Can Legume Crops Improve Cropping Returns in Western Australia?

Easton JFS, Gustavo Boitt, Peter Rees, Andreas Neuhaus.

CSBP, Kwinana Beach Rd, Kwinana WA 6966, james.easton@csbp.com.au

Abstract
Continuous cropping without legumes in the Western Australian grain belt has depleted soil nitrogen (N) reserves. In the last 30 years, legumes have declined from 20% of the cropped area to about 4%, while land use shifted from legume-based pastures to cropping. Additionally, increased yield potential from soil amelioration, improved genetics and agronomics increased the demand for N. In 2021 and 2022, CSBP established a series of replicated plot trials in the central grain belt of Western Australia to determine the potential benefits of growing legumes to following crops - including the effects on responses to N fertiliser. At Dandaragan, there were similar responses to 118 kg N/ha in wheat after lupins (W/L) as wheat after canola (W/C), but yields were 1.5 t/ha higher after lupins. At Meckering, with 118 kg N/ha, canola yield after lupins (C/L), was 1.1 t/ha higher than canola after wheat (C/W). At Dandaragan and Meckering results showed that a productive legume phase may be required to capitalise on the good seasons, especially if soil N reserves are low and soil amelioration has increased yield potential. At Bruce Rock and Toodyay, higher N rates on W/W and C/W produced comparable yields as W/L and canola after faba beans (C/FB), but higher grain/seed N concentrations after the legume crops suggested that these rotation strategies could have produced higher yields with lower risk had yield potential been higher. Collectively, these trials show the potential for increasing cropping returns in high yielding environments by including legumes in the rotation.

Keywords
Legumes, cropping rotations, nitrogen fertiliser, financial returns, risk.

Introduction
Continuous cropping without legumes in the Western Australian grain belt has depleted soil nitrogen (N) reserves (Harries et al. 2021). In the last 30 years, legumes have declined from 20% of the cropped area to about 4% (from 1.2 to 0.4 million ha of the 8.6 million ha cropped in 2023) (ABARES, 2024). Intensified cropping has also taken the place of productive legume based pastures with land use shifting from about 60% grazing to about 60% cropping (ABARES, 2024). In addition, increased crop yield potential from soil amelioration (such as liming, deep ripping, ploughing and rotary hoeing), along with improved genetics and better agronomic practices have increased the demand for N. Nitrogen fertiliser can be very profitable to apply but higher rates increase financial risk and decrease the N use efficiency of farming systems. Higher N rates may also not be enough to capitalise on the increased potential of better seasons when there is above average rainfall and mild spring temperatures. CSBP established a series of replicated field trials in 2021 and 2022 in the central grain belt of Western Australia to investigate the potential benefits of growing legumes to following crops and the effects on N fertiliser responses. Legumes are grown primarily to build organic N reserves, provide a disease break and to broaden weed control options. Typically the crops are harvested for grain.

Methods
Experimental sites, treatments set-up and field measurements
Field experiments were established in 2021 at Dandaragan, and in 2022 at Meckering, Toodyay and Bruce Rock. All sites are located in the central grain belt of Western Australia. The sites at Dandaragan, Meckering and Bruce Rock were deep yellow loamy sands with a recent history of lime applications and deep ripping. Toodyay was a red brown loamy clay. Soil tests (0-10 cm) indicated low organic N reserves at Dandaragan (0.4% organic carbon, OC) and Meckering (0.6% OC), and higher levels at Bruce Rock (1.1% OC) and Toodyay (1.1% OC). Soil organic carbon content is used in WA as an estimate of soil N reserves considering typical C:N ratios between 12 and 14 (Hoyle, 2013). All sites had been continuously cropped for many years without a legume, except Bruce Rock which had lupins (*Lupinus angustifolius*) in 2020. Average rainfall (cumulative) data by location and year of assessment is presented in table 1.

In the first year of all experiments, blocks of a legume (lupins or faba beans [*Vicia faba*]) and a non-legume (canola [*Brassica napus*] or wheat [*Triticum aestivum*]) crop were sown with a small plot seeder . Plots were 15 × 2.5 m. All crops were machine harvested and the following crop sown into residual stubble in the following year.

Table 1. Rainfall (mm) at the nearest meteorological station to experimental locations. In the central grain belt of Western Australia, the growing season is considered to be April to October.

Location	Year	Jan-Mar	Apr-Oct	Nov-Dec
Dandaragan	2021	70	584	4
	2022	57	510	37
	2023	31	297	12
Meckering	2022	59	305	13
	2023	30	201	33
Bruce Rock	2022	70	397	14
(Babakin)	2023	30	214	16
Toodyay	2022	25	361	19
(Northam)	2023	37	200	8

At Dandaragan, one block of each crop species was grown. At Meckering, Bruce Rock and Toodyay, three randomised blocks of each crop species were grown. In the subsequent year, wheat (Dandaragan and Bruce Rock) or canola (Meckering and Toodyay) were grown. Treatments comprising three or four rates of N were established within each block of the preceding species and randomly arranged in triplicates. In the third year at Dandaragan, barley was grown with N re-applied at the same rates as the previous year in the same sub-plot area as the previous year (Table 2). All plots were machine harvested for grain/seed yield and sub-samples analysed for grain/seed N concentration (for protein content estimates) and oil percentage in the canola.

Table 2. Trial site location, crop species, and nitrogen rate applied to the non-legume crop (kg N/ha)

	2021	2022	2023
Dandaragan	lupins (0), canola (169)	wheat (0, 59, 118)	barley (0, 59, 118)
Meckering		lupins (0), wheat (59)	canola (0, 30, 59, 118)
Bruce Rock		lupins (0), wheat (59)	wheat (0, 30, 59, 118)
Toodyay		faba beans (0), wheat (93)	canola (0, 51, 101, 198)

Statistics

Data processing, visualisation and statistics were performed in R version 4.3.2, using the package "*agricolae*" (de Mendiburu, 2019). Data (means) from different treatments (crop rotation and N rates) were analysed using Analysis of Variance (ANOVA) and Fisher's LSD test at 5% significance level according to each trial's experimental design.

Results

Grain yield

Dandaragan
In 2021, lupin yield was 3.8±0.16 (mean±standard error) t/ha and the canola 1.8±0.14 t/ha (estimated to be 2.1 t/ha prior to bird damage). In 2022, 118 kg N/ha significantly increased (p-value <0.001) wheat yield after canola from 1.6±0.03 t/ha to 3.9±0.03 t/ha. After lupins, the response to N was from 3.0±0.06 to 5.4±0.17 t/ha on average (Figure 2A). The crop rotation effect on barley yield in 2023 was still significant (ANOVA p-value for rotation <0.001) whereby over 8% higher yields (on average) were observed in plots with lupins compared to plots with canola in 2021. In 2023 barley following 2021 canola, 59 kg N/ha increased yield from 2.6±0.04 to 3.7±0.05 t/ha. There was no significant additional response to 118 kg N/ha, i.e. barley yield was 3.7±0.02 t/ha. After 2021 lupins, 59 kg N/ha increased barley yield from 2.8±0.12 to 3.9±0.03 t/ha, and up to 4.2±0.03 t/ha with 118 kg N/ha applied (Figure 2B).

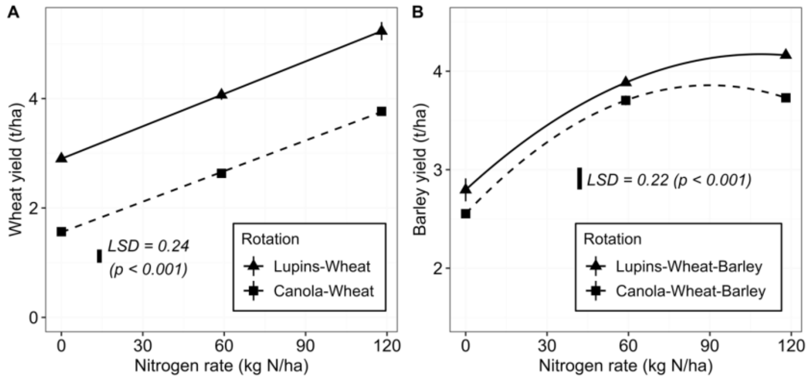

Figure 2. Wheat grain yield responses to nitrogen at Dandaragan after lupins and canola in 2022 (A), and barley in 2023 (B). Note that scales on the *y*-axis differ. Data shown are means±standard error; Fisher's LSD values are given (represented by the vertical black bars); ANOVA *p*-values are in parenthesis.

Meckering

In 2022, lupin yield was 3.6±0.11 t/ha and the wheat 4.1±0.1 t/ha. In 2023, canola yield after wheat without N fertiliser was 1.0±0.06 t/ha, and 118 kg N/ha increased yield to 1.8±0.1 t/ha (Figure 3A). After lupins, canola yield without N applied was 2.6±0.11 t/ha, and 2.9±0.04 t/ha with 118 kg N/ha.

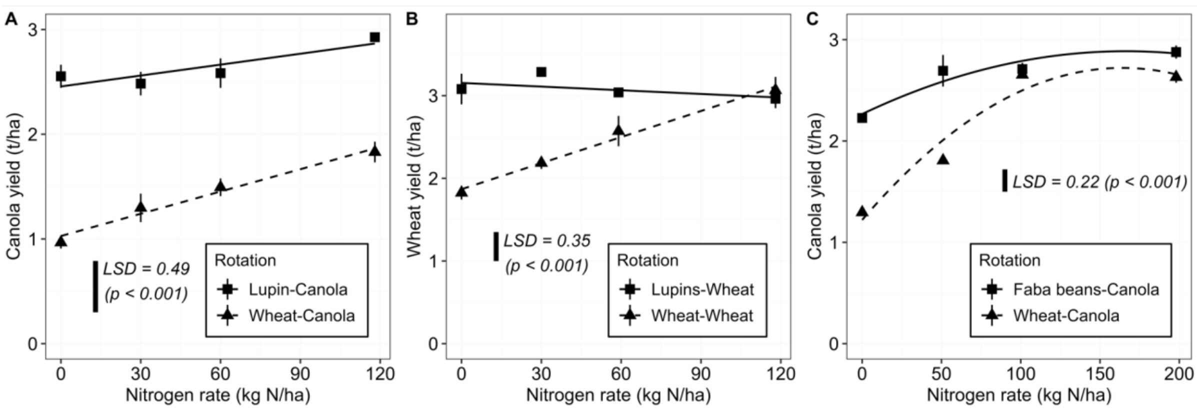

Figure 3. Canola yield response to nitrogen at Meckering after lupins and wheat (A); wheat yield response to nitrogen after lupins and wheat at Bruce Rock (B); and canola yield response to nitrogen after faba beans and wheat at Toodyay (C). Note that scales on the *y*-axis differ. Data shown are means±standard error; Fisher's LSD values are given (represented by the vertical black bars); ANOVA *p*-values are in parenthesis.

Bruce Rock

In 2022, lupin yield was 3.5±0.18 t/ha and the wheat 5.5±0.07 t/ha (Figure 3B). In 2023, the yield of wheat after wheat without N fertiliser was 1.8±0.08 t/ha, and 118 kg N/ha increased yield to 3.1±0.16 t/ha. After lupins, the wheat yield was 3.1±0.19 t/ha and there was no response to applied N (ANOVA *p*-value = 0.32).

Toodyay

In 2022, faba bean yield was 3.2±0.2 t/ha, and the wheat 4.7±0.14 t/ha. In 2023, canola after wheat 101 kg N/ha increased yield from 1.3±0.03 to 2.6±0.02 t/ha. After faba beans, 51 kg N/ha increased yield from 2.2±0.03 to 2.7±0.06 t/ha. There was no additional response to higher rates of N on either rotation.

Grain/seed N analysis

There was a clear trend to higher grain/seed N concentrations after legumes, especially at the higher rates of N applied (data not presented). In wheat at Dandaragan in 2022, with 118 kg N/ha applied, grain protein in wheat was 9.1±0.07%, on average, after lupins compared to 8.4±0.2% after canola (*p*-value <0.05). In 2023 barley, grain protein with 118 kg N/ha was 13.2±0.22% after lupins in 2021 compared to 12.9±0.16% after canola in 2021, however differences were not significantly different. In canola at Meckering, oil concentration was on average 47.5±0.2% for all treatments and no differences were detected for crop rotation or N rates treatments. In wheat at Bruce Rock, grain protein was on average over 45% higher after lupins (mean protein content = 13.2±1.1%) than after wheat (mean = 9.1±0.5%), with levels after lupins increasing from 11.0 to 15.4% with 0 to 118 kg N/ha applied. The main effect of crop rotation on wheat protein in 2023 was highly significant (ANOVA *p*-value <0.001). At Toodyay, canola oil was 49 to 50% on all treatments, except with 198 kg N/ha after faba beans which significantly (*p*-value <0.05) reduced oil content to 46±0.5%.

Discussion

Growing conditions in 2021 and 2022 were exceptional and grain yields in all experiments were well above average for the district. An analysis of 92 farm business consultant clients from the area encompassed by the experiments, showed that the 10 year averages for wheat, canola, barley and lupins are 2.1, 1.3, 2.5 and 1.4 t/ha, respectively (Planfarm, personal communication, 18 September 2024).

All experiments showed strong agronomic and yield benefits from growing a legume crop. Without a preceding legume, there were significant responses to N fertiliser. However, at Dandaragan and Meckering, there was still a large yield gap between rotations with a high N rate. Lupins were required to capitalise on the good season in the following year.

In wheat at Dandaragan in 2022, the response to N was as strong after lupins as after canola, but at the highest rate of N, the yield after lupins was still 1.5 t/ha higher with higher protein. At Meckering, there was a good response to N in canola after wheat but the canola yield after lupins at the highest rate of N was 1.1 t/ha higher. Both these sites had high yield potential but soil N reserves were low. It is unlikely that much higher N rates would have bridged the yield gap, and for a grower, the rates required would be expensive and risky to apply. The legacy response in barley two years after lupins were grown at Dandaragan show the need to consider these potential benefits when making decisions on paddock rotations.

While cropping gross margins depend upon input costs and returns, profitability is driven by lowering the cost per unit of production. At Dandaragan, the 40% higher wheat yield after lupins with 118 kg N/ha effectively lowers other variable and fixed costs by 30%. At Meckering, the 60% higher canola yield with 118 kg N/ha effectively reduced these costs by 40%.

At Bruce Rock and Toodyay, soil N reserves were higher than the other sites. There was a yield benefit from the legumes at low rates of N, but the yield gap was bridged with higher N rates to crops without a preceding legume. Higher wheat grain protein after lupins at Bruce Rock and lower canola oil after faba beans at Toodyay indicate that the N benefit from the legumes was limited by yield potential. Therefore, the N benefit should carry through to future crops. These trials will continue in 2024 to assess the longer term rotational benefits from legume crops.

Conclusion

These experiments showed that productive legumes do not just reduce the need for N fertiliser, they may be needed to capitalise on investments in soil amelioration practices, improved genetics, and better agronomic practices. The alternative of using more N fertiliser may be more profitable, but may not be enough to maximise returns in high yielding environments where soil N reserves are low.

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