03

Break Crops and Brown Manures: Effects on nitrogen, grass weeds, grain yield and profit

2012 Trial Sites

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Break Crops and Brown Manures: Effects on nitrogen, grass weeds, grain yield and profit

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In collaboration with project DAV00113 Expanding the use of pulses in the Southern region.

Key Messages

- Results from experimentation undertaken in southern NSW in 2011 and 2012, have demonstrated that crop sequences which include a brassica or legume break crops can be as profitable as, and in many instances more profitable than, continuous wheat.
- Canola was consistently the most profitable break crop option. However, the rotational benefits of canola were usually restricted to just the first subsequent wheat crop whereas additional wheat yields can occur for two years after a legume.
- Growing pulses for grain maximises profit, particularly in favourable seasons, but compromises grass weed control and (depending upon species) reduces N available to subsequent crops compared to brown manuring.
- Growing pulses for hay was found to be profitable across a range of season types, achieves excellent grass weed control and provides greater N inputs and higher carry-over of soil water than when the same crop is grown for grain.
- Growing pulses for brown manure loses money in the year they are grown, but achieves excellent grass weed control, high N inputs, residual carry-over of soil water, provides more ground cover, and requires less labour than when grown for hay or grain.

Key Words

Pulses, canola, wheat, profit

Background

Most grain-growers recognise that they should include broadleaf species in their cropping program to reduce disease incidence for cereals and to improve soil nitrogen (N) fertility. However, the area sown to legume pulse crops or canola declined dramatically between 1999 and 2009. There were many good reasons why growers reduced the frequency of broadleaf species during that time which were related to late starts to the growing season, drought and risk aversion. Yet it appears that much of the decline can also be attributed to the wide-spread perception that broadleaf options are higher risk and not as profitable as cereals. The aim of the work described here was to challenge this notion, and to examine the potential beneficial impacts of break crops on the longer-term financial performance of following wheat crops.

The Benefits of Break Crops

Data collated from many research experiments indicate average yield improvements equivalent to 0.6-0.8 t wheat grain/ha when wheat is grown after canola or mustard compared to wheat on wheat (Figure 1), and between 1.1-1.8 t/ha by wheat grown following a grain legume compared to the yield of wheat on wheat in the absence of N fertiliser (Figure 2). Some of this increase in wheat yield can be derived from (Kirkegaard et al., 2008; Peoples et al., 2009; Kirkegaard and Hunt, 2010): (i) breaking of cereal disease cycles, (ii) changes in soil structural characteristics that encourage a deeper rooting depth, (iii) carry-over of residual soil water, or (iv) providing a range of weed contol options. In the case of legumes rotational benefits can also be derived from specific affects on: (v) the composition of soil microbial populations, (vi) increased availability of soil N, and/or (vii) increased availability of phosphorus.

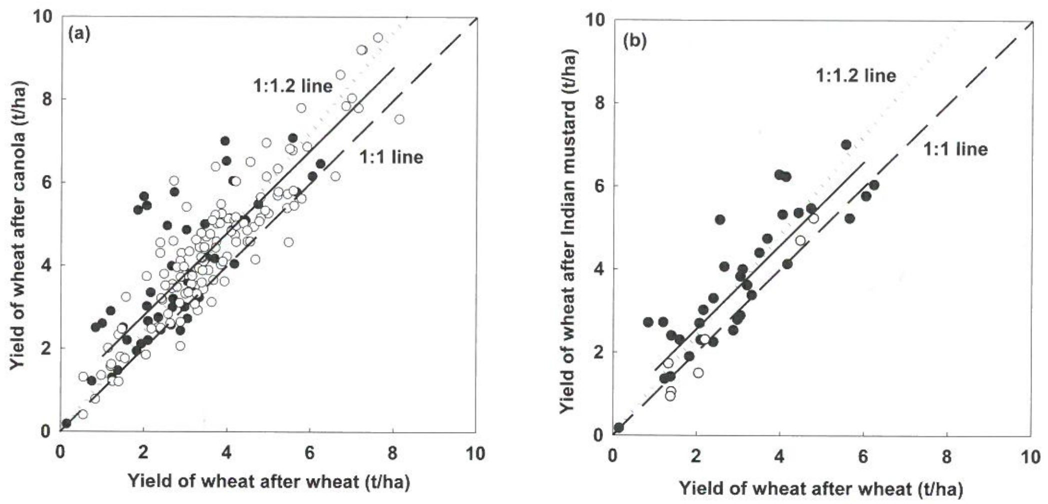

Figure 1. Effect on wheat grain yield of a previous crop of (a) canola or (b) Indian mustard compared to yields achieved where wheat was grown after wheat. Solid points refer to experiments in Australia and open points to experiments elsewhere. The solid line represents fitted regression equations, the dotted line represents a 20% yield increase and the dashed line represents equal yields (Angus et al. 2011).

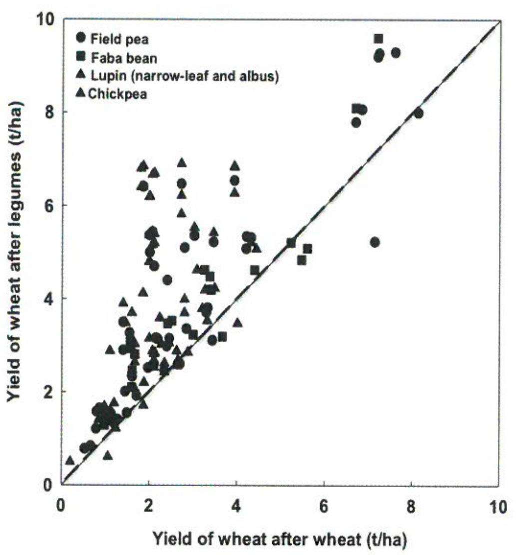

Figure 2. Comparison of yield of wheat growing after grain legumes, with wheat after wheat in absence of additional fertiliser N. The dashed line represents equal yields (Angus et al., 2008).

This report focuses on the effect of break crops on grain yield and profit derived from data generated from GRDC project CSP000146 experimentation undertaken in association with FarmLink and NSW DPI in southern NSW.

Four key research questions are addressed:

(1) Can a brassica or legume break crop be as profitable as a cereal in its own right?

(2) Are there trade-offs between different break crop options and end-uses?

(3) Do the rotational benefits of break crops improve the profitability of subsequent cereal crops?

(4) Can resistant ryegrass be managed cost-effectively under break crops?

Comparing the profitability of break crops with cereals. Are there trade off's between break crops and different end uses?

Junee Reefs, NSW 2011

Aim: To compare the productivity and relative profitability of various low input/low risk cropping options with alternative high input/high risk, but potentially higher return crops.

Experimental details: Soil pH (0-10 cm in $CaCl^2$) was 5.50. Soil mineral nitrogen in April (0-150cm) was 100 kgN/ha.

Treatments and relative input cost (risk) category were as follows:

1. **Canola** (Low: Crusher TT open pollinated variety) + (Jockey + Gaucho) + 25 kg/ha MAP (3 kg N/ha) + 100 kg/ha urea (46 kg N/ha) and 80 kg/ha ammonium sulphate (17 kg N/ha) in-crop.
2. **Canola** (High: Hyola 505 RR Hybrid) + (Jockey + Gaucho) +100 kg/ha ammonium sulphate (21 kg N/ha) + 75 kg/ha MAP(8 kg N/ha) + 500 g/l flutriafol (Impact Endure) @ 200 ml/ha + 100 kg/ha urea in-crop (46 kg N/ha).
3. **Lentil** (Medium: Flash) + N-prove inoculant + 25 kg/ha MAP(3 kg N/ha).
4. **Chickpeas** (High: Slasher) + P-Pickel T + Biostacked inoculum + 75 kg kg/ha MAP (8 kg N/ha)
5. **Lupins** (Medium: Mandelup for grain) + Biostacked inoculum + 75 kg kg/ha MAP (8 kg N/ha)
6. **Lupins** (Low: Mandelup for brown manure) + Nodulaid inoculant + 25 kg/ha MAP (3 kg N/ha)
7. **Field peas** (Low: Morgan for brown manure) + P-Pickel T + Nodulaid inoculant + 25 kg/ha MAP(3 kg N/ha)
8. **Barley** (Low: Hindmarsh) + Raxil + 25 kg/ha MAP (3 kg N/ha) + 100 kg/ha urea (46 kg N/ha) in-crop
9. **Wheat** (Low: Lincoln) + Raxil + 25 kg/ha MAP (3 kg N/ha) + 100 kg/ha urea (46 kg N/ha) in-crop
10. **Wheat** (High: Lincoln) + Dividend + 75 kg/ha MAP (8kg N/ha) + 500 g/l flutriafol (Impact Endure) @ 200 ml/ha + 200 kg/ha urea (92 kg N/ha) in-crop

There were two sowing times in 2011: late April (canola and lupins), mid May (lentil, chickpeas, peas, barley and wheat). Treatments were replicated four times and were sown in a randomised design. Trifluralin was used as a pre-emergent for all treatments except the TT canola (low) which also had atrazine, and wheat (high) which used Boxer Gold. Chickpea had a particularly expensive PSPE application of terbuthylazine (Terbyne), isoxaflutole (Balance) and metribuzin. There were two in-crop glyphosate applications to the RR canola (high) and a single in-crop atrazine applied to TT canola (low). Foliar fungicides were applied as Prosaro + Hasten to wheat (high), Tilt to barley, and two applications of Barrack to lentils and chickpea.

Results

Shoot dry matter (DM) accumulation over the 2011 growing season, grain yield, the amounts of N removed in grain at harvest, and estimates of the total inputs of fixed N by the legume treatments are presented in Table 1.

Growing season rainfall (GSR) was 216mm which was somewhat lower than the long-term average GSR of 300mm, but heavy rainfall in February 2011 (226mm) resulted an annual total of 639mm which was approximately 130mm wetter than the long-term average (508mm). The full soil water profile at the beginning of the growing season contributed to large amounts of shoot DM and resulted in respectable grain yields for the various break crops and cereals grown at Junee Reefs (Table 1). Net N balances were calculated for each treatment by comparing inputs of fixed N and fertiliser N with grain N removal. These data indicated that canola and wheat cropping represented the greatest losses of N from the system while the largest net returns of N were derived from the brown manured legume treatments and lupin grain crop (Table 1).

Canola yields were 3.2-3.3 t/ha with an oil content of 46-49%. The N fertiliser applied to wheat (low input = 48 kg N/ha and high input = 100 kg N/ha) had little effect on yield (4.8 cf 5.2 t/ha; respectively), but did have a large impact on grain protein (low input 10.4% and high input 12.5%). Low grain prices received for wheat in 2011 ($155/t for ASW and $203/t for AH2) resulted in canola and lentil being more profitable than both wheat and barley, and lupin to be more profitable than the low input wheat treatment (Table 2). However, it should be noted that >150mm rainfall fell across large areas of southern NSW in November and December 2011 which delayed the harvest of many farmers' crops and resulted in the down-grading of much of the grain. As a consequence, gross margins achieved on-farm for wheat in 2011 may have been lower than shown in Table 2.

No income was generated by the brown manure treatments, but potentially they will contribute in future years through additional N supply and/or carry-over of residual soil water for the benefit of following wheat crops. The favourable gross margins received for canola and lentil relative to cereals were reflected in profit : input cost ratios of between 1.6:1 and 3:1 compared to 0.9-1.3 for wheat (Table 2). In other words, $1.60-$3 profit was recieved for every $1 spent when growing these particular break crops in 2011, but $1.30 profit or less was achieved for every $1 invested in wheat.

Table 2. 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 and input	Grain yield (t/ha)	Gross income ($/ha)	Total variable costs ($/ha)	Gross margin ($/ha)	Profit/cost ratio
Canola – low	3.2	$1,581	$381 ($181)	$1,199	3.1
Canola – high	3.3	$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

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) and lentils to Victoria (extra freight cost = $53/t).

Wagga Wagga, NSW 2011

Aim: To compare the productivity and relative profitability of continuous wheat with wheat grown after one or two years of various break crop options in different sequences.

Experimental details: This experiment aims to compare the effects of one and two year breaks with a range of broadleaf species on wheat productivity (see Table 3). In addition to grain crops, high-density clover forage and vetch treatments grown for hay or brown manure were included in the experimental design, but data only from canola, pulses and wheat will be presented here. Results reported in this section come from the first year of the trial as indicated in Table 3.

Results: The GSR in 2011 at the Wagga trial site was 318mm which represented a decile 4 growing season (long-term average GSR = 342mm). However, the total annual rainfall of 664mm was above-average (long-term = 553mm) due to 158mm in February and 148mm in November 2011. The net result was wheat yields (5.1 t/ha) and biomass production by the pea brown manure (7.6 t/ha) were quite acceptable (Table 4). However, despite canola yields being less than 50% of wheat, the gross margin for canola still proved to be $200/ha higher than wheat (Table 4). This was partly due to the low grain price received for wheat in 2011 as discussed above in relation to the Junee Reefs trial.

Table 3. Treatments at the Wagga Wagga site.			
	2011	2012	2013
Single break	Canola Lupin Pea (Harvest for grain) Pea (Brown manure	Wheat	Wheat
Double breaks	Pulses (Lupin or Pea) Canola	Canola Pulses (Lupin or Pea)	Wheat Wheat
Continuous wheat	Wheat Wheat	Wheat Wheat + N	Wheat Wheat + N

Table 4. Comparisons of grain yield and brown manured (BM) pea herbage dry matter (DM) production, income, variable costs and gross margins at Wagga Wagga, NSW in 2011. Crops arranged in order of descending gross margin.					
Crop	Grain or DM yield (t/ha)	Gross income ($/ha)	Total variable costs ($/ha)	Gross margin ($/ha)	Profit/cost ratio
Canola	2.2	$1,089	$439	$649	1.5
Wheat	5.1	$790	$343	$447	1.3
Pea	2.5	$554	$297	$257	0.9
Lupin	2.0	$493	$261	$232	0.9
Pea BM	7.6	0	$235	-$235	-1.0

Note: (") Grain prices used in the calculations were current at the around the time of harvest and assumed local delivery. Variable costs were derived from NSW DPI farm budget book published in 2012 (Dryland south-east winter crop gross margins: http://www.dpi.nsw.gov.au/agriculture/farm-)

Comparisons of the performance of different pulses in 2012

The grain yields from the trials in 2011 were very good considering the below average GSR across the region. With the 2012 growing season being slightly drier, lower grain yields were recorded across the district. However, pulse crops still performed reasonably well and some of the new varieties such as the new variety of lentil - 901, offer potential for high returns (approximately equal to $1000 gross income in 2012; Table 5). Resistant weeds can sometimes be harder to control in pulse grain crops, but where late grass weeds emerge, spray topping with herbicides such as paraquat at maturity to sterilise weed seeds can significantly reduce seed carryover.

Table 5: Comparision of the performance of various pulse crops grown for plant dry matter (DM) and grain at Junee Reefs (Harts legume trial), Wagga FarmLink brown manure/time of sowing (TOS) trial and from the DPI Wagga Pulse breeding trials in 2012.			
Location/Trial site	Crop	Grain Yield (t/ha)	Peak Biomass Shoot DM (t DM/ha)
Junee Reefs – Harts	Morgan Field Peas	1.8	7.3
Junee Reefs – Harts	Nura Faba Beans	3.0	7.6
Wagga – FarmLink/NSW DPI	Percy Field Peas	2.4	6.7
Wagga – FarmLink/NSW DPI	Morgan Field Peas	2.0	6.3
Wagga – FarmLink/NSW DPI	Hayman Field Peas	2.1	6.9
Wagga – FarmLink/NSW DPI	Morava Vetch	1.6	7.4
Wagga – FarmLink/NSW DPI	Mandelup Lupins	1.7	5.9
Wagga – NSW DPI	Ace Lentils	1.9	5.4
Wagga – NSW DPI	901 Lentils	2.5	nd
Wagga – NSW DPI	Herald XT Lentils	2.0	nd
Wagga – NSW DPI	Slasher Chickpeas	1.7	3.0
Wagga – NSW DPI	Boundary Chickpeas	1.7	4.2
Wagga – NSW DPI	Farah Faba Beans	3.0	7.0

Source: Junee Reefs – Kaylx (Peter Hamblin pers.com 2012)
Wagga FarmLink trial: NSW DPI (Luke Gaynor, Eric Koetz) and FarmLink Research (Paul Breust)
Wagga DPI trials: NSW DPI Pulse breeding trials 2012 (Dr Eric Armstrong, Luke Gaynor and Eric Koetz).

Do the rotational benefits of break crops improve the profitability of subsequent cereal crops?

Junee Reefs, NSW 2012

First wheat after break crops.

Experimental details: Each replicated plot of all the break crop and cereal treatments from 2011 were split and sown to Spitfire wheat mid-May 2012 under either a low or high input regime.

Low input wheat: target density of 75 plants/m², seed-dressing of Raxil and a starter fertiliser of 25 kg/ha MAP (3 kg N/ha) deep-banded. The initial knock-down consisted of 450 g/L glyphosate (Roundup CT) @ 1.6 L/ha + 240 g/L oxyflurofen (Goal) @ 75 ml/ha + LI700 0.25% v/v and 100 g/L bifentherin (Talstar) @ 200 ml/ha. In-crop herbicides included 500 g/L terbutryn (Igran) @ 550 ml/ha, 750 g/L MCPA amine (Agritone 750) @ 220 ml/ha, and 600 g/kg metsulfuron (Ally) @ 5 g/ha. Foliar fungicide was 430 g/L tebuconazole (Folicur) @ 145 ml/ha. The crop was top-dressed with 100 kg/ha urea (46 kg N/ha). Total input costs were $143/ha.

High input wheat: target density of 150 plants/m², seed-dressing of Dividend @ 260 ml/100 kg seed + Activist Zinc @ 8 L/t of seed and a starter fertiliser of 75 kg/ha MAP (8 kg N/ha) + 500g/L fluriafol (Impact Endure) @ 200 ml/ha deep-banded. The initial knock-down consisted of 450 g/L glyphosate (Roundup CT) @ 1.6 L/ha + 240 g/L oxyflurofen (Goal) @ 75ml/ha + LI700 0.25% v/v and 100 g/L bifentherin (Talstar) @ 200 ml/ha. Pre-emergent IBS was 850 g/kg pyroxasulfone (Sakura 850WG) @ 118 g/ha. In-crop herbicides included 210 g/L bromoxynil 37.5 g/L pyrasulfotole (Velocity) @ 1 L/ha and Hasten @ 1% v/v. Foliar fungicide was 85 g/L pyraclastrobin 62.5 g/L epoxiconazole (Opera) @ 1 L/ha + non-ionic surfactant @ 0.25% v/v. The crop was top-dressed with 200 kg/ha urea (94 kg N/ha). Total input costs were $379/ha.

Rationale for inclusion of the choice of various inputs in the high input treatment was:

- Higher seeding rates for greater competition with weeds
- Flutriafol (Impact) for take-all
- Difenoconazole + metalaxyl-M (Dividend) and zinc seed dressing for rhizoctonia
- More starter fertilizer for early vigour for competition with weeds and root diseases
- Use of new pre-emergent grass herbicide chemistry
- Use of new post-emergent broadleaf herbicide chemistry with greater crop safety to maintain competition.

Results: Despite 115mm of rainfall in March 2012, residual effects of some of the 2011 treatments on soil water reserves were still measured when wheat was sown in May 2012. The stand out break crop treatments were chickpea and the brown-manured field peas and lupin which had between 40-65mm more soil water (0-160mm) than where wheat had been grown in 2011 (data not shown).

The concentrations of soil mineral N measured in autumn 2012 were all significantly higher after the 2011 legume treatments than following canola or cereals (Table 6). Trends in soil mineral N were related to, but were not exactly aligned with, net N balances determined in 2011 (Table 6). The enhanced availability of soil N after chickpea may have been related to the high proportion of chickpea N partitioned below-ground in nodules (Khan et al. 2003). In other words, a higher proportion of the chickpea N in residues would have been located below-ground in a form which had high N concentrations (6%N) and low C:N ratio that is conjucive to more rapid decomposition and mineralisation compared to other legume species.

Table 6. Concentrations of soil mineral N (0-160cm) measured just prior to sowing wheat in 2012 at Junee Reefs, NSW following cereals and various break crops grown for grain or brown manure (BM) in 2011. Crops are arranged in order of descending soil mineral N.

Crop	Soil mineral N in autumn 2012 (kg N/ha)
Chickpeas	172
Lupin BM	169
Pea BM	126
Lentils	122
Lupin	119
Wheat – low	77
Canola – low	76
Canola – high	69
Wheat – high	69
Barley	59
LSD (P<0.05)	35

The relative impact of the different 2011 crop treatments on wheat shoot DM accumulation by August 2012 (GS30; stem elongation) was very similar at both input levels applied to wheat; however, the amounts of DM produced were greater for the high input wheat than the low input wheat (Table 7) due to the higher plant density (150 plant/m² and 75 plants/m² respectively).

The 2011 crop effects on early wheat DM production in 2012 (Table 7) reflected the trends in concentrations of soil mineral N at sowing (Table 6). However, since GSR (169mm) in 2012 was well below the long-term average (300mm), the higher soil water availability after chickpea and the brown-manured legumes could also have contributed to the enhanced DM production in these treatments.

Although the same general trends observed at GS30 were also apparent in shoot DM measurements at maturity for the low input wheat, the DM difference between the low and high input wheat crops did not persist until maturity (Table 7).

Given the 1-2 decile GSR experienced at Junee Reefs in 2012, wheat grain yields following the pulse treatments in 2011 were significantly higher than after cereals or canola (Table 8). However, the application of the higher N fertiliser rates in the high input wheat treatments 2012 following pulse treatments 2011 resulted in high grain protein contents, high screenings (>5%) and a reduction in grain yield suggesting that the wheat 'hayed-off' (van Herwaarden et al.1998) (Table 9).

The gross margins and profit: cost ratios calculated for the low input wheat in 2012 were greater than that achieved by the high input wheat for the same 2011 pre-crop treatments reflecting the lower production costs in a dry cropping year (compare Tables 8 and 9).

Table 7. Impact of various break crops grown for grain or brown manure (BM) at Junee Reefs, NSW in 2011 on wheat shoot dry matter (DM) at GS30 (stem elongation) in August 2012 and at maturity in November 2012. Treatments from 2011 are arranged in order of descending maturity shoot DM observed for low input wheat in 2012.

Crop and input in 2011	Wheat GS30 shoot DM with low input (kg/ha)	Wheat GS30 shoot DM with high input (kg/ha)	Wheat maturity shoot DM with low input (t/ha)	Wheat maturity shoot DM with high input (t/ha)
Chickpeas	863	1386	12.2	10.7
Lupin BM	951	1558	11.2	11.1
Lentils	771	1114	11.2	10.9
Pea BM	860	1201	11.0	11.1
Lupin	737	1195	10.8	10.9
Canola – low	666	903	10.3	10.2
Wheat – high	439	813	10.0	10.4
Wheat – low	614	827	9.4	9.9
Canola – high	432	1013	9.2	10.6
Barley	495	803	8.7	10.4
LSD (P<0.05)				
Same crop in 2011	149		1.0	
2011 crop x 2012 input	206		1.1	

Table 8. Comparisons of grain yields and protein content, income, gross margins and production costs for wheat grown with low input costs ($143/ha) and total variable costs ($315) at Junee Reefs, NSW in 2012 following cereals and various break crops grown for grain or brown manure (BM) in 2011. Values in parentheses represent grain %protein. Crop 2011 pre-treatments are arranged in order of descending 2012 gross margin.

Crop and input in 2011	Grain yield and protein (t/ha) or (%)	Gross income" ($/ha)	Gross margin ($/ha)	Profit/cost ratio	Production costs ($/t)
Lupin BM	4.0 (13.6%)	$1,218	$902	2.9	$79/t
Pea BM	4.1 (12.3%)	$1,176	$861	2.7	$77/t
Chickpeas	4.0 (12.4%)	$1,166	$851	2.7	$78/t
Lupin	3.9 (12.4%)	$1,136	$821	2.6	$80/t
Lentils	4.0 (11.2%)	$1,079	$764	2.4	$78/t
Wheat - high	3.5 (11.0%)	$933	$617	2.0	$91/t
Canola - high	3.6 (9.8%)	$896	$581	1.8	$88/t
Canola - low	3.4 (9.8%)	$861	$545	1.7	$92/t
Wheat - low	3.4 (9.9%)	$855	$540	1.7	$92/t
Barley	3.4 (10.3%)	$852	$537	1.7	$93/t
LSD (P<0.05)					
Grain yield	0.3				
Grain % protein	0.8				

Table 9. Comparisons of grain yields and protein content, income, gross margins and production costs for wheat grown with high input costs ($379/ha) and total variable costs ($556) at Junee Reefs, NSW in 2012 following cereals and various break crops grown for grain or brown manure (BM) in 2011. Values in parentheses represent grain %protein. Crop 2011 pre-treatments are arranged in order of descending 2012 gross margin. * Indicate grain screenings > 5% reducing quality.

Crop and input in 2011	Grain yield and protein (t/ha) or (%)	Gross income" ($/ha)	Gross margin ($/ha)	Profit/cost ratio	Production costs ($/t)
Lentils	3.8 (12.9%)	$1,114	$558	1.0	$144/t
Wheat - low	3.8 (11.7%)	$1,083	$527	0.9	$148/t
Canola - high	3.9 (9.8%)	$1,054	$498	0.9	$142/t
Canola - low	3.8 (11.3%)	$1,013	$456	0.8	$147/t
Barley	3.7 (11.0%)	$1,004	$448	0.8	$149/t
Wheat - high	3.7 (11.2%)	$998	$442	0.8	$150/t
Pea BM	3.8 (14.1%)*	$984	$428	0.8	$147/t
Chickpeas	3.7 (13.9%)*	$971	$414	0.7	$149/t
Lupin BM	3.7 (15.1%)*	$961	$404	0.7	$151/t
Lupin	3.7 (13.7%)*	$952	$396	0.7	$152/t
LSD (P<0.05)					
Grain yield	NS				
Grain % protein	1.3				

The gross margins and profit : cost ratios calculated for the low input wheat in 2012 were greater than that achieved by the high input wheat for the same 2011 pre-crop treatments reflecting the lower production costs in a dry cropping year (compare Tables 8 and 9).

Economic analyses of the sequence at Junee Reefs 2011-2012

Calculations across the two years of the experiment indicated that the average annual gross margins fell into three distinct groups (Table 10). The sequences with the highest average annual gross margins (>$600/ha per year) involved break crops in 2011.

Table 10. Comparisons of the mean annual gross margins ($/ha) calculated for different crop sequences from two years of experimental data from Junee Reefs, NSW in 2011 and 2012. Crop sequences are arranged in order of descending average annual gross margin.

Crop and input in 2011	Crop and input in 2012	Gross margin in 2011[a] ($/ha)	Gross margin in 2012[b] ($/ha)	Average annual gross margin	2 year Profit/ cost ration
				>$600/ha	
Canola - low	Wheat - low	$1,199	$545	$872	2.5
Canola - low	Wheat - high	$1,199	$456	$828	1.8
Canola - high	Wheat - low	$1,033	$581	$807	1.8
Canola - high	Wheat - high	$1,033	$498	$766	1.4
Lentils	Wheat - low	$710	$764	$737	2.3
Lupin	Wheat - low	$455	$821	$638	2.0
Lentils	Wheat - high	$710	$558	$634	1.5
Chickpeas	Wheat - low	$386	$851	$619	1.7
				$400-$600/ha	
Wheat - high	Wheat - low	$511	$617	$564	1.0
Barley	Wheat - low	$559	$537	$548	1.6
Barley	Wheat - high	$559	$448	$503	1.1
Wheat - low	Wheat - low	$425	$540	$482	1.5
Wheat - high	Wheat - high	$511	$442	$476	0.6
Wheat - low	Wheat - high	$425	$527	$476	1.1
Lupin	Wheat - high	$455	$396	$426	1.0
Chickpeas	Wheat - high	$386	$414	$400	0.8
				<$400/ha	
Lupin BM	Wheat - low	-$150	$902	$376	1.6
Pea BM	Wheat - low	-$139	$861	$361	1.6
Pea BM	Wheat - high	-$139	$428	$145	0.4
Lupin BM	Wheat - high	-$150	$404	$127	0.4

[a] Derived from Table 2 [b] Derived from Tables 8 and 9.

These break crop-wheat sequences generally had higher profit : cost ratios than the second cohort (average annual gross margins between $400-$600/ha per year) which was dominated by cereal-wheat sequences. They also included the lupin and chickpea (grain crops 2011) with high inputs 2012 (high screenings). The final group (average annual gross margins <$400/ha per year) were the brown manure legumes-wheat sequences despite the low input treatments exhibiting some of the highest wheat gross margins in 2012, and the BM high input treatments having the lowest gross margins for 2012 (Table 10).

First wheat after break crops

Wagga Wagga , NSW 2012

Experimental details: Each replicate plot of each 2011 treatment was sown to wheat in 2012. Supplementary N fertiliser was only applied to one of the wheat on wheat treatments (Table 3). This consisted of 50 kg/ha of urea (23 kg N/ha) applied at sowing, with another 100 kg/ha of urea (46 kg N/ha) top-dressed in-crop at tillering. This represented the total application of 69 kg N/ha which contributed an additional $98/ha to the total variable costs of $343/ha to grow wheat at the trial site.

Results: The GSR in 2012 at the Wagga trial site was 188mm which represented a decile 1 growing season, although total annual rainfall of 561mm was close to average due to 193mm of rain in March. The application of additional fertiliser N significantly increased wheat on wheat grain yields from 2.4 t/ha to 3.5 t/ha, but there were no significant difference between the yield achieved by the N fertilized treatment and any of the sequences where break crops had been grown in 2011 (Table 11). Gross margins of all break crop-wheat sequences were higher (from ~$60/ha up to $370/ha), and costs of production markedly lower (by $24-$34/t), than both wheat on wheat treatments (Table 11).

Table 11. Comparisons of gain yield, income, gross margins, and production costs for wheat grown at Wagga Wagga, NSW in 2012 following different crops in 2011. Crop sequences are arranged in order of descending 2012 gross margin.

Crop sequence 2011-2012	Wheat yield (t/ha)	Gross income[a] ($/ha)	Gross margin[b] ($/ha)	Profit/ratio cost ($/ha)	Production costs ($/t)
Pea brown manure - Wheat	3.7	$1,010	$667	1.9	$92/t
Canola - Wheat	3.5	$942	$599	1.7	$98/t
Pea - Wheat	3.5	$942	$599	1.7	$98/t
Lupin - Wheat	3.4	$905	$562	1.6	$102/t
Wheat - Wheat (+70 kgN/ha)	3.5	$945	$504	1.1	$126/t
Wheat - Wheat (nil N)	2.4	$640	$297	0.9	$145/t
LSD (P<0.05)	0.40	-	-	-	-

Economic analyses of the sequence at Wagga Wagga 2011-2012

Calculations across the two years of the experiment indicated that only the average annual gross margins for canola-wheat exceeded that of the N-fertilised wheat on wheat, but all break crops options except the brown manure pea in 2011 were determined to have higher average annual gross margins than the unfertilised wheat on wheat (Table 12).

Table 12. Comparisons of the mean annual gross margins ($/ha) calculated for different crop sequences from two years of experimental data from Wagga Wagga, NSW in 2011 and 2012. Crop sequences are arranged in order of descending average annual gross margin.

Crop sequence	Gross margin in 2011[a] ($/ha)	Gross margin in 2012[b] ($/ha)	Average annual gross margin ($/ha)	2 year Profit/ratio cost ($/ha)
Canola - Wheat	$649	$599	$624	1.6
Wheat - Wheat (+70kgN/ha)	$447	$504	$476	1.2
Pea - Wheat	$257	$599	$428	1.3
Lupin - Wheat	$232	$562	$397	0.7
Wheat - Wheat (nil N)	$447	$297	$372	1.1
Pea brown manure - Wheat	-$235	$667	$216	0.7
LSD (P<0.05)	0.40	-	-	-

[a] Derived from Table 4. [b] Derived from Table 11.

Can resistant ryegrass be managed cost-effectively under break crops?

There is substantial evidence from surveys of the frequency of herbicide resistence in weeds collected at random from 187 and 192 random farmers paddocks in southern and western NSW, respectively (Table 13) and from SA and Victoria (Table 14) that there is wide-spread resistence or partical resistence to a wide range of herbicide groups. One of the most common reasons farmers' give for replacing a cereal with a broadleaf brassica or legume is to provide new herbicide options to manage difficult to control weeds. A study was initiated at Eurongilly in southern NSW in 2012 to investigate the efficacy of different break crop strategies and herbicides.

Table 13: The percentage of paddocks in southern and western NSW with partial or resistant annual ryegrass in 2007.

Product name	Herbicide group	Chemical family	2007 Southern NSW	2010 Western NSW
Hoegrass(R)	A	Fop	81	56
Sertin(R)	A	Dim	43	70
Select(R)	A	Dim	21	4
Achieve(R)	A	Dim	nt	32
Glean(R)	B	SU	70	53
Intervix(R)	B	Imi	65	38
Simazine	C	Triazine	1	0
Trifluralin(R)	D	DNA	6	0

Source: 2007 data (Southern NSW) - Broster, Koetz and Wu 2011 Plant protection Quarterly, Vol.26 (1).
2010 data (Western NSW) – John Broster pers. comm. Unpublished, EH Graham Centre, Wagga Wagga, NSW.

Table 14: The percentage of paddocks in SA and Vic that have partial or resistant annual ryegrass

Product name	Herbicide Group type	SA-Mid North 2008	SA-Eyre Pennisula 2009	Vic-Western 2010	Vic-Northern 2011	Vic-Southern 2009
Hoegrass(R)	A - Fop	76	30	40	55	79
Select(R)	A - Dim	40	11	5	8	23
Axial(R)	A - Den	59	30	33	31	68
Glean(R)	B - SU	73	78	73	87	88
Intervix(R)	B - Imi	nt	47	18	29	39
Trifluralin(R)	D - DNA	40	5	25	0	0

Source: Preston et al. (2013) Maintaining the best options with herbicides 'in GRDC 2013 NSW Advisor Update, Temora Feb 2013".

Eurongilly, NSW 2012

Aim: To compare the productivity and profitability of cropping in the presence of a background of herbicide-resistant ryegrass, and to assess the implications of various low or high input grass control options applied to wheat and break crops on production costs and ryegrass management.

Experimental details: The sensitivity/resistance of the ryegrass population present at the trial site was tested by Plant Science Consulting SA in March 2012. The results of the analysis presented in Table 15 indicate some degree of resistance to a range of grass-selective herbicides, but suggested that ryegrass may still be susceptible to Factor (butroxydim) and glyphosate. This information was used to determine the research herbicide treatments for experimental purposes.

Table 15. Herbicide resistance assessments determined in March 2012 for resident ryegrass population at the trial site near Eurongilly, NSW.

Herbicide	Herbicide group	Survival (%) Rating
Verdict + 1% Hasten 75 A	Fops	70 **RR**
Select + 1% Hasten 300 A	Dims	55 **R**
Axial + 0.5% Adigor 300 A	Den	65 **RR**
Factor + 1% Supercharge 180A	Dims	0 **S**
Hussar + 1% Hasten 200 B	Sulfonylureas	95 **RRR**

Resistance- rating: RRR - indicates plants tested have strong resistance; RR- indicates medium- level resistance; R - indicates low- level but detectable resistance; S - indicates no detection of resistance.

Soil pH was 4.5 (0-10 cm and 10-20 cm in CaCl²) at Eurongilly prior to applying lime in April 2012. Colwell available P (0-10 cm) was 29 mg/kg, and soil mineral N (0-150 cm) was 87 kg N/ha just before sowing. The treatments and the relative input cost (risk) categories were as follows:

1) **Canola** (Low: Crusher TT open pollinated variety) target density 40 plants/m^2 + (Jockey + Gaucho) + 25 kg/ha MAP deep-banded; initial knock-down with 450 g/L glyphosate (Roundup CT) @ 1.6 L/ha; pre-emergent of 480g/L trifluralin (TriflurX) @ 2 L/ha; 900g/kg atrazine @ 1.1kg/ha; in-crop herbicide 250 g/kg butroxydim (Factor) @ 80 g/ha + 900g/kg atrazine @ 0.9kg/ha + Supercharge @ 1% v/v; insecticide 500 g/kg primicarb (Pirimor) @ 150 g/ha; top-dressing in-crop = 100 kg/ha ammonium sulphate and 100 kg/ha urea.

2) **Canola** (High: Hyola 505 RR Hybrid) target density 40 plants/m^2 + (Jockey + Gaucho) +100 kg/ha ammonium sulphate + 75 kg/ha MAP + 500 g/l flutriafol (Impact Endure); initial knock-down with 450 g/L glyphosate (Roundup CT) @ 1.6 L/ha ; pre-emergent of 480g/L trifluralin (TriflurX) @ 2L/ha; in-crop herbicide glyphosate (Round-Up Ready) @ 0.9 kg/ha at 2-3 leaf and 6 leaf stage; insecticide 500 g/kg primicarb (Pirimor) @ 150 g/ha; top-dressing in-crop = 200 kg/ha urea.

3) **Lentil** (Low: Herald XT) target density 120 plants/m^2 + Nodulaid inoculant + 25 kg/ha MAP deep-banded; initial knock-down with 450 g/L glyphosate (Roundup CT) @ 1.6 L/ha; pre-emergent 480 g/L trifluralin (TriflurX) @ 2 L/ha; 900 g/kg simazine @ 0.5 kg/ha; 500 g/L diuron @ 0.6 L/ha; in-crop herbicide 250 g/kg butroxydim (Factor) @ 180 g/ha + Supercharge @ 1% v/v; 240 g/L clethodim (Select) @ 500 ml/ha + Uptake @ 0.5% v/v; 250 g/L paraquat (Gramoxone) @ 400 ml/ha + non-ionic surfactant @ 0.1% v/v.

4) **Lupins** (High: Mandelup for grain) target density 40 plants/m^2 + Biostacked inoculum + 75 kg kg/ha MAP deep-banded; initial knock-down with 450 g/L glyphosate (Roundup CT) @ 1.6 L/ha ; pre-emergent 480g/L trifluralin (TriflurX) @ 2L/ha; 900 g/kg simazine @ 2.2 kg/ha; in-crop herbicide 250 g/kg butroxydim (Factor) @ 180 g/ha + Supercharge @ 1% v/v; 250 g/L paraquat (Gramoxone) @ 400 ml/ha + non-ionic surfactant @ 0.1% v/v.

5) **Lupins** (Low: Mandelup for brown manure) target density 40 plants/m^2 + Nodulaid inoculant + 25 kg/ha MAP deep-banded; initial knock-down with 450 g/L glyphosate (Roundup CT) @ 1.6 L/ha ; pre-emergent 480g/L trifluralin (TriflurX) @ 2 L/ha; 900 g/kg simazine @ 1.3 kg/ha; brown-manure herbicide 450 g/L glyphosate (Roundup CT) @ 2 L/ha + 300 g/L clopyralid (Lontrel) @ 150 ml/ha + 240 g/L carfentrazone-ethyl (Hammer) @ 25 ml/ha; fallow maintenance 450 g/L glyphosate (Roundup CT) @ 2.5L/ha + non-ionic surfactant @ 0.1% v/v.

6) **Field peas** (Low: Morgan for brown manure) target density 40 plants/m^2 + Nodulaid inoculant + 25 kg/ha MAP deep-banded; initial knock-down with 450 g/L glyphosate (Roundup CT) @ 2.5 L/ha +; pre-emergent 480g/L trifluralin (TriflurX) @ 2L/ha; 900 g/kg simazine @ 1.0 kg/ha; brown manure herbicide 450 g/L glyphosate (Roundup CT) @ 2 L/ha + 300 g/L clopyralid (Lontrel) @ 150 ml/ha + 240 g/L carfentrazone-ethyl (Hammer) @ 25 ml/ha; fallow maintenance 450 g/L glyphosate (Roundup CT) @ 2.5L/ha + non-ionic surfactant @ 0.1% v/v.

7) **Fallow** (Low) initial knock-down with 450 g/L glyphosate (Roundup CT) @ 1.6 L/ha; fallow established September 2012 with an application of 450 g/L glyphosate (Roundup CT) @ 2 L/ha + metsulfuron-methyl (Ally) @ 5 g/ha + non-ionic wetting surfactant @ 0.1% v/v, then follow-up with 250 g/L paraquat (Gramoxone) @ 2 L/ha + non-ionic wetting surfactant @ 0.1% v/v.

8) **Wheat** (Low: Spitfire) target density 75 plants/m^2 + Raxil + 25 kg/ha MAP (6 kg N/ha) deep-banded; initial knock-down with 450 g/L glyphosate (Roundup CT) @ 1.6 L/ha ; pre-emergent 480g/L trifluralin (TriflurX) @ 2L/ha + diuron 500 g/L @ 1 L/ha; in-crop herbicide 800 g/L prosulfocarb +120 g/L s-metalochlor (Boxer Gold) @ 1.5 L/ha; foliar fungicide 430 g/L tebuconazole (Folicur) @ 145 ml/ha; top-dressing in-crop 100 kg/ha urea (47 kg N/ha).

9) **Wheat** (High: Spitfire) target density 150 plants/m^2 + Dividend @ 260 ml/100 kg seed + Activist Zinc @ 8 L/tonne of seed + 75 kg/ha MAP (16 kg N/ha) deep-banded; initial knock-down with 450 g/L glyphosate (Roundup CT) @ 1.6 L/ha ; pre-emergent 850 g/kg pyroxasulfone (Sakura 850WG) @ 118 g/ha + 500 g/L tri-allate (Avadex Xtra) @ 2 L/ha; in-crop herbicide 800 g/L prosulfocarb +120 g/L s-metalochlor (Boxer Gold) @ 2.5 L/ha + 100 g/L pinoxaden 25 g/L cloquintocet (Axial) @ 150ml/ha + adjuvant (Adigor) @ 0.5% v/v; foliar fungicide 85 g/L pyraclastrobin 62.5 g/L epoxiconazole (Opera) @ 1 L/ha + non-ionic surfactant @ 0.25% v/v; top-dressing in-crop 200 kg/ha urea (94 kg N/ha).

There were two sowing times in 2012: late April (canola and lupins), mid May (lentil, peas and wheat), the weed-free fallow was commenced in early September.

Results: The efficacy of the various research herbicide treatments used in the Eurongilly experiment (see details described above) are presented in Table 16.

The number of ryegrass panicles measured in late spring were 1,042 per m^2 in untreated areas immediately outside the experimental plots, and ranged from 78-504 per m2 under wheat to zero under the RR canola and bare fallow. No viable ryegrass seed was set in 2012 by the brown manure treatments. So cheaper, more effective ryegrass control was achieved in the break crops and fallow compared to the options available for in-crop grass management within wheat (Table 16). The different levels of control will have undoubtedly have implications for ryegrass incidence, crop production and profit in 2013.

Table 16. Measures of peak shoot dry matter (DM) accumulation of wheat and various break crops grown for grain or brown manure (BM) and other treatments at Eurongilly, NSW in 2012, the cost of ryegrass control measures, and ryegrass DM and panicle numbers. Crops arranged in order of descending ryegrass panicle numbers.

Crop and input	Crop shoot DM (t/ha)	Costs of grass herbicides ($/ha)	Ryegrass DM (t/ha)	Ryegrass panicle number (no./m^2)
Untreated area	0	0	Not available	1,042
Wheat - low	5.0	$56	1.6	504
Lentils	1.4	$67	0.6	215
Wheat - high	8.4	$142	0.3	78
Lupin	6.5	$65	0.1	43
Canola - low	8.3	$62	Not available	32
Canola - high	12.0	$46	0	0
Fallow	-	$35	0	0
Lupin BM	1.9	$68	2.4	Killed before seed set
Pea BM	4.5	$66	0.7	Killed before seed set
LSD (P<0.05)	**1.1**	**-**	**0.7**	**147**

The GSR in 2012 at Eurongilly was 179mm compared to a long-term average of 329mm, which resulted in reduced shoot DM accumulation (Table 16) and grain yields (Table 17). Canola and lupin grain were more profitable than both wheat treatments with a profit : cost ratio of between 1.8 and 2.6 compared to 0.4 to 0.9 for wheat (Table 17). In contrast to the results from Junee Reefs in 2011, lentil performed poorly at Eurongilly both in terms of yield and gross margin. This may be the result of the low pH (4.5) in the surface 0-20cm.

Table 17. Comparisons of grain yield, income, variable costs and gross margins of wheat and various break crops grown for grain or brown manure (BM) or fallow at Eurongilly, NSW in 2012. (Values in parenthese represent the contribution of input costs to total variable costs). Crops arranged in order of descending gross margin.

Crop and input	Grain yield (t/ha)	Gross income[a] ($/ha)	Total variable costs ($/ha)	Gross margin ($/ha)	Profit/cost ratio
Canola - high	3.5	$1,963	$704 ($427)	$1,259	1.8
Canola - low	3.0	$1,620	$453 ($249)	$1,166	2.6
Lupin	3.1	$1,004	$321 ($168)	$683	2.1
Wheat - high	3.2	$843	$586 ($430)	$257	0.4
Wheat - low	2.0	$532	$283 ($169)	$250	0.9
Lentils	0.7	$297	$230 ($132)	$67	0.3
Fallow	0	0	$45 ($35)	-$45	-1.0
Pea BM	0	0	$160 ($120)	-$160	-1.0
Lupin BM	0	0	$168 ($129)	-$168	-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) and lentils to Victoria (extra freight cost = $53/t).

Inputs of fixed N by farmers' brown manure crops in 2012 with and without incorporation

Managing weeds, nitrogen and optimising soil moisture are key aims for a successful pulse break crop. When weeds become a critical constraint to a productive cropping system, options such as brown manuring become a viable management tool. The timing of the termination of the pulse crop using herbicides influences both DM and ultimately shoot N fixed, with the timing often dictated by the maturity of the weed species. The termination of the pulse crop can be achieved by herbicides (brown manure –plant residue left on soil surface) or green manure (green plant residues ploughed into soil by mechanical means such as offset disc). Farmers generally brown manure their crops, however, some early research by Mayfield (1996) found that there could be an increase in the amount of nitrogen mineralised if the crop was incorporated into the soil.

Experiments were established in two farmer paddocks at Lockhart and Ariah Park in 2012 to investigate the impact of residue incorporation (Table 18). Pulse crops were grown through to peak biomass (early-mid pod-fill) in 2012, brown manured and incorporated into the soil within two weeks of herbicide application. At each of the farmer paddocks, there was a shallow (<5cm) and deep incorporation (10-15cm) treatment as well as a control (stubble retained on soil surface). In 2013, the soil will be measured for moisture and mineral nitrogen (April), plant DM samples taken at GS30, anthesis and maturity and grain yields taken to determine if there is any benefit in incorporating pulse residues.

The low shoot DM at Lockhart in 2012 was a result of disease (pea crop sown early) and the necessity to spray out the crop early to control the early maturity of the wild oats. As a result, the total above ground shoot DM was 2.6t/ha which was less than desired by the farmer (Table 18). This will result in about 78kg/ha of shoot N or 44 kg N/ha fixed being derived from the above ground shoot material, and 133 and 60kg N/ha at Ariah Park.

Table 18: Measures of shoot dry matter (DM) accumulation, shoot N (kg N/ha), N fixed (%), and shoot N fixed from two farmer paddocks at Lockhart and Ariah Park, NSW in December 2012.

Location/Crop	Shoot DM (t DM/ha)	Shoot N (kg N/ha)	% N fixed	Shoot N fixed (kg N/ha)	Profit/cost ratio (kg N/t DM)
Lockhart -Field Peas	2.6	78	59	44	18
Ariah Park-Field Peas	4.4	133	44	60	13

To estimate how much total plant N will be derived from the total plant residues (roots and shoots), we can multiply the values in Table 18 by a root factor for peas of 1.5 (Table 19). The estimated total N in the pea residues (kg N/ha) and total N derived from fixation (kg N/ha) are detailed in Table 20.

Table 19: Rough rule of thumb to estimate the Total Plant Nitrogen fixed by legume.

Species	Estimated Shoot N fixed (kg N/ t DM)	Estimated Below Ground N % of Total N	Root factor	Estimated Total Plant N fixed (kg N/ t DM)
Fieldpea, lupin, faba bean, vetch	20	33%	1.5	30
Chick peas	20	52%	2.06	41
Lucerne	20	50%	2.0	40
Subclover	20	42%	1.72	34

Unkovich, Baldock & Peoples (2010), prospects and problems of simple linear models for estimating symbiotic N2 fixation by crop and pasture legumes. Plant & Soil 329:75-89.

Table 20: Measures of shoot dry matter (DM) accumulation, total N (kg N/ha), and total N fixed from two farmer paddocks at Lockhart & Ariah Park, NSW in December 2012.

Location/Crop	Shoot DM (t DM/ha)	Total N (shoot and root) (kg N/ha)	% N fixed	Total N fixed (shoot and root)	
				(kg N/ha)	(kg N/t DM)
Lockhart - Field Peas	2.6	117	59	69	27
Ariah Park-Field Peas	4.4	200	44	88	20

When growing pulses for both grain and brown manure, maximising the plant shoot DM is critical for providing the greatest inputs of fixed nitrogen. Higher dry matter also equates to more potential soil mineral nitrogen in following crops. The brown manuring seems to be a viable management tool when the cropping system is both low in mineral nitrogen and there are major weed constraints to cropping. Our current results suggest that the rotation may need to be greater than three years for the system to break-even with cereal/canola rotations. However, where herbicide resistant weeds are a problem, the break-even point may be earlier (to be determined at Eurongilly in 2013).

Conclusion

Research trials in southern NSW indicate that brassica and legume break crops were frequently as profitable, and in a number of instances considerably more profitable, than wheat. Sequences with canola were largely profitable due to the high returns from canola itself.

Wheat following break crops had lower costs of production and was consistently more profitable than wheat on wheat. Crop sequences with a break crop were more sustainable in terms of root diseases and N inputs than continuous wheat, and provided cheaper, more effective strategies for controlling herbicide resistant ryegrass. Brown manured legumes achieved excellent grass weed control, provided high N inputs and residual carry-over of soil water which greatly enhanced the yield of following wheat crops, but the increased yields were insufficient to fully compensate for the loss of income in the first year.

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.

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References cited

Angus JF, Peoples MB, Kirkegaard JA, Ryan MH, Ohlander L (2008) The value of break crops for wheat. Proc. 14th Australian Agronomy Conference, 21-25 September, Adelaide. www.agronomy.org.au

Angus J, Kirkegaard J, Peoples M, Ryan M, Ohlander L and Hufton L (2011) A review of break-crop benefits of brassicas. In: Proc. 17th Australian Research Assembly on Brassicas, Wagga Wagga, NSW, Australia, pp. 123-127.

Broster JC, Koetz, EA, Wu H (2011) Herbicide resistance levels in annual ryegrass (Lolium rigidum Gaud.) in southern New South Wales. Plant Protection Quarterly 26(1) 22-28.

Khan DF, Peoples MB, Schwenke GD, Felton WL, Chen D, Herridge DF (2003) Effects of below-ground nitrogen on N balances of field-grown fababean, chickpea and barley. Australian Journal of Agricultural Research 54, 333-340.

Kirkegaard JA, Hunt JR (2010) Increasing productivity by matching farming system management and genotype in water-limited environments. Journal of Experimental Botany 61, 4129-4143.

Kirkegaard JA, Christen O, Krupinsky J, Layzell D (2008) Break crop benefits in temperate wheat production. Field Crops Res. 107, 185-195.

Mayfield A. (1996) Maximising benefits of green manuring, Project No. AMC35R. In: Final report prepared for GRDC.

Peoples MB, Brockwell J, Herridge DF, Rochester IJ, Alves BJR, Urquiaga S, Boddey RM, Dakora FD, Bhattarai S, Maskey SL, Sampet C, Rerkasem B, Khan DF, Hauggaard-Nielsen H, Jensen ES (2009) The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis 48, 1–17.

Preston C, Boutsalis P, Malone J, Abu-Yeboah Patricia, Kleemann S, Saini RK, Gill Gurjeet (2013) Maintaining the best options with herbicides. 2013 NSW GRDC Grains Research Update for Advisors, Temora.

Unkovich MJ, Baldock J, Peoples MB (2010) Prospects and problems of simple linear models for estimating symbiotic N2 fixation by crop and pasture legumes. Plant and Soil 329, 75-89.

van Herwaarden AF, Farquhar GD, Angus JF, Richards RA, Howe GN (1998) ''Haying-off'', the negative grain yield response of dryland wheat to nitrogen fertilizer. I. Biomass, grain yield and water use. Australian Journal of Agricultural Research 49, 1067–1081.

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