Farming systems profit and risk over time: exploring the N legacy impacts on profit in different farming systems

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Take home message

- A range of different systems were profitable and had similar average annual gross margin over 6 years, but differed significantly in variability and return on investment (ROI)
- Despite being the most profitable at only two of the four sites, Diverse systems involving grain legumes with a low N strategy had consistently higher ROI than Baseline cereal-canola systems
- Reduced N inputs to legumes and to cereal and canola crops following legumes were more important economically than yield benefits following the legumes, which were rare
- Fababean was more profitable than lupin and had a greater legacy on subsequent crops
- Issues related to nitrogen supply (costs and response) underpin most of the productivity and profitability differences observed between the systems.

The Southern Farming Systems Project – a brief description

The southern NSW farming systems project was established in 2017 after 12-month consultation period and extensive literature review demonstrated a significant gap in profitability and rainfall efficiency ($/ha/mm) of current cropping systems (i.e. actual *vs* potential) despite good agronomy of individual crops. The average annual gross margin of the best 3-4-year sequences was often ~$400/ha higher than the worst, and $150 to $250/ha higher than the common 'Baseline' sequences. Research sites and simulation studies were established to investigate strategies to increase the conversion of rainfall to profit across a crop sequence while managing weeds, diseases, soil fertility and risk.

Four sites covered soil and climate variability across southern NSW at Greenethorpe, Wagga Wagga and Condobolin (high, medium and low rainfall sites on red acidic loam soils), and a 4th site on a sodic clay vertosol at Urana. At each site, the 'Baseline' system (sequence of canola-wheat-wheat or canola-wheat-barley; timely sown in late April-early May; and with a conservative decile 2 N strategy) was compared with a range of other systems that varied in (i) crop diversity (inclusion of legumes), (ii) sowing time (early and timely) and (iii) N strategy (conservative decile 2 and optimistic decile 7) (Table 1). Management protocols for all other input and management decisions (e.g. tillage and stubble management; variety choice; herbicide, fungicide and pesticide applications) were agreed by the project team using a consensus approach of best practice that was continually reviewed.

Table 1. Selected systems common to most sites including different crop sequence, time of sowing and N strategies. Early-sown (March) treatments included winter grazed crops at Wagga and Greenethorpe. Diverse systems including a legume are shown in grey.

System	Crop sequence	Sowing time[1]	N strategy[2] (Decile 2 or 7)	Grazing
Baseline	Barley[3]-canola-wheat	Timely	2, 7	No
Intense Baseline	Canola-wheat	Early, Timely	2, 7	Yes
Diverse low value	(Faba/lupin)-canola-wheat	Timely	2, 7	No
Diverse high value	(Lentil/chickpea)-canola-wheat	Early, Timely	2	No
Diverse mix	Vetch-canola-wheat	Timely	2	No
Continuous wheat	Wheat-wheat-wheat	Timely	2, 7	No
Fallow	Fallow-canola-wheat	Early, Timely	7	No

[1] Early sowing= from March 1 if grazed, April 1 if un grazed; Timely sowing = late April to mid-May

[2] The N strategies (decile 2 or decile 7) apply top-dressed N each year in July to cereals and canola assuming the season will finish as either decile 2 (lower yield and less N) or decile 7 (higher yield so more N). N requirement is adjusted in each treatment to account for soil N measured pre-sowing, so carry-over 'legacy N' from previous seasons (fertiliser or legume N) means less N will be required for the current crop and so the value of legacy N from fertiliser or legumes is captured in the lower input costs.

[3] At Greenethorpe, a 2nd wheat crop replaced the barley

Seasonal conditions at the sites during the 2018-2023 seasons

The 2018 and 2019 seasons were dry (decile 1-2), the 2020 to 2022 were wet (decile 7-10) while the 2023 season was closer to long-term average (decile 5-6), except at Urana (decile 8) (Table 2).

Table 2. Rainfall (+irrigation) at the experiment sites from 2018 to 2022 and the long-term median (LTM) rainfall and the decile for that season (brackets).

Site	2018	2019	2020	2021	2022	2023	LTM
Greenethorpe	359 (2)	353 (2)	726 (10)	943 (10)	875 (10)	590 (5)	579
Wagga Wagga	403 (3)	320 (2)	557 (8)	757 (10)	886 (10)	559 (6)	526
Urana	276 (1)	222 (1)	488 (6)	564 (9)	968 (10)	552 (8)	449
Condobolin	218+120 (1)	162+118 (1)	685 (9)	806 (10)	958 (10)	474 (6)	434

Brief background to the outcomes so far

Phase 1 (2018-2020)

In Phase 1, the outcomes for the different systems were highly influenced by the two consecutive dry seasons (see Kirkegaard *et al.,* 2021). The key outcome for grain-only systems for phase 1 was that at all sites, the diverse systems that included a legume, and with a decile 2 N strategy were more profitable than the *Baseline* system, were less risky, had stable or declining weed and disease burdens, and lower average input costs. Simulation also predicted these results to be robust for a range of seasons modelled over the longer term. In mixed (grazing crop) systems, the most profitable systems involved early sown grazed crops (wheat-canola) with a higher N fertiliser strategy (decile 7).

Phase 2 (2021-2023)

The effect of the 3 consecutive wet seasons (2020 -2022) on these early results were considered in detail in (Kirkegaard *et al.*, 2022, 2023). The wet conditions provided opportunities to lift yield and profitability, capitalise on higher N strategies and earlier-sown crops, but also increased the risks of disease, lodging, grain quality reduction and reduced the timeliness of operations. Grain legumes can suffer significant yield losses to disease and lodging and/or significant costs for multiple fungicide applications. Consequently, during these wet seasons, the Baseline and Intense Baseline systems with more canola and higher N supply performed well in terms of profit but had lower return on investment, while some systems with legumes (e.g. chickpea) performed poorly.

As a consequence, after 5 years, the diverse systems with grain legumes and decile 2 N strategy remained the most profitable at two sites (Urana and Greenethorpe), while the *Baseline* and *Intense Baseline* were more profitable at Wagga and Condobolin, but with greater risk.

Profit and risk after 6 years (2018-2023)

Effect of diversity and N strategy in timely-sown grain-only crops

A summary of outcomes for selected timely-sown grain-only systems across all sites is provided in Table 3, with a focus on the effect of crop diversity, and nitrogen strategy. The systems are arranged in Table 3 for each site in order of increasing crop diversity (Continuous wheat = 100% cereal, Baseline systems = 66% cereal, Intense Baseline = 50% cereal, Diverse = 33% cereal). For the diverse systems, the most profitable of the legume sequences was used in each case.

Profitability is represented by average annual $GM (2018-2023), risk by both the variability (standard error) of annual $GM, and the profit/cost ratio (ROI). The average annual N applied as fertiliser (kg/ha/yr) is also shown in Table 3, as N fertiliser was a significant cost driver.

At the two sites (Wagga and Greenethorpe) where continuous wheat systems were included, they had significantly lower $GM than the Baseline systems although the variability in $GM was also relatively low (Table 3). The ROI was also relatively low compared to the Baseline at Wagga Wagga but similar at Greenethorpe, perhaps reflecting the lower level of N applied at Greenethorpe. At Wagga, the average $GM of continuous wheat system was responsive to higher N in the decile 7 treatment (extra 56 kg N/ha/yr), but this did not match the profitability or ROI of the more diverse systems with lower N.

Intensifying the Baseline systems by moving to Intense canola-wheat (C-W) systems reduced average $GM at Wagga Wagga and Urana while increasing the $GM at Greenethorpe and Condobolin. At all sites, the variability in $GM was increased, while ROI was either reduced (Wagga Wagga, Urana) or unchanged. Average N supply increased at all sites in the Intense Baseline system, most notably at Greenethorpe with minor increases at the other sites (Table 3). Increasing N supply to the Intense Baseline systems (average increase 40-60 kg/ha/yr) had most impact on $GM at Urana (+$164), smaller effects at Wagga Wagga and Greenethorpe (~+$50/ha) and a small reduction at Condobolin. The additional income barely covered the higher N costs, with ROI declining or remaining relatively unchanged and variability in $GM generally increasing.

The diverse system with low N was the most profitable system at Urana, matched the most profitable at Greenethorpe, but was less profitable than the Baseline at Wagga and Condobolin. However, the Diverse systems consistently had the highest ROI at all sites by a significant margin, This was partly related to the much lower average annual N required (40-50 kg/ha/yr less) in those systems. The variability in $GM was similar or lower than Baseline at Wagga and Condobolin but higher at Greenethorpe and Urana – possibly reflecting the variable performance of the legumes across the years with respect to yield and price compared to canola, wheat and barley.

Table 3. Average gross margins ($/ha/yr) and variation (standard error) in gross margin for timely-sown, grain-only systems at four experimental sites over 6 years (2018-2023). Profit/cost ratio ($GM/$Variable costs) are shown as a measure of return on investment and risk. The average annual N application as fertiliser (kg N/ha/yr) to each system is also shown. N2 and N7 refer to the decile 2 and decile 7 nitrogen strategies.

System	Crop sequence	Average annual gross margin (GM) ($/ha/yr)		Variability in gross margin (Std. Err.) ($/ha/yr)		Profit/Cost ratio (ROI)		Average N applied (kg/ha/yr)	
		N2	N7	N2	N7	N2	N7	N2	N7
Wagga Wagga									
Cont. wheat	W-W-W	652	732	86	129	0.94	0.91	77	133
Baseline	C-W-B	902	944	116	121	1.11	1.06	97	143
Int. Baseline	C-W	767	819	143	143	0.87	0.9	103	144
Diverse	Lu-C-W	802	-	97	-	**1.20**	-	54	-
Greenethorpe									
Cont. wheat	W-W-W	953	-	96	-	**1.47**	-	47	-
Baseline	C-W-W	1108	1130	131	159	1.42	1.32	77	119
Int. Baseline	C-W	1163	1219	198	222	1.37	1.33	88	135
Diverse	Fa-C-W	1179	-	172	-	**1.46**	-	40	-
Urana									
Baseline	C-W-B	816	-	109	-	1.12	-	72	-
Int. Baseline	C-W	682	847	115	163	0.91	0.98	78	137
Diverse	Fa-C-W	992	-	130	-	**1.38**	-	29	-
Condobolin									
Baseline	C-W-B	781	-	127	-	1.14	-	67	-
Int. Baseline	C-W	826	809	153	158	1.15	1.08	74	116
Diverse	Lu-C-W	730	-	127	-	**1.31**	-	42	-

In summary, while the most profitable diverse systems have matched the average profit of the Baseline and Intense Baseline systems at some but not all sites, the consistent benefit is the increased ROI of the Diverse systems at all sites, partly related to the reduced requirement for N fertiliser. Economic responses to increased N fertiliser were relatively small with lower ROI. There are a few exceptions to this. The N7 Int. Base at Urana was quite a bit more profitable ($165/ha) than the N2 and has a higher profit/cost ratio. This was also the case at Wagga Wagga, however not as pronounced.

The Diverse systems involving chickpea/lentil matched the profit of the system involving fababean at Urana, but were less profitable by $145/yr. at Condobolin (*cf* lupin), $90 at Greenethorpe (*cf* fababean), and $37/yr at Wagga (*cf* lupin). The chickpea was especially affected by waterlogging and cold conditions in 2022, and by the need for repeated fungicide sprays for Ascochyta in 2020 and 2021.

Effect of earlier sowing in grain-only crops

Recent research has demonstrated that earlier sown crops selected to flower within the optimum flowering window can have a grain yield and water-use efficiency advantage over timely-sown crops especially when stored subsoil water is available (Flohr *et al.,* 2020). They also provide grazing opportunities on mixed farms. However early sown crops may leave a legacy of drier and lower N subsoils which can reduce the growth of following crops in a sequence. Consequently, the effect of earlier sown crops on the profitability of the system was of interest in this project.

At 3 of the 4 sites (not at Greenethorpe), we could make direct comparisons of grain-only systems that differed only in the sowing time of the wheat and canola crops (Table 4).

The benefit of early-sown wheat and canola in the Diverse N2 system was significant at Condobolin where it added $139/yr to the average annual $GM and this was mostly driven by the higher yield of the earlier-sown wheat and canola. At Wagga, a smaller benefit was achieved by sowing early in the Diverse N2 system, but not in the N7 system, because the additional cost of the increased N applied was not recovered. At Urana in the Intense Baseline canola-wheat system there was only marginal benefit from sowing earlier in the N2 system and reduced profit at N7, similar to the Wagga observation.

In summary the value of earlier-sown crops is dependent on the site and the system (both crop sequence and N strategy) but can provide a significant boost to the profitability of the system in the medium term.

Table 4. Effect of wheat and canola sowing times in selected systems at three sites on the average annual gross margin from 2018-2023.

Site	**System**	**Average annual gross margin ($/ha/yr)**		
		Timely sown	**Early sown**	**Difference**
Condobolin	Diverse N2 (Le/Ch-C-W)	585	724	+139
Wagga	Diverse N2 (Le/Ch-C-W)	765	786	+21
	Diverse N7 (Le/Ch-C-W)	748	609	-139
Urana	Int. Baseline N2 (C-W)	682	695	+13
	Int. Baseline N7 (C-W)	847	775	-72

N legacy impacts on profit

The effect of N legacies at the experimental sites have been reported at previous Updates by Swan *et al.,* (2022) and Dunn *et al.*, (2023). In exploring the value of N legacies from legumes on following crops and on the profit and risk of the systems there are several questions that can be considered.

1) Is there a legacy of higher soil mineral N in the soil after legumes compared to non-legumes?
2) How much less fertiliser was applied to the system as a result?
3) Was there a yield increase in following crops?
4) Did (1)-(3) contribute to increased profit and reduced risk?

In answer to (1) Table 5 summarises the soil mineral N in the soil prior to the canola crops following wheat or barley crops in the Baseline systems and following legumes (lupin or fababean) in the Diverse systems (as previously shown in Table 3). Except in the flood year at Condobolin (2022), a legacy of higher mineral N following the legumes was observed at all sites and in all seasons, with an additional average pre-sowing mineral N of 26, 98, 48 and 42 kg N/ha at Wagga, Greenethorpe, Urana and Condobolin respectively. This would have reduced the N applied to reach the target yield in the canola crops within those systems each year. In addition to the higher N in the soil prior to the canola, there was also higher N in the soil prior to the subsequent wheat crops which averaged +27, +50, +16 kg N/ha at Wagga, Greenethorpe and Urana while there was 10 kg N/ha less prior to wheat at Condobolin (data not shown). Though it is difficult to attribute this legacy specifically to the legume due to the differences in top-dressed N and N removal by the canola crops, the overall effect was to reduce the average annual application of N fertiliser to the Diverse system by 43, 37, 43, and 25 kg N/ha/yr (as shown previously in Table 3).

Table 5. Mineral N in the soil prior to sowing canola following barley or wheat in the Baseline systems and following fababean or lupin in the Diverse systems at the four sites. Note all crops in 2018 (Yr 1) followed wheat so no legacy effects existed in that year.

System	**Crop sequence**	**Mineral nitrogen in soil prior to canola (kg N/ha)**					
		2019	**2020**	**2021**	**2022**	**2023**	**Mean**
Wagga Wagga							
Baseline	B-**C**-W	47	81	91	91	47	**71**
Diverse	Lu-**C**-W	78	67	114	128	154	**97**
Greenethorpe							
Baseline	W-**C**-W	217	180	109	127	58	**136**
Diverse	Fa-**C**-W	260	264	339	233	133	**234**
Urana							
Baseline	B-**C**-W	45	84	66	47	45	**57**
Diverse	Fa-**C**-W	101	106	123	112	133	**105**
Condobolin							
Baseline	B-**C**-W	53	64	15	11	132	**52**
Diverse	Lu-**C**-W	133	146	48	2	190	**94**

With respect to (3), any yield benefit following the legumes in the subsequent canola crop cannot necessarily be attributed to the extra N measured pre-sowing, because the canola crops were top-dressed to a decile 2 yield target according to the N available at sowing. Indeed, the N applied to the canola crops was reduced on average by 18, 58, 41 and 27 kg N/ha at Wagga, Greenethorpe, Urana and Condobolin respectively following the legumes in the Diverse systems. This represented a cost saving, but had an equalising effect on N supply, although additional N may have mineralised after sowing following the legumes, to provide an additional N benefit for the following crop. As the higher soil N legacy persisted to the subsequent wheat crops, there was also around 20 kg N/ha less N applied to the wheat crops on average in the Diverse systems. These N savings were significant but were small compared to the reductions in N applied to the legume crops themselves (<5 kg N/ha applied) compared to barley or wheat (50 to 100 kg N/ha applied) which were 86, 47, 62 and 50 kg N/ha at Wagga, Greenethorpe, Urana and Condobolin respectively.

There was little overall yield benefit measured in the canola crops following the legumes in the Diverse systems at the 4 sites (+0.3 t/ha at Urana only) or in the subsequent wheat crops (+0.3 t/ha at Greenethorpe only) (data not shown). Consequently, except for these two cases, little of the economic benefits within the Diverse systems have arisen from higher yields and income in the canola or wheat crops following the legumes in the Diverse systems.

In assessing the impact of legacy N on profit and risk, it is useful to examine the overall performance of the different crops in the sequence across the 6 years in light of the impacts on N inputs (Table 6). At Wagga, despite the N legacy effects of the lupin reducing the overall N inputs, the lower profitability of the lupin itself (average yield 3.1 t/ha) compared with the barley (average yield 6.0 t/ha) in the system was the major driver of the lower $GM of the Diverse system (Table 6). A somewhat similar outcome occurred at Condobolin, although the boost in canola $GM offset the lower profitability of the lupin compared with the barley. The fababean in the Diverse system at Greenethorpe (average yield 4.4 t/ha) and Urana (average yield 4.7 t/ha) were as profitable or significantly more profitable than the wheat (average yield 5.4 t/ha) or barley (average yield 6.2 t/ha) in the Baseline systems at those sites, and there were also higher $GM in the following canola and wheat crops following the fababean.

In summary, the reduced N fertiliser input costs in the Diverse systems due to low N applied to the legume crops and reduced N applied to subsequent canola and wheat crops due to legacy N has contributed to the $GM of the Diverse systems much more than increased yield of subsequent crops following the legumes. Urana is the exception to this. The increased yield and profit ($257/ha for canola) following fababeans have been quite pronounced. However the lower profitability of lupin compared to barley has eroded that economic advantage at Wagga and Condobolin, while the higher profitability of fababean has added to the economic advantage at Greenethorpe, and especially at Urana.

Table 6. Average annual 6-yr gross margins for individual crops in the grain-only Baseline N2 (barley-canola-wheat) and Diverse N2 (legume-canola-wheat) systems from 2018 to 2023.

System	**Crop sequence**	**Average annual $GM ($/ha/yr) 2018-2023**			
		Cereal/Legume	**Canola**	**Wheat**	**Mean**
Wagga Wagga					
Baseline	B-C-W	1103	838	764	**901**
Diverse	Lu-C-W	800	812	794	**802**
Greenethorpe					
Baseline	W-C-W	1094	1034	1195	**1107**
Diverse	Fa-C-W	1058	1228	1252	**1179**
Urana					
Baseline	B-C-W	1089	475	884	**816**
Diverse	Fa-C-W	1301	732	942	**992**
Condobolin					
Baseline	B-C-W	818	771	752	**780**
Diverse	Lu-C-W	604	834	752	**730**

Do legacies occur with higher fertiliser strategies?

At two sites (Wagga and Greenethorpe) Baseline systems were included with both decile 2 and decile 7 strategies (see Table 3). The question arises as to whether there is evidence that the higher N applied each season to the N7 treatment that is not used by the crop, carries over to subsequent crops in the same way that legume N carries over.

At Wagga there was an average of +17, +32 and +27 extra kg N/ha/yr measured pre-sowing in the N7 compared to the N2 prior to the canola, wheat and barley respectively, an average of +25 kg N/ha for the system. This compares with an extra 50 kg N/ha/yr applied to the N7 treatment (Table

3). At Greenethorpe there was an average of +37, +102 and +6 extra kg N/ha/yr measured pre-sowing in N7 compared to N2 prior to the canola, wheat 1 and wheat 2 crops respectively. This compares with an extra 41 kg N/ha/yr applied in the N7 treatment (Table 3). This suggests that a significant portion of the increased N applied that may not be utilised by the crops can carry over as legacy N within the system, although in this case it has only generated a small increase in $GM but a lower ROI within the systems (Table 3). A more complete N balance will be carried out to provide more detail on the fate of the applied N in terms of offtake, changes in soil organic matter or N losses.

Whole-farm and business considerations

The results at the four sites demonstrate that a range of different systems with relatively small differences in average annual gross margin over 6 years can be quite profitable but may differ in performance in different seasons (wet, dry) and have different risk profiles. This reminds us that different systems may suit specific businesses depending on a range of factors other than the agronomic management - many of which cannot be measured in these small-scale experiments but must be considered when making decisions to integrate grain legumes into the business. For example, it is likely that to ensure the best outcome from grain legumes that some storage capacity may be required on farm, the capacity to handle the inoculation process in a timely and effective manner, and careful and timely application of fungicides in wetter seasons. These will generate labour peaks and demand on machinery that must be considered. Enterprises with significant areas of legume-based pastures may find that these can perform much the same function of organic N supply, disease and weed management as that played by grain legumes in the systems reported here and are suited to phased rotation with more intensive cereal-canola systems. The choice of legume is also clearly important based on those best adapted to specific paddocks.

Never-the-less, the emerging data from these systems experiments demonstrate the importance of fully assessing the value of grain legumes in different systems beyond their performance in individual years, as much of the benefit derives from legacy effects, input savings and more even performance across seasons. These are difficult to assess without longer-term side-by-side comparisons and supporting data to understand the mechanisms behind the responses.

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References

Kirkegaard J, Dunn M, Swan T, Whish J, Pumpa R, Fiske K (2023) Farming systems profit and risk over time: the impact of three wet consecutive seasons. GRDC Updates Wagga Wagga 2023. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/farming-systems-profit-and-risk-over-time-the-impact-of-three-wet-consecutive-seasons

Dunn M, Kirkegaard J, Swan T, Whish J, Pumpa R, Fiske K (2023) Legacy effects and the value of legumes in the farming system after three consecutive wet seasons. GRDC Updates Wagga Wagga 2023. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2023/02/legacy-effects-and-the-value-of-legumes-in-the-farming-system-after-three-consecutive-wet-seasons

Kirkegaard J, Swan T, Dunn M, Sandral G, Whish J, Berary M, Reardon D, Woodsford-Smith A, Friske K, Pumpa R (2022) Farming systems performance at a 'macro' scale: effects of management strategies on productivity, profit, risk, WUE GRDC Update Wagga Wagga 2022. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/farming-systems-performance-at-a-macro-scale-effects-of-management-strategies-on-productivity,-profit,-risk,-wue

Swan T, Dunn M, Kirkegaard J, Goward L, Leighton E, Sandral G, Hunt J, Bullock M, Pumpa R, Fiske K, Woodford-Smith A, Reardon D, Barry M, Burns H (2022). What is the N legacy following pulses for subsequent crops and what management options are important to optimise N fixation? GRDC update, Wagga Wagga 2022. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/what-is-the-n-legacy-following-pulses-for-subsequent-crops-and-what-management-options-are-important-to-optimise-n-fixation2

Kirkegaard J, Swan T, Dunn M, Sandral G, Whish J, Leighton E, Reardon D, Bullock M, Friske K, Pumpa R (2021) Managing water and N across years and crop sequences to drive profit. GRDC Updates Wagga Wagga 2021. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/02/managing-water-and-n-across-years-and-crop-sequences-to-drive-profit

Flohr BM et al., (2020) Deep Soil Water-Use Determines the Yield Benefit of Long-Cycle Wheat. *Frontiers in Plant Science* 11, 548 doi: 10.3389/fpls.2020.00548.

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