Farming systems profit and risk over time: the impact of three wet consecutive seasons

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Take home message

- Despite 3 consecutive wet seasons, diverse systems involving grain legumes with a lower N fertiliser strategy remain more profitable, have less variable annual average gross margins, and a higher return on investment than baseline cereal-canola systems
- Intensive canola-wheat systems with higher N have performed well in terms of gross margin in the wet seasons, but have a lower return on investment and performed poorly in drier seasons
- Issues related to nitrogen supply (costs and response) underpin most of the productivity and profitability differences observed between systems
- Successful integration of grain legumes on farms or parts of farms will be a decision specific to individual businesses and involve considerations beyond good agronomy.

The Southern Farming Systems Project – a brief description

The southern NSW farming systems project was established in 2017 after a 12-month consultation period and extensive literature review demonstrated a significant gap in profitability and 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 $250/ha higher than the most common 'baseline' sequences. We established research sites and simulation studies to investigate strategies to increase the conversion of rainfall to profit ($/ha/mm) 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), with 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.

System	Sequence	Sowing time	N strategy (Decile 2 or 7)	Grazing
Baseline	Canola-wheat-barley	Timely	2, 7	No
Intense baseline	Canola-wheat	Early, Timely	2, 7	Yes
Diverse high value 1	Lentil-canola-wheat	Early, Timely	2, 7	No
Diverse high value 2	Chickpea-wheat	Timely	2	No
Diverse low value	(Faba/lupin)-canola-wheat	Timely	2	No
Diverse (mix)	HDL*-canola-wheat	Early, Timely	2, 7	Yes
Continuous wheat	Wheat-wheat-wheat	Timely	2, 7	No
Fallow	Fallow-canola-wheat	Early, Timely	7	No

Early sowing= from March 1; Timely sowing = late April to mid-May

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 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 to the current crop and so the value of legacy N from fertiliser or legumes is captured in the lower input costs.

Seasonal conditions at the sites for the 2018-2022 seasons

The 2018 and 2019 seasons were dry (decile 1-2) across the sites, while 2020, 2021 and 2022 were high rainfall seasons (minimum of decile 6, with most at 9-10) across the sites (Table 2).

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

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

Outcomes from Phase 1 (2018 to 2020) – are they holding up after three wet years?

In the first phase of the project (2018-2020), the outcomes of the different systems were highly influenced by the two first dry seasons (Table 2). A detailed consideration of the productivity and profitability of the different crops and systems under the dry conditions in 2018 and 2019 was provided in two previous papers in the references (Kirkegaard et al 2020). The key outcomes which are described in more detail in the previous GRDC Update papers (see references) can be summarised as follows:

- At all sites we identified systems that were (1) more profitable by $200-300/ha, (2) less risky, (3) had stable/declining weed and disease burdens, (4) lower average input costs and (5) robust in the long term - compared to the baseline cereal-canola systems.

- In mixed (grazing crop) systems, the most profitable systems involved early sown grazed crops (wheat-canola) with a higher N fertiliser strategy (decile 7) or in sequence with a legume (vetch)
- In 'crop-only' systems, timely-sown, diverse sequences with legumes and a more conservative (decile 2) N strategy were the most profitable.

The question arises – have the three consecutive wet seasons (2020 to 2022) and especially the very wet 2022 season changed these key outcomes? In this paper we focus on the results from Wagga Wagga and Urana where data analysis is more complete. Data from Greenethorpe and Condobolin are delayed due to the late and wet harvests, but may be provided in the presentation. Some adjustments to this preliminary data may occur with further analysis.

Have the three wet consecutive seasons (2020-2022) changed the story?

Wet seasonal conditions provide opportunities to lift yield and profitability and to capitalise on higher N strategies and earlier-sown crops. However, they can also increase input costs for fungicides and fertiliser and in very wet years, increase the risks of yield penalties due to higher disease levels, lodging, grain quality reduction and reduce the timeliness of operations. In particular, grain legumes can suffer significant yield losses to disease and lodging and/or significant costs for multiple fungicide applications. The 2022 season was decile 10 at all sites across southern NSW (Table 2) and the third wet consecutive season, so the question arises: How have the wet seasons influenced the profitability and risk of the crop sequence – rather than the performance of specific crops in those years.

To answer this question, we compared the gross margin and risk of a range of systems over the entire five seasons and compared the performance of the systems in dry (2018, 2019) and wet (2020, 2021, 2022) seasons to demonstrate how seasonal conditions influence gross margin, variability and risk. In this paper we focus on the grain-only systems at the Wagga Wagga (Table 3, Figure 1) and Urana (Table 4, Figure 2) sites, as full data sets were available at the time of writing.

Wagga Wagga site

Average $GM. The highest gross margin grain-only systems at Wagga Wagga averaged over all 5 seasons have been the intensive canola-wheat systems (decile 2 & 7 N), and the diverse lupin-canola-wheat system with decile 2 N - which have all been more profitable than the barley-canola-wheat baseline systems (highlighted in grey) (Table 3). The diverse system with chickpea and low N was only marginally less profitable than the baseline, while all other systems were more than $50/ha/yr less profitable than the baseline. The least profitable systems involved either fallow (16,14), early-sown systems with legumes and/or high N (15), or the continuous cereals (10,11).

Variability and Risk. Despite the intensive canola-wheat systems generating higher average gross margins overall, this was driven by better performance in wet seasons, as they tended to perform poorly in the drier seasons (Table 3). In contrast, the diverse lupin-canola-wheat system with low N (3), had among the highest gross margins in the dry seasons, and also performed well (3rd highest) in the wet seasons. This lower variability was accompanied by the highest return on investment (ROI) (i.e. lower risk). While the continuous cereals (10,11) and the chickpea-wheat systems (12) also performed well in dry seasons and had more stable gross margins, their poor performance in wet seasons and low ROI made them less attractive overall.

In summary, the higher $GM in wet years strongly influence the average gross margins and favour systems with a higher intensity of canola (1,2), while higher N strategies in these systems (decile 7) are only marginally more profitable and have a higher profit/cost ratio than the decile 2 strategies. Diverse systems with either lupin (3) or chickpea (6) and with lower N strategy (decile 2) remain as profitable or more profitable than the baseline system (4,5) and combine high overall profitability with higher return on investment, more stable gross margins and lower risk.

Table 3. Average gross margins ($/ha/yr) for the grain-only systems at Wagga Wagga over all 5 years (2018-2022) and separated for the dry (2018, 2019) and wet (2020, 2021, 2022) seasons. Profit/cost ratio ($GM/$Variable costs) over all years are shown as a measure of return on investment and risk. The shaded system is the Baseline system (barley-canola-wheat, timely-sown, decile 2 N)

Crop sequence	Sow time	N strategy (decile 2 or 7) *Average N applied (kg/ha/yr)*	Average annual gross margin ($/ha/mm)			Seasonal variability ranking (1= least variable)	Profit/cost ratio	Profit/cost rank (ROI) (1 = high)
			All years (2018-2022)	Dry years (2018-2019)	Wet years (2020-2022)			
1. C-W	T	7 *(160)*	822	136	1279	12	0.89	6
2. C-W	T	2 *(107)*	815	183	1236	11	0.98	3
3. Lup-C-W	T	2 *(58)*	805	275	1159	4	1.12	1
4. Bar-C-W	T	7 *(155)*	796	245	1148	6	0.87	9
5. Bar-C-W	T	2 *(103)*	778	263	1121	5	0.95	4
6. Chi-C-W	T	2 *(62)*	773	238	1130	8	1.02	2
7. Chi-C-W	T	7 *(98)*	723	108	1133	13	0.89	8
8. Chi-C-W	E	2 *(73)*	720	68	1155	14	0.92	5
9. Vet-C-W	T	2 *(59)*	649	235	903	9	0.89	7
10. W-W-W	T	7 *(146)*	620	223	884	3	0.72	13
11. W-W-W	T	2 *(90)*	597	345	765	1	0.80	10
12. Chi-W	T	2 *(38)*	581	286	777	2	0.79	12
13. Vet-C-W	T	7 *(98)*	570	187	825	10	0.72	14
14. F-C-W	T	7 *(100)*	504	150	741	7	0.79	11
15. Chi-C-W	E	7 *(118)*	488	-35	837	16	0.58	16
16. F-C-W	E	7 *(113)*	385	-65	685	15	0.59	15

Lup=Lupin, Bar=Barley, Chi=Chickpea, Vet=vetch, F=Fallow
T=Timely-sown (mid-April to mid-May); E=Early-Sown (early March to early April)

Figure 1 demonstrates in the trade-off between average gross margin and ROI (profit/cost ratio), the diverse systems provide similar overall gross margins as the baseline systems but with a higher ROI (i.e. less risk), while continuous cereal systems have lower average gross margins and lower ROI.

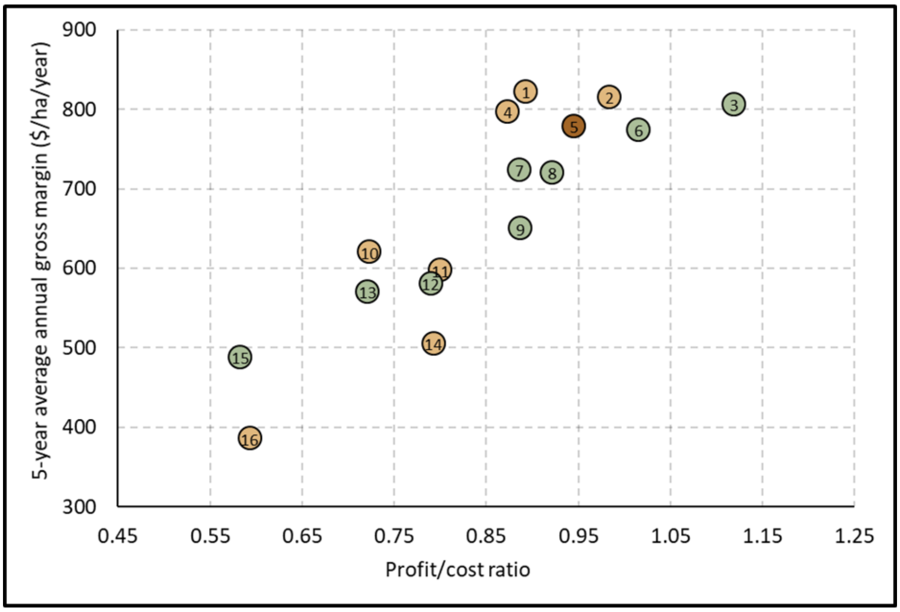

Figure 1. Average gross margins and profit to cost ratio for systems numbered in Table 1. Systems without legumes are light brown, the baseline is dark brown and systems with legumes in green.

Urana site

Average $GM. The most profitable grain-only systems at Urana averaged over all 5-years have been the diverse legume-canola-wheat systems involving chickpea or fababean with lower (decile 2) N strategy (Table 4, Systems 1,2,3). These have been $100-$200/ha/yr higher gross margin than the intense canola-wheat systems (4-7) or the baseline barley-canola-wheat system (8). Within the cereal-canola systems (i.e., no legume), the early-sown canola-wheat with higher N was the most profitable overall and was around $100/ha/yr more profitable than the baseline system. The least profitable systems at Urana were those involving fallow or vetch (9,10). The striking difference with the Wagga Wagga results (*cf* Tables 3 and 4), was the relatively low profitability of the baseline system at Urana, and the exceptional performance of the diverse systems with faba-bean or chickpea with a lower (decile 2) N strategy.

Variability and risk. The high overall profitability of the diverse systems involving chickpea and fababean resulted from their excellent performance across both dry and wet seasons (Table 4). In contrast, the intensive canola-wheat systems sown early had very low profitability in the dry seasons despite being among the highest gross margins in wet seasons, especially with a higher N strategy. The diverse systems with low N also had much higher ROI (1.05 to 1.37), well above that of the intense canola-wheat systems or the baseline system (0.87 to 0.97). The fallow-canola-wheat system (10) had a relatively high ROI (1.09) and performed surprisingly well in the wet years, presumably due to fewer inputs and higher yielding wheat and canola crops, but the lack of income in every 3rd year, and the limited value of stored water in the wet seasons generated low overall gross margins.

In summary for Urana, diverse systems with legumes (faba or chickpea) combine high overall and stable gross margins over different seasonal conditions and a high return on investment (lower risk) despite a run of wet years, and very low chickpea yields in very wet and cold 2022 season (1.2 t/ha). Intensive canola-wheat systems have also outperformed the baseline barley-canola-wheat system, presumably due to a greater frequency of the more profitable canola crops during recent wet seasons, which responded to earlier sowing and higher N.

Table 4. Average gross margins ($/ha/yr.) for the grain-only systems at Urana over all 5 years (2018-2022) and separated for the dry (2018, 2019) and wet (2020, 2021, 2022) seasons. Profit/cost ratio ($GM/$Variable costs) over all years are shown as a measure of return on investment and risk. The shaded system is the Baseline system (barley-canola-wheat, timely-sown, decile 2 N)

Crop sequence	Sow time	N strategy (decile 2 or 7) *Average N applied (kg/ha/yr.)*	Average annual gross margin ($/ha/mm)			Seasonal variability ranking (1= least variable)	Profit/cost ratio	Profit/cost rank (ROI) (1 = high)
			All years (2018-2022)	Dry years (2018-2019)	Wet years (2020-2022)			
1. Chi-C-W	T	2 *(29)*	915	568	1146	4	1.37	1
2. Faba-C-W	T	2 *(22)*	875	513	1116	2	1.26	2
3. Chi-C-W	T	7 *(77)*	764	383	1017	6	1.05	4
4. C-W	E	7 *(152)*	757	22	1267	9	0.86	10
5. C-W	T	7 *(131)*	711	434	895	1	0.87	9
6. C-W	T	2 *(62)*	702	420	890	5	0.97	6
7. C-W	E	2 *(76)*	696	18	1148	10	0.94	7
8. Bar-C-W	T	2 *(61)*	644	441	780	3	0.88	8
9. Vet-C-W	T	2 *(31)*	632	335	830	7	0.97	5
10. F-C-W	E	7 *(75)*	595	38	966	8	1.09	3

Lup=Lupin, Bar=Barley, Chi=Chickpea, Vet=vetch, F=Fallow
T=Timely-sown (mid-April to mid-May); E=Early-Sown (early March to early April)

Figure 2 demonstrates the exceptional performance of the diverse, lower N strategies compared to the other systems as they combine high average overall gross margin with a high return on investment.

In terms of the consequences of consecutive wet seasons, both sites have diverse systems with low N strategies that deliver either the highest or among the highest gross margin with lower variability and high ROI. The more intense canola-wheat systems have emerged to be more profitable than the baseline systems, but with greater variability and lower ROI at both sites.

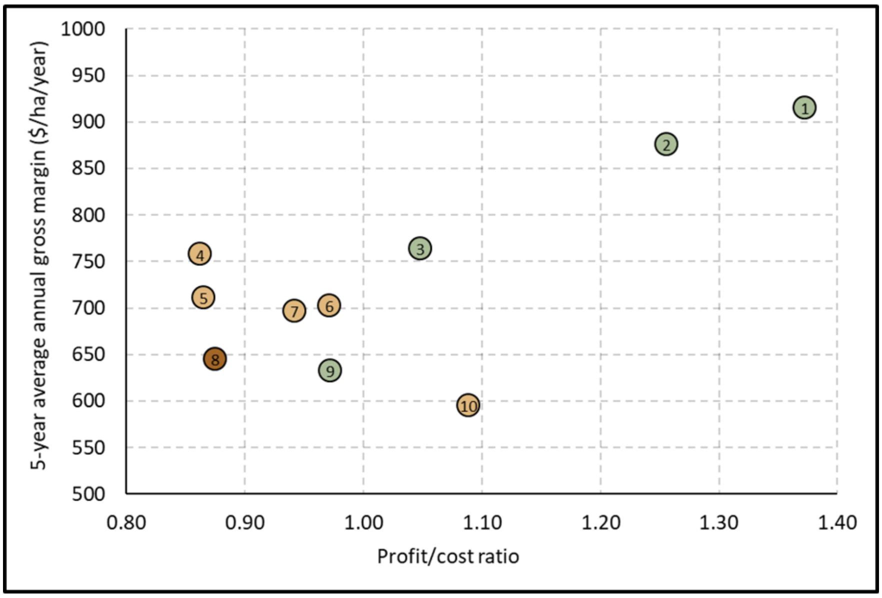

Figure 2. Average gross margin and profit to cost ratio for systems numbered in Table 4. Systems without legumes are light brown, the baseline is dark brown and systems with legumes in green.

Overall, despite the three consecutive wet seasons, diverse systems involving legumes with a lower decile 2 N strategy remain either the most profitable (Urana) or among the most profitable (Wagga Wagga) systems, with the highest ROI and low variability of gross margin. Intense systems involving more canola (i.e., C-W systems) and higher N have improved in their economic performance compared to the baseline systems at both sites due to the higher gross margins from canola in wet seasons.

Mechanisms underpinning the systems responses at the sites

In an accompanying paper (Dunn et al., 2023), the mechanisms driving these overall economic outcomes are discussed in more detail, but issues related to the nitrogen supply to the crops within the systems have been a big driver of the responses discussed above. This relates to several aspects including:

- Nitrogen is a big driver of yield potential in wet seasons when water is not limiting, especially in canola. For example, at Wagga Wagga, canola yields increased by 0.4 t/ha on average in decile 7 N baseline (barley-canola-wheat) and intense baseline (canola-wheat) systems compared to equivalent decile 2 systems, while wheat was less responsive (data not shown). In very wet years such as 2022, the additional costs of multiple fungicide sprays and additional N, and yield reductions related to higher disease or lodging can diminish the responsiveness to N
- Grain legumes do not require N fertiliser (cost saving) and reduce the amount of N required on subsequent crops (cost saving). Tables 3 and 4 show that the average amount of N supplied to the diverse legume-canola-wheat decile 2 N systems was 60 kg N/ha/yr at

Wagga and 25 kg/ha/yr at Urana, compared with 103 kg/ha/yr and 61 kg/ha/yr for the baseline barley-canola-wheat system. This reduced N requirement of around 40 kg N/ha/yr represents a considerable cost saving, especially as N prices increased in recent years. At Wagga, supplying 50 kg N/ha/yr more N fertiliser on the baseline treatment (i.e., in the decile 7 baseline system) increased overall gross margins above the decile 2 baseline system only marginally (by $18/ha/yr), but it remained less profitable than the diverse lower N system, and with a much lower return on investment

- Canola crops following legumes in the diverse sequences have had significant yield and gross margin increases compared to those in the baseline systems at Urana, which generated a further increase in the systems gross margin. This increase in canola yield was not observed at Wagga. The possible reasons for this are discussed more in Dunn et al. (2023)
- Cost savings through reduced N costs and increased gross margin from higher yield has more than outweighed the lower gross margins of the legume crops themselves, despite higher fungicide costs and some yield reduction in wet years. With the notable exception of the poor yield of chickpea in 2023 (due to prolonged cold and wet conditions), the yields and gross margin of the legumes in the wet seasons (2020, 2021 and 2022) has been reasonable. Average chickpea yield has been ~3.0 t/ha at Wagga Wagga and Urana ($800 - $1000/ha gross margin), lupin yield of 3.8 t/ha ($670/ha) at Wagga Wagga and fababean yield of 5.9 t/ha ($1200/ha) at Urana. Though not always the highest gross margin crop in specific seasons, the gross margins have been reasonable and sufficient with the legacy effects to make them a profitable inclusion in the system.

Whole-farm and business considerations

The results at both sites demonstrate that a range of different systems with relatively small differences in average annual gross margin over 5 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 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, along with 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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