Legacy effects and the value of legumes in the farming system after three consecutive wet seasons

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Key words

crop sequences, legumes, nitrogen, gross margin

GRDC code

CSP2110-004RMX

Take home messages

- Some crop sequences that include a legume have been as profitable (Wagga Wagga) or more profitable (Urana) than the baseline sequence of barley-canola-wheat despite three consecutive wet seasons
- In the wet seasons of 2020, 2021 & 2022 legume crops provided positive legacy effects at both Wagga Wagga and Urana sites
- The positive legacy effects at Wagga Wagga were mostly related to the reduced urea requirement due to increased soil mineral nitrogen following legumes. On average this benefit was an extra 36 and 34 kg N/ha at sowing of the first and second crops following the legume, respectively
- At Urana, in addition to increased soil mineral nitrogen following legumes (73 and 13 kg/ha N in the first and second year, respectively) and subsequent reduced urea requirement, a significant and consistent increase in grain yield of the following canola was observed (0.72 t/ha increase on average). Together these benefits increased the average annual canola gross margin by $572/ha/year when following a legume compared to barley
- The low grain yield of some grain legumes in individual seasons should be considered from a whole farm system perspective as considerable additional legacy value may be present.

The Southern Farming Systems Project – background and description

Australian farmers have been enthusiastic adopters of crop benchmarking tools (such as the French and Schultz water use efficiency calculation or Yield Prophet®) to compare the performance of individual crops to their water-limited potential. However, in dryland farming systems, it is important to consider the efficiency of water use across crop sequences to account for the inevitable legacy effects (i.e., carry over effects on soil water, soil fertility, nutrition, weeds and disease).

To cover the range of soils and climate in southern NSW, experimental field sites were established at Wagga Wagga, Greenethorpe, Condobolin and Urana. A range of fully phased crop sequences were established in 2018 and compared with the common canola-wheat-barley baseline crop sequences. These included more intensive cereal sequences (wheat and barley), a range of high-value (lentil, chickpea) and low-value (lupin, faba bean) legume options as well as grazing (Wagga Wagga & Greenethorpe only) and forage options. In addition, interactions of early sown (March/early-April) and timely sown (mid-April/mid-May) wheat and canola options (grazed and un-grazed) and nitrogen (N) management strategies based on either decile 2 or decile 7 outlooks were included. These treatments generated different water and N use patterns as well as weed, disease and residue loads which were monitored across each crop sequence.

This paper focuses exclusively on the timely sown, grain-only crop sequences at Wagga Wagga and Urana in wet seasons of 2020, 2021 and 2022 to examine overall system profitability, and dive deeper into the individual factors driving system performance. The overall results from other sites and treatments can be found in other Update papers.

The results presented in this paper, while robust, are preliminary and may be subject to change with further analysis.

Nitrogen strategies

The N management strategies compared across systems are based on either a conservative seasonal outlook (decile 2), or a more optimistic (decile 7) seasonal outlook. For each non-legume crop in each year of the sequences, soil mineral N was measured pre-sowing and a potential yield estimate made based on starting soil water, N level and seasonal conditions up to that time. N was then top-dressed as urea in July assuming either a decile 2 or a decile 7 finish to the season. Assuming an average season is decile 5, this means that often the decile 2 N strategy would be too low, and the decile 7 treatment too high to maximise yield potential in any year. Using this approach, the legacy benefits of carry-over N from either legumes or unused fertiliser N would be accounted for in the pre-sowing tests and less N applied accordingly. This approach (compared to set N rates) better mimics farmer practice. This paper focuses exclusively on the comparison between timely crop sequences fertilised with the decile 2 N strategy.

Sites

Wagga Wagga: located at the Wagga Wagga Agricultural Institute on a red kandosol with <2% slope. It has a stratified soil pH profile with a 0-10 cm soil pH_{Ca} of 5.7 and an acidic band of 4.5 pH_{Ca} at 12.5-15cm. It has a 0-10 cm organic carbon concentration of 1.02%.

Urana: located between Lockhart and Urana on a brown/grey vertosol with a <1% slope. It has a 0-10cm soil pH_{Ca} of 6.1 with pH_{Ca} increasing at depth, a 0-10 cm exchangeable sodium percentage (ESP) of 3.4 gradually increasing to 15.6 at 30-60 cm, and a 0-10 cm organic carbon concentration of 1.26%.

Seasons experienced

The project used fully phased crop sequences, which means that each stage of a crop sequence occurs in every season. This method helps account for seasonal variability and generates more relevant quality results from a shorter number of experimental seasons. However, it is important to note that the seasons experienced during the experiment differed significantly. At both Urana and Wagga Wagga, well below average annual rainfall was received in 2018 and 2019, however above-average rainfall in 2020, 2021 and 2022 provided a run of wet seasons (Table 1). This paper explores the results only from the recent three wet seasons (2020, 2021, 2022).

Table 1. Annual rainfall received at Wagga Wagga and Urana field experiment sites. Data source: SILO (Jeffrey et al., 2001).

Season	Wagga Wagga site total annual rainfall (mm)	Urana site total annual rainfall (mm)
2018	403 (decile 2)	275 (decile 1)
2019	330 (decile 1)	214 (decile 1)
2020	648 (decile 8)	543 (decile 8)
2021	757 (decile 9)	564 (decile 8)
2022	886 (decile 10)	968 (decile 10)
Long term average	570	438

Economic calculations

Gross margins were calculated by subtracting variable costs from the gross income at a plot level. Variable costs include: crop inputs (seed, fertiliser, pesticides), operation costs (sowing, spraying, spreading, harvesting and cartage expressed as contracting rate), fallow management costs, levies, insurances and EPRs. Variable costs have been obtained from a combination of annual NSW DPI winter cropping guides and annual SAGIT farm gross margin guides. Gross income is calculated by multiplying the grain yield by the harvest spot price relevant to each field site location.

Overall system profitability – have crop sequences that include legumes performed over the last three wet seasons?

Three-year average annual gross margins varied significantly between crop sequences at both sites, ranging from $903 to $1121/ha/year at Wagga Wagga (Table 2) and $815 to $1135/ha/year at Urana (Table 3). At the Wagga Wagga site, the inclusion of lupin or chickpea into the sequence (instead of barley) did not result in a significant change in average annual gross margin. However, at the Urana site the inclusion of faba bean or chickpea (instead of barley) resulted in a significantly higher average annual gross margin. At Wagga Wagga the inclusion of vetch (hay/brown manure) (instead of barley) into the sequence resulted in a lower gross margin, while at Urana the inclusion of vetch (hay/brown manure) (instead of barley) resulted in a similar gross margin.

The average annual variable costs of implementing these sequences varied significantly depending on the sequence. Overall, sequences that include a legume (instead of barley) had lower average annual variable costs. At Wagga Wagga this was on average $119 per hectare lower and at Urana $94 per hectare lower.

The lower average annual variable costs associated with sequences that include a legume were largely a result of both legume crops on their own having lower average annual variable cost compared to barley and an increase in soil mineral N following legume crops resulted in lower urea rates being applied to the crops following. On average in legume sequences (legume-canola-wheat) 64 kg/ha less urea was applied to canola and 80 kg/ha less urea to wheat compared to the baseline sequence (barley-canola-wheat) at Wagga Wagga. At Urana, on average in legume sequences, 110 kg/ha less urea was applied to canola and 58kg/ha less urea to wheat compared to the baseline sequence.

Table 2. Wagga Wagga economic results averaged across 2020, 2021 and 2022 seasons. Only timely sown decile 2 N treatments displayed. Means with the same letter are not significantly different from each other (*P*>0.05). [1]Lentil in 2020. [2]Cut for hay in 2020 & 2021, brown manure in 2022.

Crop sequence (fully phased)	Average annual gross margin ($/ha/year)	Average annual variable costs ($/ha/year)	Profit/cost ratio
Barley – canola – wheat	1121_a	960_a	1.17
Lupin – canola – wheat	1159_a	817_b	1.42
Chickpea[1] – canola – wheat	1130_a	883_d	1.28
Vetch[2] – canola – wheat	903_b	822_c	1.10

Table 3. Urana economic results averaged across 2020, 2021 and 2022 seasons. Only timely sown decile 2 N treatments displayed. Means with the same letter are not significantly different from each other (*P*>0.05). [1]Lentil in 2020. [2]Cut for hay in 2020 & 2021, brown manure in 2022.

Crop sequence (fully phased)	Average annual gross margin ($/ha/year)	Average annual variable costs ($/ha/year)	Profit/cost ratio
Barley – canola – wheat	764_b	847_a	0.90
Faba bean – canola – wheat	1101_a	770_b	1.43
Chickpea$_1$ – canola – wheat	1135_a	755_c	1.50
Vetch$_2$ – canola – wheat	815_b	733_d	1.11

Legume legacy effects – are legume legacy effects driving crop sequence performance?

At Wagga Wagga the inclusion of a legume in the crop sequence did not have a significant impact on the individual crop gross margins of either wheat or canola in the sequence, however a significant impact on the individual crop variable costs was found for both wheat and canola (Table 4). On average the annual variable costs for canola and wheat were $82 and $81/ha/year lower respectively when they followed a legume compared to barley. While no gross margin legacy effect attributed to legumes was found at Wagga Wagga, the reduction in variable costs provided a positive benefit from a risk perspective.

Table 4. Wagga Wagga wheat and canola economic results averaged across 2020, 2021 and 2022 seasons. Only timely sown decile 2 N treatments displayed. Means with the same letter are not significantly different from each other (*P*>0.05). [1]Lentil in 2020. [2]Cut for hay in 2020 & 2021, brown manure in 2022.

Crop sequence (fully phased)	Canola		Wheat	
	Average annual gross margin ($/ha/year)	Average annual variable costs ($/ha/year)	Average annual gross margin ($/ha/year)	Average annual variable costs ($/ha/year)
Barley – canola – wheat	1540_a	1073_a	1097_a	915_a
Lupin – canola – wheat	1499_a	1027_b	988_a	755_d
Chickpea[1] – canola – wheat	1663_a	1000_c	984_a	835_c
Vetch[2] – canola – wheat	1485_a	945_d	1028_a	848_b

At Urana, the inclusion of a legume in the crop sequence did not have a significant impact on the individual wheat crop gross margins, however, did result in significant increase in canola crop gross margins (Table 5). Canola crop gross margins were between $617 and $703/ha/year higher following a legume compared to following barley (Table 5).

Table 5. Urana wheat and canola economic results averaged across 2020, 2021 and 2022 seasons. Only timely sown decile 2 N treatments displayed. Means with the same letter are not significantly different from each other (P>0.05). [1]Lentil in 2020. [2]Cut for hay in 2020 & 2021, brown manure in 2022.

Crop sequence (fully phased)	Canola		Wheat	
	Average annual gross margin ($/ha/year)	Average annual variable costs ($/ha/year)	Average annual gross margin ($/ha/year)	Average annual variable costs ($/ha/year)
Barley – canola – wheat	535_c	908_a	1082_a	793_a
Faba bean – canola – wheat	932_b	790_c	1159_a	675_d
Chickpea[1] – canola – wheat	1152_{ab}	816_b	1103_a	755_c
Vetch[2] – canola – wheat	1238_a	791_c	1040_a	780_b

The large increase in canola gross margin when a legume is included in the crop sequence at Urana is largely a result of two factors. Firstly, canola grain yield was significantly higher (by 0.71 t/ha/year on average) following a legume compared to following barley (Table 6). Secondly, canola that followed a legume had lower average annual variable costs (by $109/ha/year on average) compared to canola that followed barley (Table 5). The reduction in variable costs is largely a result of lower urea rates being applied due to N budget compensation for the increase in soil mineral N following legume crops (Table 6).

Table 6. Urana canola grain yield and urea top-dressing results averaged across 2020, 2021 and 2022 seasons. Only timely sown decile 2 N treatments displayed. Means with the same letter are not significantly different from each other (P>0.05). [1]Lentil in 2020. [2]Cut for hay in 2020 & 2021, brown manure in 2022.

Crop sequence (fully phased)	Average annual canola grain yield (t/ha/year)	Average annual canola urea application rate (t/ha)
barley – canola – wheat	2.23_b	207
faba bean – canola – wheat	2.71_a	100
chickpea[1] – canola – wheat	3.04_a	100
vetch[2] – canola – wheat	3.08_a	90

What is driving the grain yield legacy benefits of legumes at Urana

The observation that the inclusion of a legume before canola in the cropping sequence at Urana resulted in significant canola grain yield increases, but not at Wagga Wagga is noteworthy. Given N availability is a key driver of crop performance (particularly when not water limited), it is possible differences in the availability of N is involved. N fixation by legumes at Wagga has been similar to that of Urana in most seasons, so is unlikely to be a significant factor (Swan et al., 2022). However, the rate and pattern of N mineralisation may have been affected by soil property differences. The Wagga Wagga site has a more acidic, lighter textured and lower organic carbon topsoil compared to the Urana site. The combination of soil chemical, texture and structural properties at Urana may have favoured longer/more rapid periods of mineralisation with, on average, double the soil mineral N following the legumes prior to sowing of the following canola crop was found at Urana compared to Wagga Wagga (73 vs 36 kg N/ha respectively). This extra available soil N prior to top dressing (July) combined with a likely higher rate of in-crop mineralisation, may have contributed to the significant canola grain yield increases found at Urana, but not Wagga Wagga.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC and NSW DPI, the author would like to thank them for their continued support. The authors would like to especially thank Warakirri Cropping “Karoola Park” for their support and co-operation in hosting the Urana field experiment. The authors would also like to acknowledge the contributions of Graeme Sandral for his role as site leader during the first two and a half seasons of the project. We also thank Chris Baker (Baker Ag Advantage), Tim Condon (Delta Agribusiness), Greg Condon (Grassroots Agronomy), James Madden (Lockhart), Heidi Gooden (Delta Agribusiness), Peter Watts (Elders), Rod Kershaw (Iandra), John Stevenson (Warakirri Cropping) and John Francis (Agrista) for the many useful discussions in their role on the project advisory committee.

References

Jeffrey SJ, Carter JO, Moodie KB and Beswick AR (2001) Using spatial interpolation to construct a comprehensive archive of Australian climate data. Environmental Modelling & Software, 16 309–330. https://doi.org/10.1016/S1364-8152(01)00008-1.

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 and Burns H (2022) What is the N legacy following pulses for subsequent crops and what management options are important to optimise N fixation? 2022 GRDC

update, Wagga Wagga. 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

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Date published

February 2023