
I	Faba Bean	3.08	606	287	Crusher TT	2.37	460	821	Phantom	5.06	449	884	1515	1992
J	Faba Bean	4.05	626	562	Hyola 555TT	2.36	540	767	Phantom	5.64	466	1117	1632	2446
K	Lupin	1.59	318	103	Garnet	2.50	419	1050	Revenue	6.18	422	1220	1159	2373
L	Field Pea	1.45	326	-154	Cougar RR	3.51	1523[D]	228	Revenue	7.17	507	1247	2356	1321
M	Field Pea	0.00[B]	371	0[C]	Taurus	2.07	634	652[E]	Phantom	5.96	434	1141	1439	1793

[A]planned brown manure, [B]failed crop due to inadequate weed control, [C]includes income from silage cut, [D]subsoil manured treatment, [E]includes income from grazing over summer.

Q.1 Inverleigh Crop competition

The crop competition at Inverleigh highlighted the great variability in profitability that can be achieved through the use of different management strategies of various pulse species. In Year 1, single year gross margins (see table above) varied from -$376/ha for a brown manure faba bean crop to $653/ha for a faba bean crop harvested for grain that had good weed control. Lupins and field peas grown for grain were other options explored. The difference of greater than $300/ha between the best faba bean grain treatment ($653/ha) and the poorer managed faba bean grain treatment ($277/ha) highlights how much of a difference good agronomic management can make.

Q.1 Lake Bolac Crop competition

The crop competition at Lake Bolac highlighted the great variability in profitability that can be achieved through the use of different management strategies of various pulse species. This site had a high background ryegrass population and how well this was managed had a great impact on the gross margins achieved. In Year 1, single year gross margins varied from -$376/ha for a failed Faba Bean crop to $562/ha for a Faba bean crop harvested for grain (4 t/ha) that had good weed control. It is also interesting to note that where ryegrass wasn't managed well in the field peas grown for grain treatment that there was a negative gross margin (-$154/ha) and the opportunity to manage the weed seedbank was missed which resulted in one of the poorest cumulative gross margins.

Q2. Are sequences including break crops more profitable than continuous wheat?

Grain yield and the cost of production were highly significant (P<0.001) indicators of financial returns from crop sequences (Figure 1.). Cost structures across all teams were similar (http://www.agronomy2015.com.au/papers/agronomy2015final00155.pdf) with the exception of Team L, whose investment into subsoil manure was not offset by subsequent yields and returns from canola and wheat. Subsoil manure is likely to provide longer term yield responses (Sale *et al*. 2012) and a three year study insufficient time to assess the economic merits of this strategy. Nonetheless, the additional cost incurred by Team L decision to subsoil manure meant the cost of production (Figure 1a) provided a better prediction of gross margin than grain yield (Figure 1b).

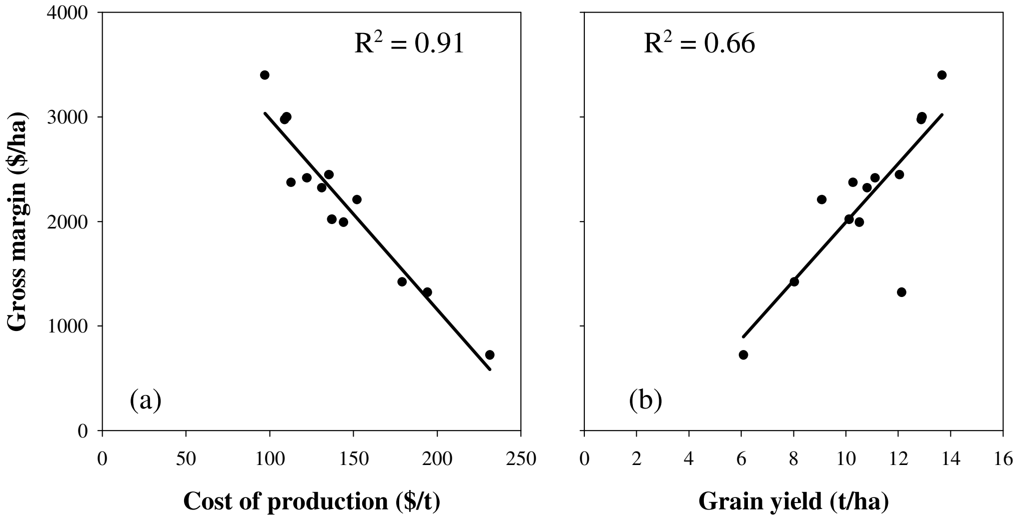


Figure 1. Relationships between total rotational (pulse, canola and wheat) cost of production (a) and grain yield (b) with total rotational gross margin.

- Inverleigh Crop Competition
- Lake Bolac Crop Competition

Q.2 Inverleigh Crop competition

The Inverleigh site crop competition winner achieved the highest 3-year cumulative gross margin of $3399/ha. The winning crop sequence was Lupins (grain) – CF Canola (grain) – Wheat (feed grain). The wheat variety choice in Year 3 coupled with good agronomic management choices appeared to capitalise best on the good management choices made during the double break.

Q.2 Lake Bolac Crop competition

The Inverleigh site crop competition winner achieved the highest 3-year cumulative gross margin of $2446/ha. The winning crop sequence was Faba Bean (grain) – TT Canola (grain) – Wheat (grain). Whilst this was a different rotation to the winner at Inverleigh, the same relationship existed for the cumulative 3 year gross margin and costs of production. This highlights that, agronomic management needs to be coordinated for each year of the cropping sequence.

Q.3 Can a weed problem be managed more cost effectively with break crops than in a continuous cereal system?

Effective weed control and timely fungicide treatments in the first crop at both sites strongly influenced pulse yield and gross margin. At Inverleigh, pulse yields were higher where post emergence herbicides were applied to control wild radish. Weed control at Lake Bolac was entirely dependent on incorporating pre- emergent herbicide at sowing; teams opting to spray later were unable to control ryegrass populations that appeared resistant to in-crop herbicide treatment, resulting in unplanned brown manured crops.

Financial returns from canola and wheat at both sites were largely driven by robust herbicide programs that minimised weed pressures, in combination with conservative N fertiliser applications and longer seasoned wheat cultivar selection. Weed control strongly influenced crop performance and returns, highlighted by Team E, at Inverleigh who applied Atrazine post emergent to canola, but did not follow up with a second application later in the season resulting in unsatisfactory wild radish control. Teams G and K at Lake Bolac had low ryegrass populations (data not shown) and produced higher yielding wheat crops and gross margins compared with most teams, except Team L where subsoil manure may have also helped increase ryegrass populations. Generally teams applied conservative rates of N fertiliser, most underestimating demand especially in the wheat crop receiving favourable spring rainfall, at both sites grain protein levels were well below 11% (data not shown).

Q.4 What effects do break crops have on soil nitrogen availability?

The N_2 fixation data collated across all 21 crops in the SFS 'Pulse Challenge' indicated a strong relationship between the amounts of shoot N fixed (ranged from 1-163 kg N/ha) and shoot DM (0.04 t DM/ha where grass weeds were not controlled to 7.2 t DM/ha) and on average 19 kg shoot N was fixed per tonne shoot DM accumulated (Fig. 1c and d). Similar relationships were observed in trials undertaken in association with MFMG in SA and FarmLink in southern NSW, and have been reported previously across a range of environments and legume species.

See more at: http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Legume-effects-on-soil-N-dynamics-Corowa#sthash.QBmufjRK.dpuf

Where direct comparisons have been undertaken, field pea generally fixed less N than either faba bean or lupin. When the three pulses were compared side-by-side, in the SFS 'Pulse Challenge' competition, field pea fixed less N per tonne shoot dry matter (DM) production than either lupin or faba bean (Fig. 1a). Field pea's lower reliance upon N_2 fixation for growth (%Ndfa) suggested that it was more sensitive to soil nitrate at sowing than the other crops (40 and 84 kg N/ha at Inverleigh and Lake Bolac at 0-100 cm, respectively; Fig. 1b).

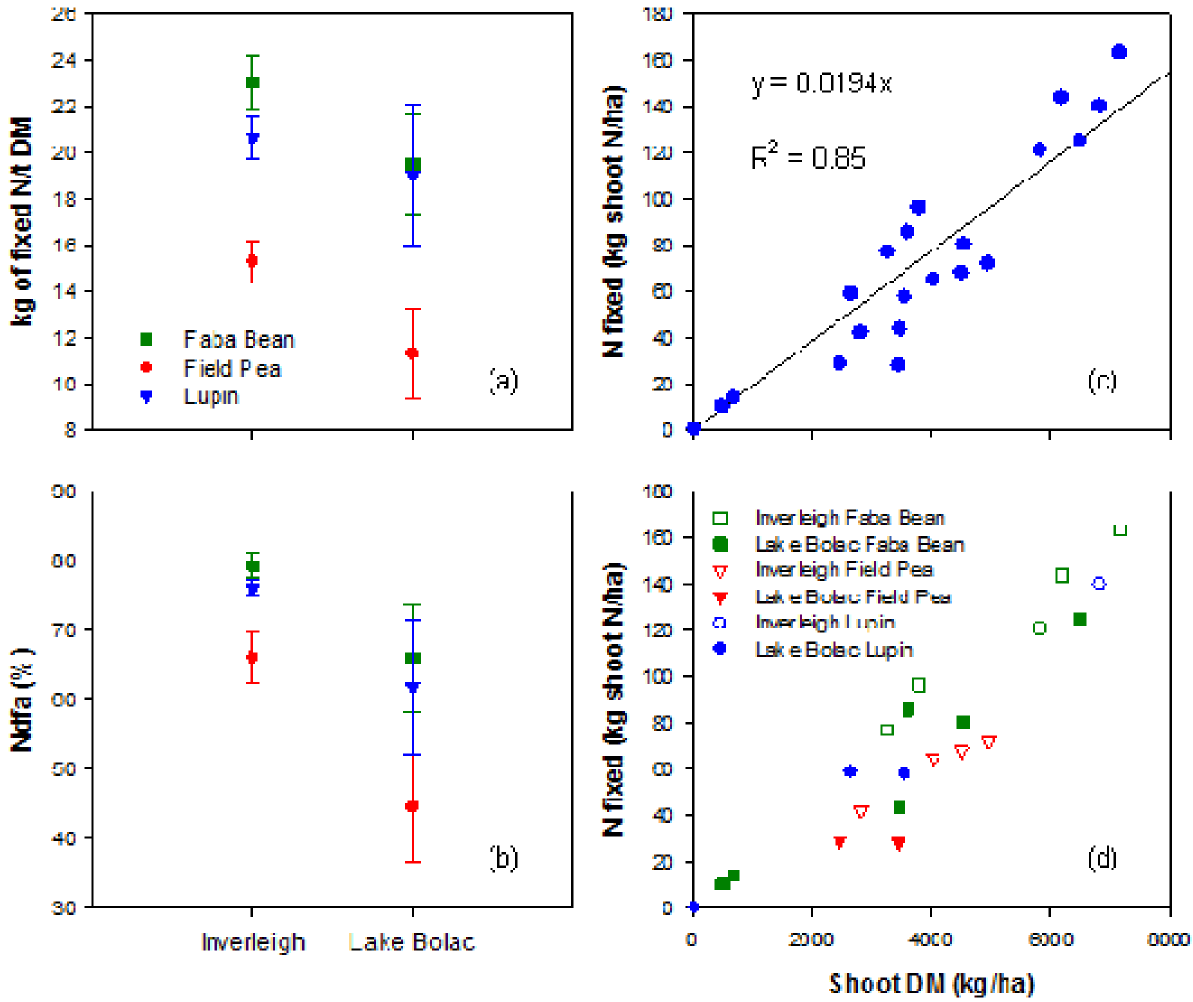
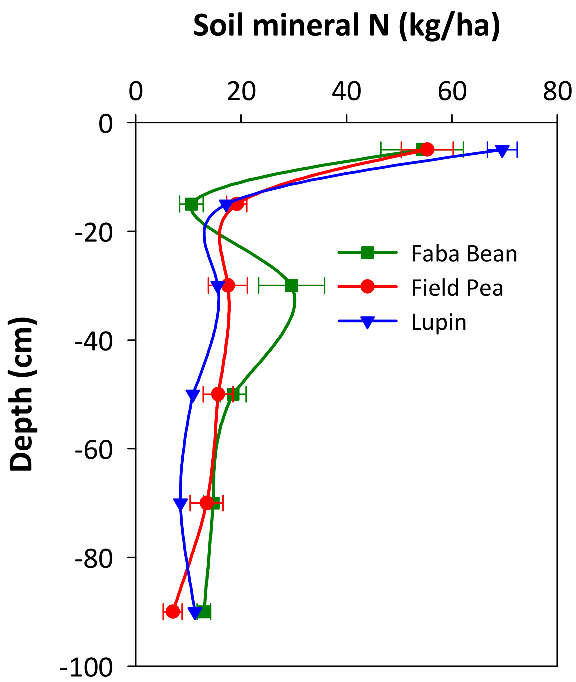


Figure 1. Estimates of (a) the amounts of shoot N fixed per tonne of above-ground dry matter (DM) by faba bean, lupin or field pea grown at Inverleigh and Lake Bolac, Vic in 2011, and (b) the percentage of legume N derived from the atmosphere (%Ndfa) for each pulse species and location. The relationship between the amount of shoot N fixed and pulse shoot DM depicted in (c) and (d) represented 19.4 kg N per tonne DM accumulated across all crops (R2 = 0.85).
Bars indicate standard deviation.

- Inverleigh Crop Competition
- Lake Bolac Crop Competition

Q.4 Inverleigh Crop competition

Residual soil mineral N levels at the Inverleigh site in the year after break crops, were greatest after faba bean, compared with lupin and field pea crops (see figure below). The soil mineral N data correlated well with the N fixation measurements taken from the previous pulse crops, indicating that faba beans produced more legume biomass and fixed more N (see Figure 1 above), providing greater subsequent contributions to soil N build up.



Distribution of Soil Profile N at Inverleigh in 2012 following one year of break crops.
Bars indicate standard deviation.

Q.4 Lake Bolac Crop competition

At the Lake Bolac site, the association between previous N fixation and subsequent soil mineral N (Figure 1) was less evident, and this may be explained by the higher background soil N, in comparison to the Inverleigh site measured prior to the commencement of the competition in 2011 (Figure 2 below). The lower %Ndfa measured in the pulse crops grown at the Lake Bolac site (see Figure 1 above) provides support for this theory. It has been demonstrated that N_2 fixation in pulse crops declines in the presence of high soil N, as soil N uptake was less taxing on plant energy reserves than atmospherically derived N (Evans et al. 1989; Peoples et al 2009).

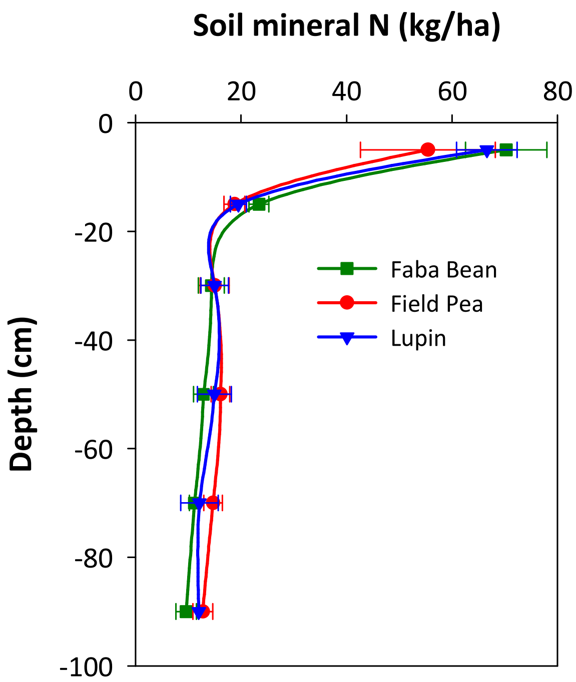


Figure 1. Distribution of Soil Profile N at Lake Bolac in 2012 following one year of break crops.
Bars indicate standard deviation.

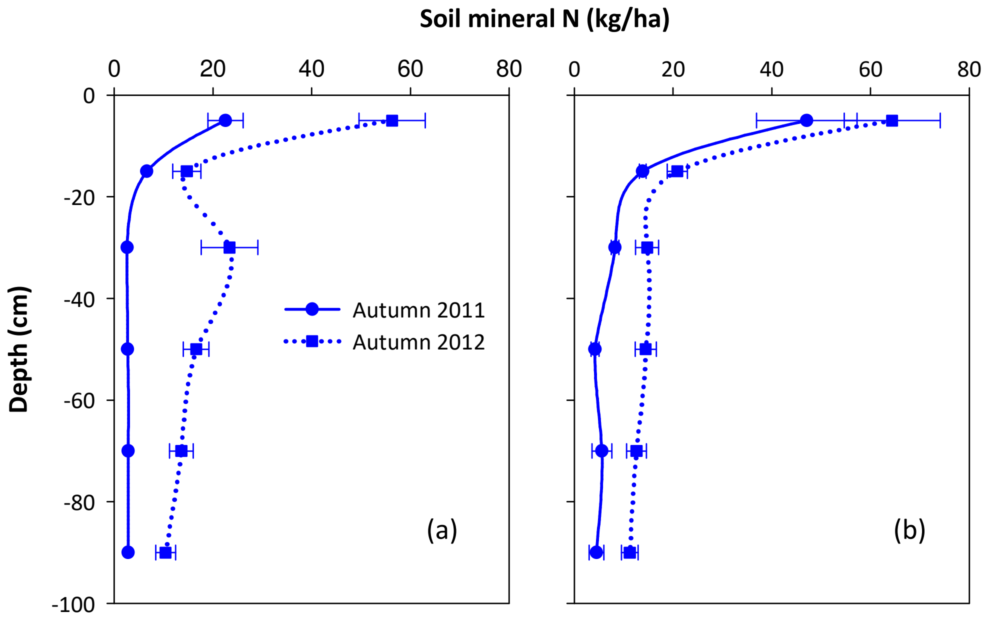


Figure 2. Comparison of soil profile N near the break of season in 2011 and 2012 at Inverleigh (a) and Lake Bolac (b). Mean of all pulse crops.
Bars indicate standard deviation.

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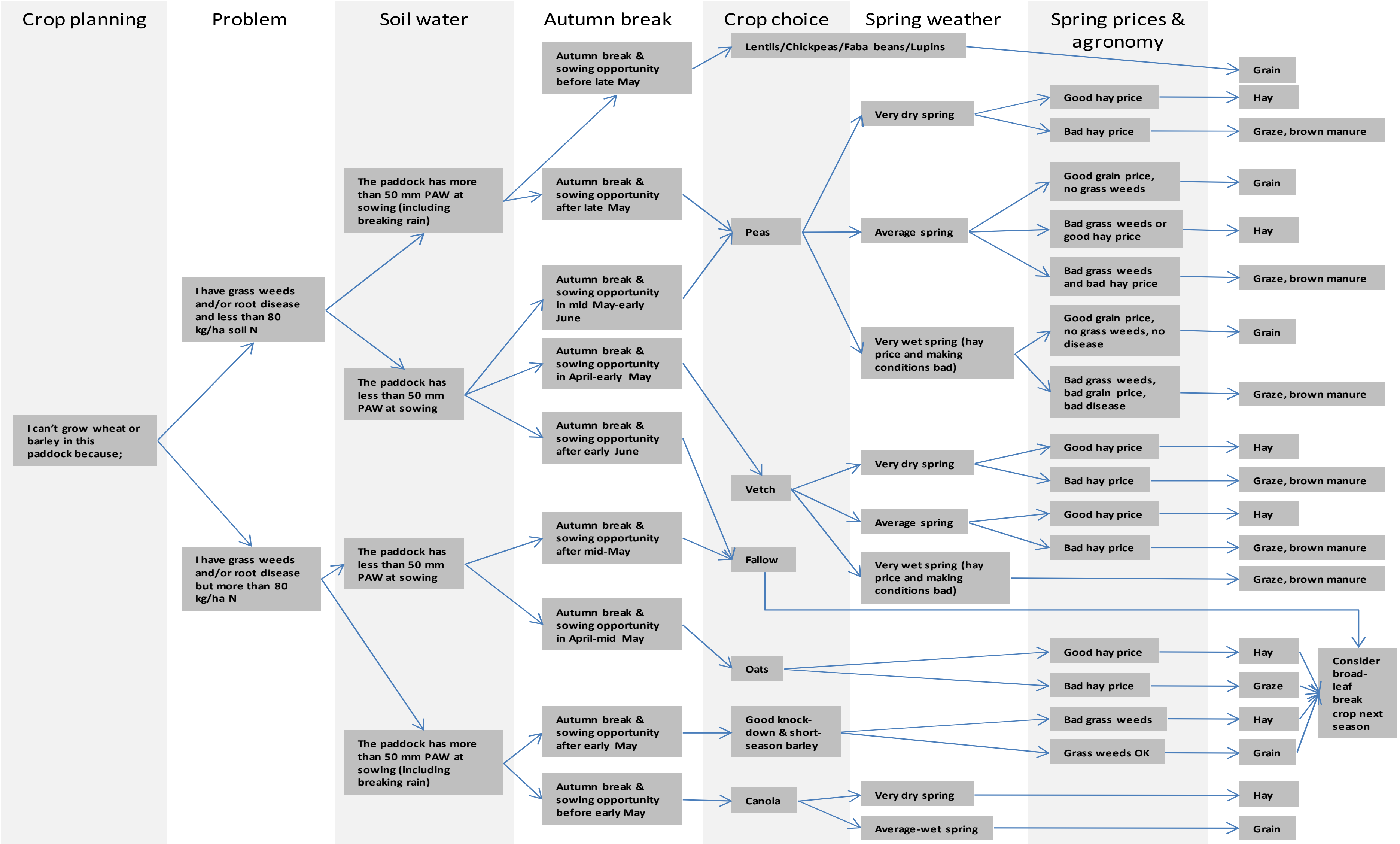
Appendices

Appendix A

Break crop decision-tree: Using paddock history and seasonal growing conditions to decide when it is best to use broadleaf options



Appendix B

Break Crop Checklist

Break Crop Checklist

Red	Reconsider
Amber	Caution
Green	OK

Crop option	Rainfall Zone			Soil Factors					Weeds		Paddock History	Disease Risk			
				Mineral N		pH	Texture		Grasses	Broadleaves	Herbicide residues	Root		Other	
	High/ Irrigated	Medium	Low	High	Low		Light	Heavy				Take All	Crown Rot	Yellow Spot	Blackleg/ Sclerotinia
Grain															
Lentil	Caution	OK	Caution	Caution	OK	Reconsider			OK	Caution	Caution	OK	OK	OK	OK
Faba bean	OK	OK	Caution	Caution	OK	Caution			OK	Caution	Caution	OK	OK	OK	OK
Lupin	OK	OK	OK	Caution	OK	Caution			OK	Caution	Caution	OK	OK	OK	OK
Field Pea	Caution	OK	OK	Caution	OK	Caution			OK	Caution	Caution	OK	OK	OK	OK
Chickpea	Caution	OK	Caution	Caution	OK	Reconsider			OK	Caution	Caution	OK	OK	OK	OK
Vetch	OK	OK	OK	Caution	OK	Caution			Caution	Caution	Caution	OK	OK	OK	OK
Canola	OK	OK	Caution	OK	Caution	Caution			OK	Caution	Caution	OK	OK	OK	Reconsider
Hay															
HDL	OK	OK	Reconsider	Caution	OK	Caution			OK	Caution	Caution	OK	OK	OK	OK
Subclover	OK	OK	Reconsider	Caution	OK	OK			OK	Caution	Caution	OK	OK	OK	OK
Cereal	OK	OK	OK	OK	Caution	OK			OK	OK	Caution	Reconsider	Reconsider	Reconsider	OK
Brown Manure															
Field Pea	OK	OK	OK	Caution	OK	Caution			OK	Caution	Caution	OK	OK	OK	OK
Vetch	Caution	OK	OK	Caution	OK	Caution			OK	Caution	Caution	OK	OK	OK	OK
HDL	OK	OK	Reconsider	Caution	OK	Caution			OK	Caution	Caution	OK	OK	OK	OK

Appendix C

Summary of key experimental findings and on-farm measures of N_2 fixation

Comparisons of different legume species

Pulse crops - Several project studies have demonstrated the impact of crop species and their productivity on inputs of fixed N. This was exemplified by the SFS 'Pulse Challenge' competition where 21 farmer, agribusiness and researcher teams grew either field pea, lupin or faba bean at either Lake Bolac or Inverleigh, Vic in 2011. The N_2 fixation data collated across all 21 crops indicated a strong relationship between the amounts of shoot N fixed (1-163 kg N/ha) and shoot dry matter (DM) production (0.04 t DM/ha where grass weeds were not controlled to 7.2 t DM/ha) regardless of the species with on average 19 kg shoot N fixed per tonne shoot DM accumulated (R^2 = 0.85). As discussed elsewhere, similar relationships were observed in many other experimental trials. An easy way for growers to estimate the likely amounts of N_2 fixed being achieved in their own crop is to take advantage of the observation that the harvest index (proportion of above-ground biomass partitioned in grain) of crop legumes is often 30-35%. Therefore, the total shoot dry matter accumulated by a pulse crop would approximate 3 x the weight of legume grain harvested (t/ha). Consequently the amounts of shoot fixed (kg N/ha) would equate to approximately 60 x harvested legume grain yield (t/ha).

Where different pulses have been compared side-by-side either lupin or faba bean often fixed more N than other legume crops, which often reflects greater biomass production by these two species.

Pasture legumes - An on-farm trial sown at Ariah Park, NSW in May 2010 compared 13 different annual legume species in a paddock where the farmer was re-establishing a pasture following several years of drought. There had been heavy rainfall over summer stimulating mineralisation of the native soil organic N, resulting in the top 90 cm of the soil profile containing 200 kg nitrate-N/ha at the time of sowing. The legume genotypes responded differently to above-average spring rainfall in terms of herbage DM production (3.5-7.7 t herbage DM/ha) and N_2 fixation (28-106 kg shoot N/ha). Estimates of the percentage of the legume N derived from atmospheric N_2 (%Ndfa) for most species ranged between 33 and 57%, but the %Ndfa for rose clover and pink serradella were 65-71%. Since these higher %Ndfa values were not necessarily related to biomass production, it appeared that these species either have some degree of genetic tolerance to high soil nitrate in terms of nodulation and N_2 fixation, or less capacity to scavenge soil mineral N relative to the other species.

Other studies across southern NSW have indicated that %Ndfa by annual legumes were often higher than lucerne, especially in the year of pasture establishment and where lime was applied to acid soils. The %Ndfa by annuals could be further increased if they were grown in mixtures with a perennial grass such as phalaris. However, this also resulted in reduced legume productivity so that the amounts of N fixed were lower than when legumes were grown alone. Annual amounts of N fixed was generally greatest where lucerne was sown with annual legumes, although there were apparent differences between annual species in their capacity to fix N.

Net inputs of fixed N by different species - Estimates of net inputs of fixed N (ie total amounts of N fixed – N removed or lost) tended to be greater for brown manure crops and pasture legumes (hay cut or grazed) than pulses grown for grain at almost all experimental sites since 2011 because of the large amounts of N exported from the paddock in high-protein grain (from 30-60 kg N per tonne harvested).

The effect of rhizobial inoculation

An inoculation study was undertaken in 2010 in collaboration with the GRDC National Rhizobium Program (UMU00032) and the Riverine Plains on an acid soil site at Culcairn, NSW which had a history of >10 years cereals. Inoculation increased %Ndfa (23% to 64% for faba bean; 26% to 58% for lupin), shoot N fixed per tonne of shoot DM accumulated (from 4 to 18 kg N/t DM for faba bean; 5 to 18 kg N/t DM for lupin), and the amounts of shoot N fixed (from 24 to 208 kg N/ha for faba bean, and 37 to 169 kg N/ha for lupin). There was no significant effect of inoculation on lupin grain yield (3.5 to 3.7 t/ha), but yield by faba bean increased from 1.8 to 2.7 t/ha resulting in an additional return of ~$300/ha for the cost of $7/ha in inoculant.

Another inoculation study with lupin was undertaken on acid soils in 2013 by CWFS near Condobolin in central NSW. Again a measurable increase in %Ndfa (56% *cf* 77%) and shoot N fixed per tonne of shoot DM (from 13 to 17-21 kg N/t DM) were observed with inoculation. However, three studies undertaken by BCG on alkaline soils at Rupanyup in 2011 (previous legumes were lentils in 2007 and chickpea in 2003), Birchip in 2012 (previous legume was vetch in 2001), and at Watchupga East, Vic in 2013 (previous legume was vetch in 2006) failed to detect measurable responses to inoculation in %Ndfa or fixed N for a range of pulses except chickpea at Watchupga East, where inoculation increased %Ndfa from 57% to 92%, the amounts of N_2 fixed from 12 to 32 kg shoot N/ha, and improved grain yield by 0.7 t/ha and income by $272/ha.

In summary, large increases in N_2 fixation have been observed with rhizobial inoculation where either rhizobia were absent because a particular pulse species had never been grown before, or where rhizobial numbers were low after a long period between pulse crops. However, the general lack of response to inoculation in the Vic Mallee suggests that sufficient rhizobia can often survive in alkaline soils (in contrast to acid soils) so nodulation and N_2 fixation appears less likely to be constrained by low rhizobial numbers in alkaline soils.

N_2 fixation in commercial pulse crops and pastures

A total of 47 commercial pulse crops and 5 farmers' pasture paddocks (4 cut for hay and one grazed) were sampled for determinations of on-farm measures of N_2 fixation across southern and central NSW, Vic and SA (see Table below). Amounts of shoot N fixed ranged from 12-191 kg N/ha (mean 76 kg N/ha and 15 kg N/t DM) and %Ndfa from 8-89% (mean 64%). Of the 52 assessments undertaken, there was evidence of poor N_2 fixation on 11 occasions (~20% of measures), where estimates of %Ndfa were <50% and/or <10 kg shoot N was fixed per tonne of shoot DM produced. In some instances low N_2 fixation was directly related to drought effects on growth, or associated with high concentrations of soil nitrate where periods of drought were followed by wet summer-autumns, while in others it appeared to result from either a practice of routinely sowing uninoculated crops, very early termination with knock-down herbicides for use as brown manures, or possible carry-over of herbicides applied to the previous crop.

Summary of shoot dry matter (DM) production and estimates of the proportion (%) and amounts of N_2 fixed by 47 commercial pulse crops and legumes in 5 on-farm pasture paddocks.

Values in brackets represents the mean for each species

Legume	Number	Shoot DM	Shoot N fixed		
	(*n*)	(t DM/ha)	(%Ndfa)	(kg N/ha)	(kg N/t DM)
Faba bean	16	3.1-9.2	42-89	46-191	10-21
		(6.2)	(67)	(104)	(16)
Lupin	14	0.9-10.2	20-82	20-150	9-21
		(5.6)	(63)	(83)	(16)
Field pea	8	2.3-5.9	8-85	12-87	2-20
		(3.8)	(56)	(46)	(14)
Chickpea	6	0.8-5.2	24-87	13-66	7-17
		(2.9)	(67)	(34)	(13)
Lentil	3	2.0-5.3	17-82	20-104	4-20
		(4.0)	(50)	(51)	(13)
Vetch	3	4.2-6.3	53-84	53-135	13-22
		(5.1)	(69)	(89)	(17)
Subclover	2	0.5-6.2	79-82	13-145	20-22
		(3.3)	(81)	(79)	(21)
Mean			64	76	15

Appendix D

Comparison of fertiliser and legume N

Elevated concentrations of soil mineral N (i.e. nitrate+ammonium) are frequently observed after legume crops and pastures, but only a fraction of the legume N tends to be recovered by the next crop (Peoples *et al* 2009). However, it is not easy for grain-growers or their advisors to know whether the relative recovery of N supplied by legumes to following crops is more or less efficient than N supplied as fertiliser. This section collates data collected from the Junee Reef's trial to compare estimates of the apparent recovery of N provided by either lupin stubble remaining after grain harvest, or a brown manured (Bm) lupin killed with herbicide prior to grain filling with measures of wheat's apparent uptake of top-dressed fertiliser N when grown after a preceding wheat or canola crop.

In 2012 wheat was sown into plots that had grown either lupin, canola or wheat in 2011. All the 2011 lupin plots received starter fertiliser of 25 kg/ha MAP (2.5 kg N/ha), top-dressed with 100 kg/ha urea (46 kg N/ha) at stem elongation. In the case of the 2011 wheat and canola areas, each plot was split into 2x10m sub-plots with one half being treated as described above, and the other being top-dressed with 210 kg/ha urea (97 kg N/ha) just prior to stem elongation.

The apparent recoveries of legume N from 2011 or top-dressed fertiliser N by the 2012 wheat crop were calculated as:

Apparent recovery of legume N (% 2011 total residue N)

= 100x [(wheat N_{49N} after legume) – (wheat N_{49N} after wheat)] /(total legume residue N) Equation [1]

Apparent recovery of fertiliser N (% additional N applied)

= 100x [(wheat N_{100N}) – (wheat N_{49N})] /(51) Equation [2]

Crop growth in 2011 - The 2011 growing season rainfall (GSR: April-October) was 216 mm which was lower than the 311 mm long-term average, but heavy rainfall in February 2011 (226 mm) resulted in an annual total of 639 mm, around 130 mm wetter than the long-term average (506 mm). The soil moisture profile at the beginning of the growing season was close to full which contributed to good crop establishment, growth, and grain yields (Table 1). The lupin treatments were calculated to have accumulated a total of 290 kg N/ha (lupin Bm) and 398 kg N/ha (lupin grain crop). The crop harvest indices (grain as % of above-ground DM) were 35% for lupin, 43% for wheat and 30% for canola. The N content of the stubble remaining after grain harvest was higher for the lupin crop (1.4%N; C:N ratio=28) than either canola (0.7%N; C:N=60) or wheat (0.3%N; C:N=130), but was highest in the lupin Bm treatment (2.6%N; C:N=15). The total amounts of N calculated to be remaining in the vegetative residues and roots of the lupin treatments at the end of the 2011 growing season were 3 to 5 times more than wheat, and ~2 to 3 times more than canola (Table 1).

Table 1. Above-ground dry matter (DM), N accumulation, grain yield and the amount of N estimated to be remaining in vegetative and root residues at the end of the growing season where wheat, canola, or lupin was grown for either grain or brown manure (Bm) at Junee, NSW in 2011[a]

Crop grown in 2011	Peak biomass (t DM/ha)	Above-ground N (kg N/ha)	Total crop N[b] (kg N/ha)	Grain yield (t/ha)	Grain N harvested (kg N/ha)	N remaining in residues (kg N/ha)
Lupins BM	8.4	218	290	0	0	290
Lupins	9.9	300	398	3.5	210	188
Wheat +N[a]	11.1	106	151	4.8 (10.4% protein)	87	64
Canola +N[a]	10.6	164	207	3.2 (46% oil)	94	113
LSD (P<0.05)	1.3	36	46		11	22

[a] N fertiliser was applied to wheat @ 49 kg N/ha and canola @ 66 kg N/ha.

[b] Above-ground data adjusted to include an estimate of below-ground N (Peoples *et al.* 2009).

Comparisons of wheat N uptake in 2012 - Wheat sown in 2012 after either the lupin grain or BM crops accumulated 55-80 kg N/ha (50-74 %) more N than the equivalent wheat on wheat treatments (Table 2). Presumably this reflected a combination of the higher concentrations of mineral N at sowing, and greater in-crop mineralisation. By way of comparison, N uptake by wheat grown after wheat was increased by 25-30 kg N/ha (21-28%) where the supply of top-dressed fertiliser N was raised from 49 to 100 kg N/ha (Table 2). Grain proteins were also higher after both lupin treatments and where additional fertiliser N was applied, but grain yields were only 0.4-0.6 t/ha higher than achieved by wheat grown after wheat or canola (Table 3) since the exceptionally dry spring and low GSR in 2012 (168 mm) prevented the full benefits of the increased N uptake and greater crop growth being translated into grain yield. The estimates of the apparent recoveries of legume or fertiliser N by wheat derived using equations [1] and [2] above suggested that the 2012 wheat crop recovered the equivalent of 27-28% of the lupin residue N and 47-59% of the additional top-dressed fertiliser (Table 2).

Table 2. Shoot biomass, grain yield and total N uptake by wheat in 2012 following either wheat, canola and lupin grown for grain or brown manure (Bm) at Junee, NSW in 2011, and calculations of the apparent recoveries by wheat of either N from lupin residues, or top-dressed fertiliser N.

Crop grown in 2011	N fertiliser applied[a] (kg N/ha)	Shoot biomass (t DM/ha)	Grain yield (t/ha)	Grain protein (%)	Wheat N Uptake[b] (kg N/ha)	Apparent N recovery (%)
Lupins BM	49	11.2	4.0	13.6	184	27
Lupins	49	10.8	3.9	12.4	159	28
Wheat	49	9.4	3.4	9.9	106	-[c]
Wheat	100	9.9	3.8	11.7	136	59
Canola	49	10.2	3.4	9.8	113	-[c]
Canola	100	10.3	3.8	11.8	137	47
LSD (P<0.05)		1.0	0.3	0.8		

[a]All 2012 wheat plots received a total of either 49 or 100 kg N/ha comprising of either 2.5 and 46 kg N/ha, or 7.5 and 92 kg N/ha applied at sowing and stem elongation (GS31); respectively.

[b] Total wheat N uptake derived from shoot N data assuming ~30% of the wheat total N was below-ground.

[c] There was no nil N fertiliser control so it was not possible to estimate N recovery for the 49 kgN/ha treatment.

It is difficult to find other Australian experiments to undertake similar calculations to assess how representative the estimates of N recovery presented in Table 2 might be. However, the apparent uptake of faba bean residue N by wheat was able to be determined from data collected during a trial undertaken at Breeza on the Liverpool Plains in northern NSW in the late 1990's. In this case, the equivalent of 40% of faba bean N was calculated to be recovered by the next crop (Table 3), a value slightly greater than estimated for lupin at Junee. Comparisons of treatments with or without above-ground residues imposed in the Breeza study suggested that ~70% of the faba bean N recovered by wheat came from the nodulated roots.

Table 3. Wheat N uptake in 1998 following either faba bean or barley grown at Breeza, NSW in 1997, and calculations of the apparent recoveries by wheat of the N from faba bean residues.[a]

Crop grown in 1997	Residue N in 1997[b] (kg N/ha)	Wheat N uptake in 1998 (kg N/ha)	Apparent recovery legume N (%)
Faba bean	96	97	40
Barley	73	59	-

[a] Source: Peoples *et al* (2009). Note: no fertiliser N treatments were included in this study.

[b] Includes an estimate of the contribution of below-ground N.

The relatively high apparent recovery (47-59%, Table 2) of the top-dressed fertiliser by the 2012 Junee wheat crop is not totally unexpected since the N was applied just prior to the period of peak crop demand for N, which is consistent with the most appropriate timing for N applications to achieve the highest efficiencies of N use and lowest risks of N losses (Crews and Peoples 2005). It would be misleading to compare these numbers for top-dressed N with that for lupin or faba bean N shown in Tables 2 and 3. A more appropriate comparison of the efficiency of recovery of N from legume sources would be against the uptake of the basal fertiliser N applied at sowing. Unfortunately the experimental design used at Junee prevented such an estimate to be calculated, although a number of studies have monitored the fate of fertiliser N supplied at sowing using isotopic tracers in the past in various rainfed cereal systems around the world (summarised in Table 4). While Table 4 indicates that there can be a range of results, it might be concluded that on average roughly one-third of the fertiliser N applied at sowing tends to be assimilated by the cereal crop. This value is roughly similar to the estimates obtained for the apparent recovery of lupin and faba bean reported in Tables 2 and 3.

Table 4. Summary of the fate of fertiliser N applied at sowing collated from different rainfed cereal production systems.[a]

Measures	Crop uptake (% applied N)	Recovered in soil (% applied N)	Unrecovered [assumed lost] (% applied N)
Range	17-50	21-40	16-62
Mean	36	31	33

[a] Source: Crews and Peoples (2005)

Appendix E

Nitrogen and weeds 'rules-of-thumb'

'Rule of Thumb': Nitrogen

These recommendations have been developed to help decide where to include a break crop in a cropping sequence and to assist with management of subsequent crops grown after break crops.

Additional mineral N (kg N/ha) in autumn = 15 x previous year's pulse grain yield (tn/ha)

<u>Factors affecting the amount of soil mineral N after legumes</u>

- Rainfall over the summer fallow between growing seasons – **Mineralisation of legume N is mediated by soil microbes**
- Residue biomass – **Determines the amount of legume N present**
- N content & "quality" of the residues – **Brown manure *vs* pulse stubble after harvest**
- End-use of legume – **timing of termination**

N Budgets

Net N Balance (previous pasture/crop) = N inputs-N losses

Subsequent wheat N requirement = Target yield (t/ha) x 40 (kg N/ha)

RISK: Overestimating N can result in loss of potential yield in subsequent crop whilst underestimating can cause 'haying off'.

'Rule of Thumb': Weeds

These recommendations have been developed to help decide where to include a break crop in a cropping sequence and to assist with management of subsequent crops grown after break crops.

0.5 tn/ha reduction in wheat grain yield for every 1 tn/ha annual ryegrass DM present in the spring

RECOMMENDATIONS

- ❑ Monitor spring ryegrass populations
- ❑ Use double breaks in the presence of very high weed burdens
- ❑ Be prepared to follow single breaks with high inputs in subsequent wheat
- ❑ Time spraying out of brown manure crops, spray topping of harvested pulses and silage/hay cutting to the flowering of target weed

Double break examples

Rainfall Zone	Year 1	Year 2
High/Irrigated	Faba beans (ideally crop-topped and narrow windrows burnt)	Canola (RR or RT hybrids particularly effective, ideally narrow windrows burnt)
All	Legume-based pasture (winter cleaned and spray topped, fallowed and/or cut for hay prior to annual ryegrass seed set in spring)	Cereal hay or silage (cut and sprayed prior to annual ryegrass seed set)
Low-Medium	Lupins (post-emergent grass selective and crop topping herbicides used)	Canola (RR, RT or TT depending on best fit of variety)

Appendix F

Summary of Project experiments (2010-2015)

Irrigated Systems

(a) Irrigated Cropping Council (ICC)

Prior crop effects on plant growth and yield under irrigation:

Kerang, Vic

2010: Large blocks of faba bean, canola, or wheat sown

2011: Faba bean, canola, wheat, and barley sown over previous treatments (except no beans-on-beans or canola-on-canola)

2012: Complete matrix of crops grown on 2011 crops

2013: Complete matrix of crops grown on 2012 crops

Farmer "champion" case studies:

Numurkah and Ardmona, Vic

2012-2013: Describing trends in available soil nutrients, management, grain yield, and profit of crop sequences (including both winter and summer cropping) in paddocks on 2 farms.

2014: Collate on-farm yield data from 60 paddocks of irrigated faba bean.

High Rainfall Zone

(a) MacKillop Farm Management Group (MFMG)

Evaluation of multiple-use potential of broadleaf crops and pastures:

Naracoorte, SA

2011 (Phase 1): Field peas, faba beans, canola (for grain or hay), legume pastures (simulated grazing, cut for hay, full biomass return), wheat (for grain or hay), or safflower (as a late spring/summer option should winter sowing opportunity be unable to be sown)

2012 (Phase 1): Wheat x different N rates

2013 (Phase 2): Wheat x different N rates

2012 (Phase 2): Field peas, faba beans, canola, legume pastures established.

2013 (Phase 2): Wheat x different N rates

2014 (Phase 2): Wheat

2013 (Phase 3): Field peas, faba beans, canola, legume pastures established.

2014 (Phase 3): Wheat

(b) Southern Farming Systems (SFS)

Crop challenge competition:
Lake Bolac and Inverleigh, Vic
Profit challenge: All sowing, input, management and marketing decisions at discretion of 21 different teams. Annual winners and overall winning team assessed by yearly gross margins and total gross margins calculated over the 3 years.
2011: 10 teams at each site (20 in total). Choice of field pea, lupin, or faba bean.
2012: Any crop could be grown. One team at each site grew wheat, the remainder grew canola.
2013: Wheat sown by all teams.
Weed control challenge: All sowing, input, management and marketing decisions at discretion of 17 different teams.
2014: Use of break crops to control weeds

2012 and 2013: Analysis of various pasture legume treatments for N fixation.

Medium Rainfall Zone
(a) FarmLink
Comparing low and high risk/input break crop options on profit:
Junee Reefs, NSW
2011: April sowing of TT or RR canola, and lupins/May sowing of peas, chickpeas, barley and wheat. Included grain and brown manuring treatments x different levels of inputs (costs of production)
2012: All treatments sown to low and high input wheat
2013: All treatments sown to 2nd year of low and high input wheat

Comparing break crop effects of canola to different pasture species:
Cowra, NSW
2011: Canola and wheat sown over previous lucerne/sub, chicory/sub, annual and phalaris pastures.
2012: Whole area sown to wheat.

Comparing single-break and double-break broadleaf crop and pasture options:
Wagga Wagga, NSW (Graham Centre demo site)
2011 (Phase 1): Field pea, lupin, vetch, high-density forage legumes, canola, and wheat.
2012 (Phase 1): Wheat over some treatments, 2nd year break combinations (field pea, lupin, vetch, high-density forage legumes, or canola) sown over others
2013 (Phase 1): Wheat sown over all treatments

2012 (Phase 2): Field pea, lupin, vetch, high-density forage legumes, canola, and wheat established.
2013 (Phase 2): Wheat over some treatments, 2nd year break combinations (field pea, lupin, vetch, high-density forage legumes, or canola) sown over others
2014 (Phase 2): Wheat sown over all treatments

Evaluating cost-effectiveness of strategies to control ryegrass:
Wagga Wagga (research station)
2012: Sown uniform density of ryegrass (100 plants/m^2) to portion of plots – Imposing plus grass weeds x crop-topping or brown manure and minus grass weed treatments to field peas, lupins, or canola, and grassy high density pasture legume treatment x hay cut or brown manure, with weed-free wheat comparison.
2013: Plots over-sown to wheat or 2nd year of break crop treatments.

Eurongilly, NSW (farmer paddock Eurongilly site 1)
Monitoring treatment effects on grain yield, systems profit, in-crop ryegrass incidence and trends in ryegrass seed banks:
2012: (Expt 1) Existing resident herbicide-resistant ryegrass in cropping paddock
Canola (TT and RR), chickpea, lupin (brown manure or grain), field pea (brown manure), wheat x high and low herbicide inputs.
2013: (Expt 1) Plots over-sown to either wheat or 2nd year of break crop (canola RR or wheat hay)
2014: (Expt 1) Plots over-sown to wheat.

Eurongilly, NSW (farmer paddock Eurongilly site 2)
2013: (Expt 2) Existing resident herbicide-resistant ryegrass in cropping paddock on another farm
Canola (TT and RR), lupin (brown manure or grain), field pea (brown manure), wheat x high and low herbicide inputs.
2014: (Expt 2) Plots over-sown to either wheat or 2nd year of break crop (canola RR or wheat hay)

Impact of field pea brown manuring on grass weed control and mineral N:
Lockhart and Ariah Park, NSW
2012: Comparing paddock-scale replicated strips of fallow vs brown manure, or standing vs incorporated treatments in several farmer's properties.
2013: Examine impact on soil mineral N, weeds and yield of canola or wheat

Impact of vetch management on subsequent soil mineral N:
Ariah Park, NSW
2014: In paddock treatments included harvest for grain stubble standing or incorporated, *or* hay-cut x with or without grazing.

(b) Riverine Plains
Evaluating the impact of inoculation on pulse crops:
Rutherglen and Minninera, Vic
2009: Impact of rate of inoculation on N fixation by faba bean (commenced prior to project)
Culcairn, NSW
2010: Faba bean and lupin x +/- inoculation *cf* canola and wheat +/- N fertiliser
2011: Quantify effects of 2010 treatments on soil mineral N and wheat yields +/- N fertiliser

Evaluating profitability of alternative break crops and pasture legumes:

Yarrawonga South, Vic
2012: (Phase 1) Established lupins, faba bean, field pea, chickpea, arrowleaf clover (hay), subclover (hay), vetch (hay or brown manured), canola (+/- N) and wheat (+/- N).
2013: (Phase 2) 2nd break crop experiment with similar treatments to 2012

Low Rainfall Zone
(a) Birchip Cropping Group (BCG)
<u>Impact of low risk break crops for the Mallee on wheat:</u>
Hopetoun, Vic
2009 (Phase 1) clay and sandy soil types – Field pea and vetch (split for grain, hay or brown manure), canola or wheat (for hay or grain)
2010: (Phase 1) – 1st Wheat after break crops
2011: (Phase 1) – 2nd Wheat after break crops
2012: (Phase 1) – 3rd Wheat after break crops

2009: (Phase 2) clay and sandy soil types – Field pea and vetch (split for grain, hay or brown manure), canola or wheat (for hay or grain)
2011: (Phase 2) – 1st Wheat after break crops
2012: (Phase 2) – 2nd Wheat after break crops

2011: (Phase 3) clay and sandy soil types – Field pea and vetch (split for grain, hay or brown manure), canola or wheat (for hay or grain)
2012: (Phase 3) – 1st Wheat after break crops
2013: (Phase 3) – 2nd Wheat after break crops

<u>Use of break crops and herbicide chemistry to help control brome grass</u>:
Chinkapook, Vic
2011: Field pea, medic (sown or volunteer), vetch, canola, wheat, chemical fallow.
2012: Wheat or 2nd year of alternative break crop option
2013: 1st and 2nd Wheat after break crops

<u>Impact of timing and method of vetch removal on inputs of fixed N, soil water and mineral N</u>:
Birchip, Vic
2012: Vetch x timing of termination/grazing/hay cut/brown manuring.
2013: Effect of 2012 vetch treatment on soil water, mineral N and wheat yield
2014: Residual effects of 2012 vetch treatments on wheat yield

<u>Impact of inoculation (and/or applications of N fertiliser) on pulse performance</u>:
Rupanyup, Birchip and Watchupga East, Vic
2011: Rupanyup - Chickpea/field peas/lentil/faba bean x +/- inoculation

2012: Birchip - Vetch x +/-inoculation
2013: Watchupga East - Chickpea/field peas x +/- inoculation x N fertiliser

(b) Central West Farming Systems (CWFS)
Impact of one or two year break crop effects on wheat:
Condobolin, NSW
2011: Field peas, lupin, chickpea, vetch, canola, various pasture legumes, barley, oats, wheat.
2012: Wheat or 2nd year alternative break crop option

On-farm evaluation of different break crop options:
Condobolin, Trundle, Lake Cargelligo and Forbes
2011: Paddock-scale strips of canola, wheat, peas, lupin, chickpea and/or vetch.
2012: Wheat to quantify break crop effects
2013: Paddock-scale strips of canola, wheat and legumes established at new locations

Appendix G

Trial Methodologies

BCG

Chinkapook 2013

http://www.bcg.org.au/members/view_trial.php?trial_id=895&src=trials.php

Chinkapook 2014

http://www.bcg.org.au/members/view_trial.php?trial_id=938&src=trials.php

Birchip 2013

http://www.bcg.org.au/members/view_trial.php?trial_id=892&src=trials.php

Birchip 2014

http://www.bcg.org.au/members/view_trial.php?trial_id=922&src=trials.php

Watchupga 2013

http://www.bcg.org.au/members/view_trial.php?trial_id=900&src=trials.php

CWFS

Condobolin

Case Studies

FARMLINK

Junee Reefs

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Key-outcomes-arising-from-the-crop-sequence-project

Eurongilly Exp 1

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Key-outcomes-arising-from-the-crop-sequence-project

Eurongilly Exp 2

http://agronomyaustraliaproceedings.org/images/sampledata/2015_Conference/pdf/agronomy2015final00279.pdf

Wagga Wagga

http://www.agronomy2015.com.au/papers/agronomy2015final00009.pdf

Ariah Park

ICC

Kerang

Numurkah

Ardmona

MFMG

Naracoorte

http://www.mackillopgroup.com.au/media/111%20Flyers%20KM/Final%20Report%20Project%20CSP00146%20Feb16.pdf

MSF

http://www.msfp.org.au/comparing-break-crop-performance-in-the-sa-mallee

http://www.msfp.org.au/two-year-breaks-profitably-reduce-agronomic-constraints-northern-victorian-mallee

http://www.msfp.org.au/break-crops-can-provide-1-tha-extra-wheat-three-subsequent-seasons

http://www.msfp.org.au/crop-sequences-address-agronomic-constraints-in-a-long-term-continuous-cereal-paddock

Mildura

http://msfp.org.au/wp-content/uploads/2015/02/Moodie_Crop-sequences.pdf

RIVERINE PLAINS

Yarrawonga

http://riverineplains.com.au/_literature_196161/Pulse_Crop_Article_2015

Wilby

http://riverineplains.com.au/_literature_196160/Pulse_Case_Study

SFS

Inverleigh

http://www.agronomy2015.com.au/papers/agronomy2015final00155.pdf

Lake Bolac

http://www.agronomy2015.com.au/papers/agronomy2015final00155.pdf

Appendix H

Communication outputs generated by the project

Industry reports

- Browne C, Hunt JR, Whitbread AM, Hollaway GJ, Peoples MB (2011) Break crops for the Mallee. In: *BCG 2010 Season Research Results* pp 35-41. BCG, Birchip.
- Peoples MB, Kirkegaard JA, Hunt JR, Swan AD, Brockwell J, Angus JF, Rochester IJ, Dear BS, Li GD, Nordblom TL, Hayes RC, Oates AA, Harris RH, Nuttall JG, Armstrong RA, Mayfield A, McCallum M H, McNeill AM, Unkovich MJ, Denton MD (2011) Factors contributing to the rotational benefits of legumes in cropping sequences – 36 pages. Prepared for GRDC CSP00146 milestone report.
- GroundCover issue 94 (Sept-Oct 2011): Research to reverse broadleaf decline, pp. 41
- Cullen C (2012) Legume inoculation. In: *BCG 2011 Season Research Results*. BCG, Birchip.
- GroundCover issue 96 (Jan-Feb 2012): Broadleaf crop trials seek diversity, pp. 27
- Peoples M, Swan T, Watson L, Pearce D, Phillips L, Denton M (2012) Rhizobial inoculation can boost crop performance. In: *Research for the Riverine Plains 2012*, pp. 44-46.
- GroundCover Crop Sequence supplement issue 98 (May-Jun 2012): Flexible Farming - The key to good N fixation / Longer-term financial impact of break crops / Returns from break crops can challenge wheat http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-98-Supplement-Crop-Sequencing
-GroundCover TV Episode #7 Continuous cereal cropping (May-June 2012): http://www.grdc.com.au/Media-Centre/GroundCover-TV/2012/05/GCTV7-May2012/iJDeQmm6lm4
- GroundCover issue 100 (Sept-Oct 2012): Profitable crop sequences in focus, pp. 24
- Browne C, Hunt J, McBeath T (2013) Break crops pay in the mallee. In: *BCG 2012 Season Research Results*, pp. 42-48.
- Ferrier D, Watson L, Peoples M (2013) Timing of vetch termination. In: *BCG 2012 Season Research Results*, pp. 49-53.
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- Ferrier D, van Rees H, Watson L, Peoples M (2014) Vetch termination impact on the following wheat crop. In: *BCG 2013 Season Research Results*, pp.119-125.
- Ferrier D, Peoples M, Watson L (2014) The best return on Investment: inoculating or topdressing pulses? In: *BCG 2013 Season Research Results*, pp. 181-186.
- GroundCover TV Episode #12 Break crop decision tool (January 2014): www.grdc.com.au/CSIRO-BreakCropsDST
- Celestina C (2014) Crop Challenge. In: SFS Trial Results, Victoria edition, pp. 54-63.
- Peoples M, Watson L, Swan T, Hunt J, Li G, Harris R, Pearce D, Phillips L, Denton M, Ferrier D, Browne C, Craig S, van Rees H, Mwendwa J, Hart B, Turner F, Potter T, Clover A, Midwood J (2014) Grow N or buy N? In: *Hart Field Day Guide 2014*, pp. 88-92.
- Ferrier L, Ferrier D, McClelland T (2015) Mineralisation: How much N are you getting for free? BCG News Summer Edition #129, p. 3
- GroundCover Profitable Pulses and Pastures supplement issue 115 (March-April 2015): Grain legumes can deliver and extra 1t/ha yield to wheat crops / Break crops should be a profitable choice / Break crops help tackle the ryegrass seedbank / N higher after legumes than wheat or canola.
- Ferrier D, Goward L, Peoples M (2015) Vetch termination. In: *BCG 2014 Season Research Results*, pp. 33-38.
- Peoples M (2015) Where to get your N: Legume rotation vs fertiliser. *Australian Grain* Vol 24, No.6 (March-April), p. 12
- Courtney A, Trevethan I, Peoples M, Swan T, Goward L (2015) Crop sequencing project reveals potential of broadleaf break crops. In: *Research for the Riverine Plains 2014*, pp. 57-59.
- Peoples M (2015) Where to get your N: Legumes vs fertiliser. *GRDC Southern Region Paddock Practices: Nitrogen in focus – Mineralisation, uptake and timing* (June 2015).

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- Maitland K (2015) New trials reveal true value of legumes in rotations. SANTFA – The Cutting edge magazine (spring 2015), p. 134-136.

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- Swan T, Watson L, Peoples M, Hunt J, Li G, Lowrie R, Breust P (2013) Break crops & brown manures: Effects on nitrogen, grass weeds, grain yield and profit. In: GRDC Grower Update 2013: Robust Cropping Systems – The Next Steps, Ganmain, NSW
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Appendix I

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Appendix J

Links to Grower Group web information

Birchip Cropping Group

Central West Farming Systems

Farmlink

Irrigated Cropping Council

MacKillop Farm Management Group

Mallee Sustainable Farming

Riverine Plains

Southern Farming Systems