Final Technical Results Report

2025

Growing summer active legumes for winter nitrogen in the high rainfall zone

Project code:	SCF2301-002SAX
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REPORT SENSITIVITY

Does the report have any of the following sensitivities?

Intended for journal publication	YES ☐ NO ☒
Results are incomplete	YES ☐ NO ☒
Commercial/IP concerns	YES ☐ NO ☒
Embargo date	YES ☐ NO ☒ If Yes, Date: N/A

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ABSTRACT

Volatility in nitrogen fertiliser pricing has increased interest in alternative strategies to manage nitrogen risk in high-rainfall grain production systems. This project investigated the potential for legume cover crops to supply biologically fixed nitrogen to subsequent cereal crops in the high rainfall zone (HRZ) of the Albany Port Zone, Western Australia, without disrupting traditional cereal-canola based rotations. The research evaluated both summer-active legumes grown as a replacement for a chemical summer fallow (2023 and 2024) and autumn-active legumes grown ahead of late-sown winter cereals (2025).

Small-plot, replicated field trials were established across three seasons to quantify legume establishment, biomass production, nodulation, plant nitrogen concentration, soil nitrogen dynamics, and cereal yield and quality responses. Summer legume performance varied markedly between seasons, with meaningful biomass and nitrogen fixation achieved under favourable establishment conditions but limited outcomes under hot and dry summers. Autumn-sown legumes established more reliably under cooler, wetter conditions, with faba beans consistently producing the greatest biomass and nitrogen contribution. Despite large differences in legume nitrogen production, cereal yield and protein responses were variable and strongly influenced by seasonal conditions, nitrogen mineralisation timing, and background soil nitrogen levels.

Overall, the research demonstrates that legume cover crops can contribute to system nitrogen supply and improve nitrogen resilience in HRZ farming systems; however, benefits are opportunity-driven (particularly for summer-sown legumes) rather than guaranteed. Outcomes from this project have increased grower understanding of where and when legumes may be effectively used to supplement fertiliser nitrogen, informing more resilient nitrogen management strategies under variable seasonal and market conditions.

EXECUTIVE SUMMARY

High rainfall grain growers in southern Western Australia operate high-input farming systems with nitrogen fertiliser representing one of the single largest variable costs. The sharp rise in nitrogen fertiliser prices during 2021–2022, and more recent global uncertainty (2026), has highlighted the vulnerability of these systems to global supply shocks and renewed interest in biologically based nitrogen sources. This project responded by exploring whether legumes could be incorporated into rotations as cover crops—grown explicitly for nitrogen rather than grain—without disrupting established (and highly profitable) cereal and canola rotations.

Across three years, the project assessed two complementary approaches: summer-active legumes grown during the fallow period (2023 and 2024) and autumn-active legumes grown in advance of late-sown cereals (2025). Trials were conducted using replicated, randomised small-plot designs with robust measurement of soil nitrogen, legume biomass, nodulation, tissue nitrogen, and subsequent cereal performance. Two fallow controls were included in 2023 and 2024 to separate tillage and nitrogen effects.

Key insights from the trials include:

- Summer legumes can fix meaningful quantities of nitrogen under suitable establishment conditions but are highly exposed to seasonal risk, particularly heat and moisture stress.
- Autumn-sown legumes established more reliably under HRZ conditions and delivered more consistent biomass and nitrogen outcomes, particularly faba beans.
- Species selection and timing were critical, with summer-active legumes (e.g. soybean) performing well in warm seasons but poorly under cooler conditions.
- Cereal yield and protein responses to legumes were inconsistent and often constrained by seasonal conditions and nitrogen mineralisation timing.
- Soil nitrogen measurements at single points in time did not reliably reflect legume performance or nitrogen contribution.

The project confirms that legumes can contribute to improved nitrogen resilience rather than predictable fertiliser replacement. By 2025, growers have access to region-specific evidence on how legumes may be used strategically—when soil moisture, temperature and seasonal outlooks align—to reduce exposure to nitrogen price volatility while maintaining productivity.

BACKGROUND

Between 2021 and 2022 the price of urea increased from \$256/t to \$1,026/t (Australian Trade and Investment Commission, 2023). This was driven by rising global energy prices and by Russia and China imposing fertiliser export restrictions in 2021 and constraining global supply. While urea prices have eased somewhat recently (currently approximately \$650/t), the jump in price during 2021/22 highlights the risk of price fluctuation within the fertiliser supply chain. Nitrogenous based fertiliser is the major input in high rainfall zone farming, particularly in Western Australia. Surveyed farmers within the Albany Port Zone showed average fertiliser use of 129kg N/ha for cereals and 138 kg N/ha (SCF1902-002SAX, 2022), compared to the national average of 45kg N/ha for cereals (Angus & Grace, 2017), and 70kg N/ha for canola (d'Abbadie et al, 2023). As a result of the high input farming systems common to the HRZ of WA, farmers are looking for a more sustainable way to de-risk N decision making and improve the sustainability of high input farming. In addition, the area sown to grain legumes has remained stagnant at around 4.5% of the total WA crop production. This is largely due to the difficulty of marketing legumes, and the perceived lack of legume options for certain soil types. This challenges us to explore novel ways of including legumes within a crop rotation.

It was suggested that there was potential on the south coast of WA to include a legume-based cover crop as a replacement to the traditional summer chemical fallow as rainfall in this region over late spring, summer and early autumn is relatively common. Average rainfall at Mount Barker, WA, is 154.7mm between November and March (BOM, 2024). Growing opportunistic summer crops for animal fodder has been a viable option in the WA HRZ, however, there has been very little research into growing a summer legume for the sole purpose of fixing nitrogen (N) and providing ground cover in place of a chemical fallow. When properly inoculated, forage legumes such as cowpea, lablab, and vetch nodulate well and can fix anywhere from 20 to 140 kg of residual nitrogen/ha (NSW DPI). This is the equivalent of 50-300 kg/ha of urea fertiliser, which at 2022 urea prices was valued between \$34 - \$204/ha.

The project focussed on two outcomes; how much nitrogen can be fixed by legumes over the summer fallow period (and autumn/early winter period – variation), and how does this impact the following winter cereal crop?

PROJECT OBJECTIVES

Initial Project

Broadly, the initial project piloted the effectiveness of a legume cover crop in the HRZ of the Albany port zone, in place of a summer chemical fallow. This was to supply following winter grain crops with enough residual soil nitrogen to justify cutting nitrogen fertiliser rates without compromising productivity outcomes.

Investment Outcome:

By 2025, growers in the high rainfall zone will have increased knowledge on the benefits of growing summer active legumes for additional nitrogen in their rotations.

Project Variation

Broadly, the extension to this project investigated the effectiveness of an autumn legume cover crop in the HRZ of the Albany port zone. This was to supply following late-winter grain crops with enough residual soil nitrogen to justify cutting nitrogen fertiliser rates without compromising productivity outcomes. Barley disease also featured in this investigation as it was hoped that by seeding and later incorporating a legume, the disease loading on the barley stubble (from two rotations previous) would be less, resulting in no need for fungicide application.

Investment Outcome:

By 2026, growers in the high rainfall zone will have increased knowledge on the benefits of growing autumn active legumes for additional nitrogen in their rotations.

METHODOLOGY

Summer Legume Trials – 2023, 2024

In early 2023 and 2024, separate legume trials were established during the summer fallow period. Both trial treatments were seeded, inoculated (with advice from Ron Yates, Murdoch University) and managed in line with best practice agronomy for each species selected with the aim of maximising biomass production and nitrogen fixation. The treatments were replicated, randomised, and blocked to minimise spatial and environmental error, and ensure a robust data set could be collected. Two controls were included in both trials, a chemical fallow (standard grower practice), and a tilled fallow, where the seeder tilled the soil without seed. This allowed for the observation of the tillage effect on mineralisation over the summer fallow period. The summer growing legume was protected by planting a sacrificial crop around the perimeter of the small plot trial site and was irrigated after sowing.

The initial trial site was sown on the 2 February 2023 with the following legume and control treatments:

- Common Vetch – (VC)
- Chickpea- (CP)
- Faba Beans – (C)
- Soybean – (S)
- Lablab – (LL)
- Cowpea – (CP)
- Chemical Fallow (farmer practice control) – (FC)
- Tilled fallow (tillage effect control) – (FT)

The second trial, sown one year later, on the 19 January 2024 adjacent to the existing trial, included the following treatments:

- Woolly Pod Vetch (WPV)
- Soybean (S)
- Pigeon Pea (PP)
- Lablab (LL)
- Cow Pea (CP)
- Faba Bean (FB)
- Chemical Fallow (farmer practice control) (FC)
- Tilled fallow (tillage effect control) (FT)

The 2023 trial was sown with 25mm of irrigation and the 2024 trial sown with 25mm and then a following 15mm to aid in establishment (and to replicate a summer rainfall event). 2024 was significantly drier, hence the need to irrigate twice.

In both trials, each species was terminated at peak biomass, prior to seed set. Termination was conducted on an individual species basis, based on their individual growth stage. The legumes were then tilled into the soil using a rotary tiller prior to seeding of the winter cereal.

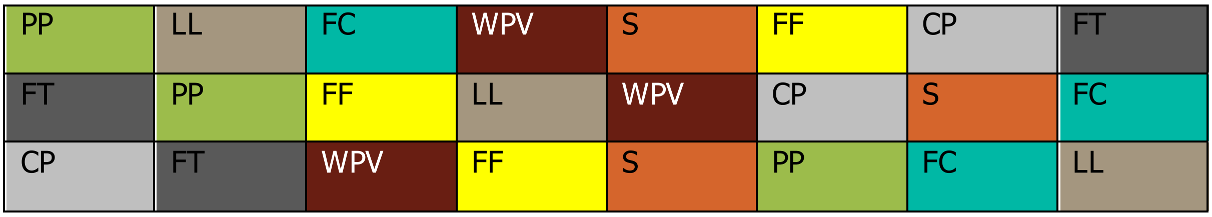
Each summer crop was followed by a winter cereal, sown over the plots. In 2023 Calibre wheat was sown over the 2023 summer crop trial and in 2024 Rockstar wheat was sown over both the 2023 and 2024 summer trials (in order to determine second year nitrogen contribution from 2023 legumes). In both years, a low N, K-till starter fertiliser was applied at seeding, and no further nitrogen fertiliser was applied to the trial during the winter growing season.

In 2023 and 2024, the following measurements were completed (with prior input from Andrew Fletcher, CSIRO) to better understand the contribution of nitrogen (N) from the legume cover crop to the following winter cereal crops (to develop a comprehensive N budget):

- Full trial site soil characterisation, Predicta B, Soil tests to 30cm (prior to seeding each cover crop, prior to seeding each winter crop).
- Deep N soil coring to at least 100cm, 3 soil intervals prior to seeding each winter crop.
- Legume crop establishment.
- Nodulation score/assessment (Prior to chemical termination).
- Legume biomass assessment and tissue test (prior to chemical termination).
- Drone Monitoring and data analysis - Biomass/NDVI and canopy cover - enhance results and provide an improved visual resource for extension of information to growers.
- Winter crop harvest biomass and grain protein.

Figure 1 shows the 2023 summer trial design and Figure 2 shows the 2024 summer trial design. All treatments were replicated, randomised, and blocked to minimise spatial and environmental error.

Figure 1: February 2023 Legume cover crop small plot trial design



PP	LL	FC	WPV	S	FF	CP	FT
FT	PP	FF	LL	WPV	CP	S	FC
CP	FT	WPV	FF	S	PP	FC	LL

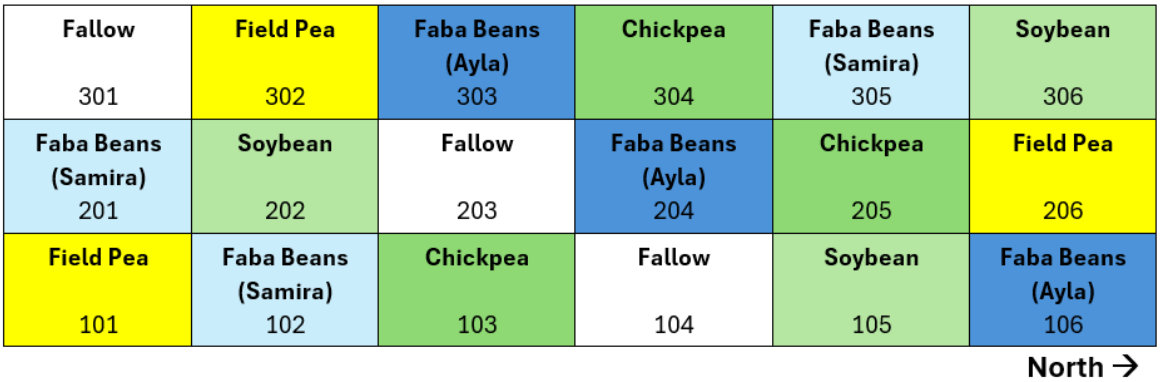
Figure 2: January 2024 Legume cover crop small plot trial design.

Autumn Legume Trial (variation) – Autumn 2025

Through the GRDC approved variation, a third trial was initiated in 2025 to investigate the effectiveness of an autumn-sown legume trial, followed by a late-sown cereal. This was in response to the difficulty in establishing legumes during the 2024 summer season. The trial was sown on the 8 April 2025 into adequate soil moisture (following good March rainfall). The trial was split into two identical blocks (same treatments), with differing legume termination times. Both blocks included five legume cover crop treatments and two control treatments:

- Faba beans – early season variety (Alya)
- Faba beans – mid-season variety (Samira)
- Field pea
- Soybean
- Cowpea
- Chemical Fallow (farmer practice control)

The trial design for block one (termination early July) is shown in Figure 3. Block 2 was identical in terms of legume and control treatment.



Fallow 301	**Field Pea** 302	**Faba Beans (Ayla)** 303	**Chickpea** 304	**Faba Beans (Samira)** 305	**Soybean** 306
Faba Beans (Samira) 201	**Soybean** 202	**Fallow** 203	**Faba Beans (Ayla)** 204	**Chickpea** 205	**Field Pea** 206
Field Pea 101	**Faba Beans (Samira)** 102	**Chickpea** 103	**Fallow** 104	**Soybean** 105	**Faba Beans (Ayla)** 106

Figure 3: Autumn 2025 Legume cover crop small plot trial design

As with the previous summer trials, the legumes were terminated prior to seeding of cereals, however, this was not at peak biomass, rather at two set dates. Block 1 was terminated on the 4 July 2024, and block 2 was terminated on the 29 July. Legumes in both blocks were incorporated using a rotary tiller.

Maximus barley was seeded over the legume plots on the 30 July (block 1) and the 11 August (block 2). At seeding, the cereals received a fertiliser blend of 35kg/ha MAP, 15kg/ha MOP, 20kg/ha Urea and 25kg/ha SOP.

Measurements for the autumn-sown legumes and following barley crop included:

- Full trial site soil characterisation, Predicta B, Soil tests to 30cm (prior to seeding legumes).

- Deep N soil coring to at least 80cm, 3 soil intervals prior to seeding the barley crop, and post-harvest.
- Legume crop establishment.
- Nodulation score/assessment (Prior to chemical termination).
- Legume biomass cuts (dry matter) and tissue test (prior to chemical termination).
- Barley Multispectral Drone – NDVI.
- Barley crop harvest biomass and grain protein.

TRIAL LOCATION/S

Please include location details: Latitude and Longitude, nearest town, Grower contact details and soil types using the table below (please add additional rows as required):

	Latitude (decimal degrees)	**Longitude (decimal degrees)**
Trial Site #1	-34.535496	118.022325
Nearest Town	Woogenellup, WA	
Grower Name & Contact Details	Nathan Crosby	
Soil Types	Sandy duplex (clayed)	

If the research results are applicable to a specific GRDC region/s (e.g. North/South/West) or GRDC agro-ecological zone/s, indicate which in the table below:

Research	Benefiting GRDC region (select up to three)	Benefitting GRDC agro-ecological zone	
Growing summer active legumes for winter nitrogen in the high rainfall zone	Western Region	☐ Qld Central ☐ NSW NE/Qld SE ☐ NSW Vic Slopes ☐ Tas Grain ☐ SA Midnorth-Lower Yorke Eyre ☐ WA Northern ☐ WA Eastern ☐ WA Mallee	☐ NSW Central ☐ NSW NW/Qld SW ☐ Vic High Rainfall ☐ SA Vic Mallee ☐ SA Vic Bordertown-Wimmera ☒ WA Central ☒ WA Sandplain

RESULTS – SUMMER LEGUME TRIAL – 2023

Baseline Soil Nitrogen & Summer Weather Data

Baseline soil nitrogen was taken at the time of seeding of the legume cover crops to 60cm, to determine the level of nitrate N or ammonia that would be potentially available for the legume plants to utilise during the growing season (Figure 4). It should be noted that mineralisation and remineralisation is in constant flux, however the warm and dry conditions prior to sowing likely meant that that biological activity and nitrate levels were stable at the time of testing.

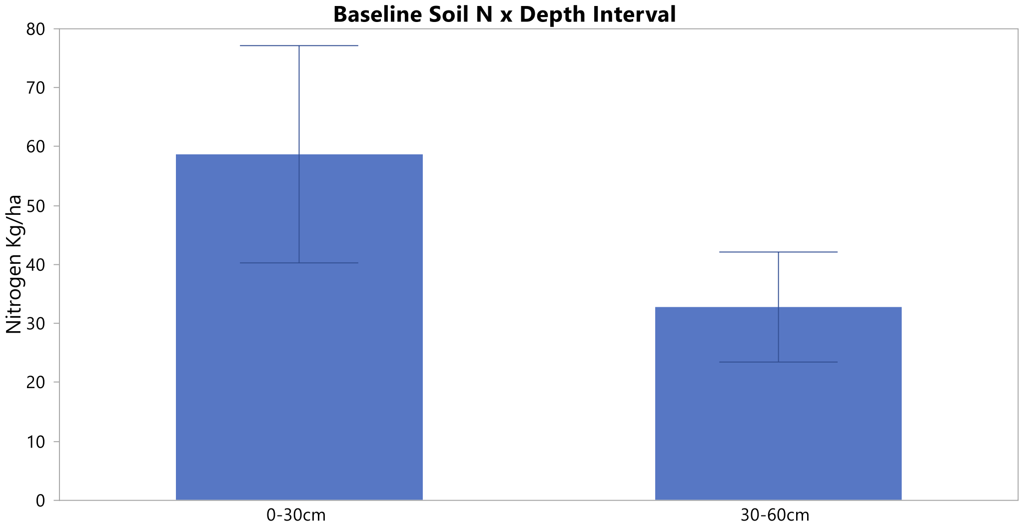


Figure 4: Baseline soil nitrogen levels (ammonium & nitrate N), January 2023m for the 30-60cm zone.

Table 1 shows the weather data from the host farmer’s weather station in the lead up to sowing the legumes and the few months afterwards. There was minimal rainfall until April 2023.

Table 1: Weather data, Woogenellup, December 2022 – April 2023.

Month	Avg temp °C	Rain mm	Rain days	Heat days
Apr-23	14.5	55.6	20	0
Mar-23	18.1	15	12	8
Feb-23	19.8	3.4	6	10
Jan-23	18.9	6.4	2	7
Dec-22	17.3	10.8	7	5

Legume Establishment & Nodulation

The summer legume cropping phase successfully produced a viable cover crop despite the limited rainfall. The crops received an initial 25mm of irrigation to replicate the conditions in which a farmer would undertake the practice of growing a summer crop (after a summer rainfall event/thunderstorm). The crops received only an additional 77mm of rainfall in the 87 days after seeding. Plant numbers were initially highest in the chickpea and vetch (Figure 5).

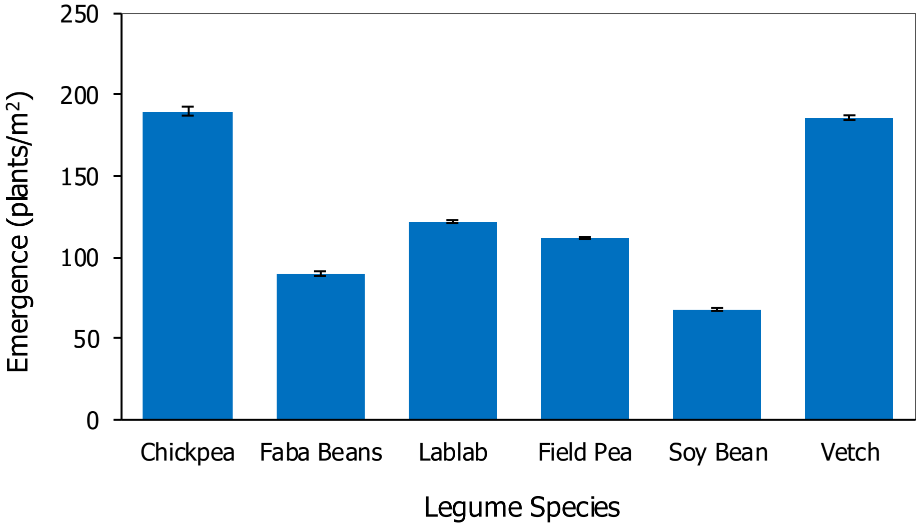


Figure 5: Average legume establishment for each of the legume treatments, March 2023.

All the legume species were inoculated at seeding with the assigned inoculant group. All species produced viable nodules, however, there was a large degree of variation in the nodulation score. The Faba beans produced the highest nodulation score and the chickpeas, the lowest (Figure 6). It should be noted that the nodulation score was taken at the time of termination, and as a result the chickpeas had 14 days fewer to produce nodules (terminated earlier – earliest to start flowering). It should also be noted that the level of background nitrate nitrogen can influence the rate of nodulation. Levels of nitrogen >50mg/L of soil will adversely influence nodulation rates (Xia et al, 2017), however at the time of baseline testing the highest level of N recorded was 25.2mg/l assuming the bulk density of the sandy soil was 1.4g/cm^3.

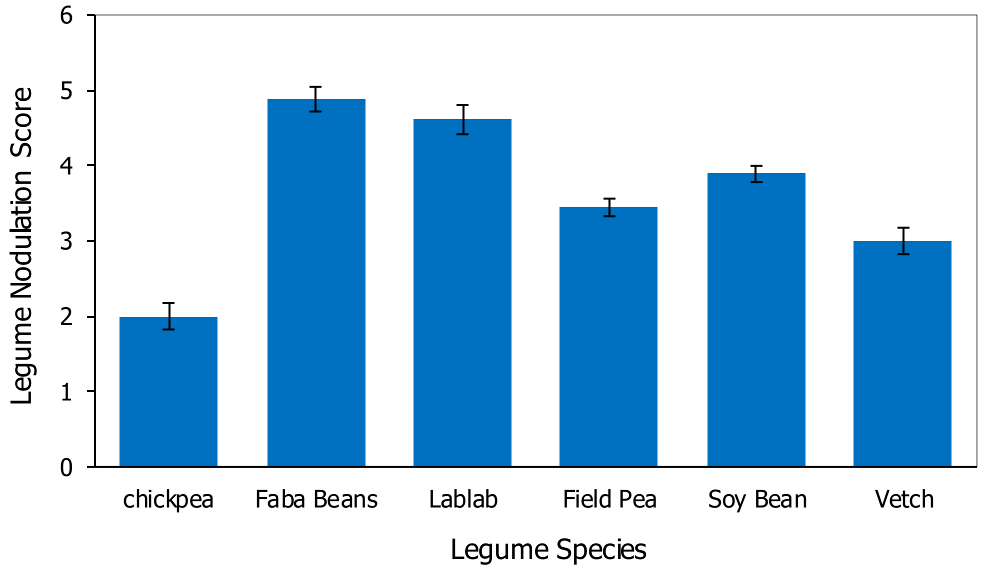


Figure 6: Nodulation scores at time of termination for each legume crop type, 2023.

Legume Biomass & Shoot N% Content

Each summer legume plot was chemically terminated, with a double knockdown prior to incorporation. The chickpeas were the only crop type that needed to be terminated due to early flowering and were terminated on the 12 April 2023. The remaining crop types were terminated on the 26 April. The incorporation of the plots into the soil was done with a rotary tillage machine to an incorporation depth of 100mm.

The legume plant biomass (t/ha) at termination was recorded by hand harvesting two 1m sections of adjacent crop row. The rapid biomass producing faba beans significantly out yielded the remaining crop types (Figure 7). The faba beans were flowering at the time of termination. The summer active legumes (lablab and cow pea) along with the vetch were slow growing and further behind in growth stage at termination. As a result, these figures do not represent the peak biomass that could have been achieved with these crop types had their growing season been longer.

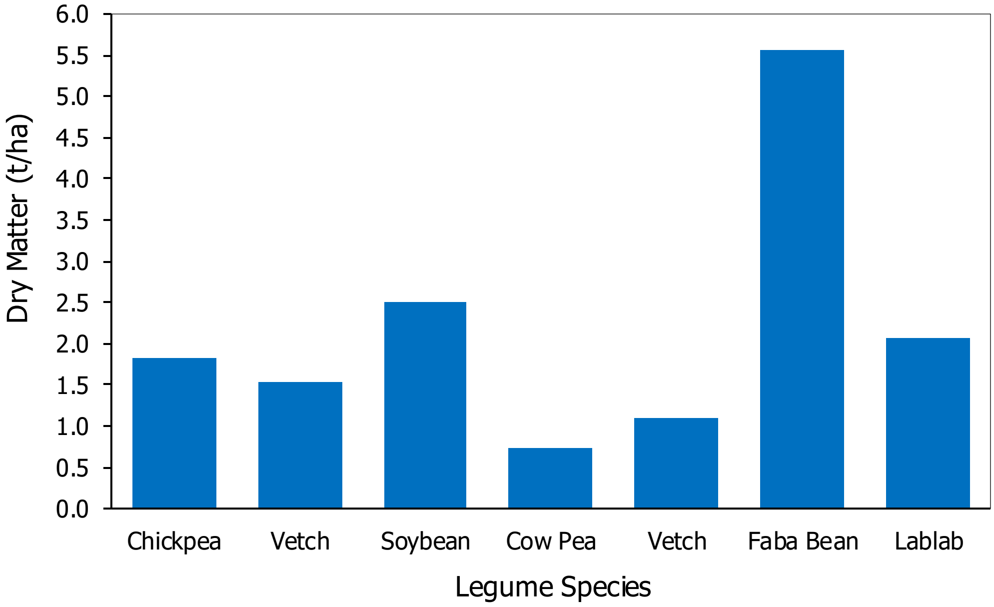


Figure 7: Legume plant dry matter at termination (t/ha), 2023.

Each legume crop type had a differing percentage of plant nitrogen (Figure 8) with faba beans having the highest nitrogen concentration. This shoot nitrogen percentage (N%) is driven by a range of factors such as plant physiology, crop growth stage and the plant's nitrogen demand curve, as well as the level of nodulation and nitrogen fixation.

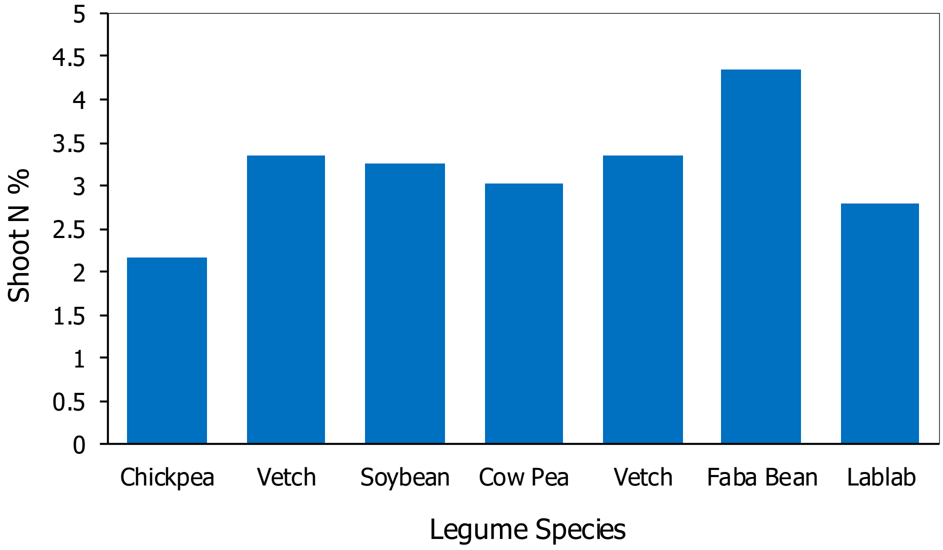


Figure 8: Legume plant shoot nitrogen % at termination, 2023.

Total N Contribution at Termination

The biomass (dry matter/ha) and shoot N% data was used to estimate the above ground nitrogen at termination. The faba beans produced significantly more above ground nitrogen compared to the other crop types at almost 250 kg N/ha (Figure 9). This was driven by both the high concentration of shoot nitrogen and high biomass yield.

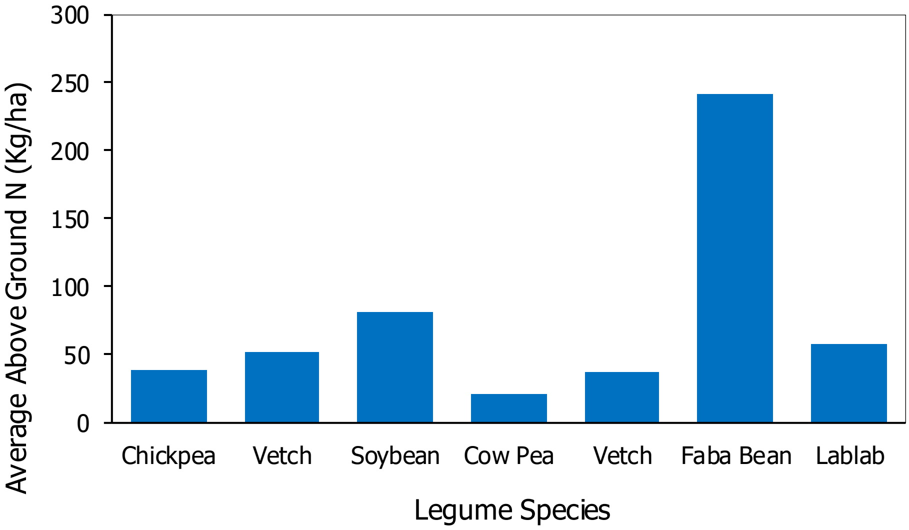


Figure 9: Above ground nitrogen production for each legume crop type (kg/ha), 2023.

Cereal 2023 - Wheat

The 2023 winter crop was seeded on the 18 May 2023 to Calibre wheat, seventeen days after the summer crop was terminated with its second knockdown, and fourteen days after it was tilled into the soil. The wheat was seeded into a full profile of moisture, and received a relatively low nitrogen, K-till blend with each plot receiving 5kg of nitrogen as a starter fertiliser. No further nitrogen fertiliser was applied to the trial plots during the 2023 growing season.

NDVI was recorded on the 7 September 2023 at approximately GS45 (Figure 10). The NDVI does not show a significant difference between treatment plots. It should be noted that a corner of the trial site was waterlogged prior to the drone flight, resulting in some outlier values, which is shown in the large standard deviation observed in some of the treatments.

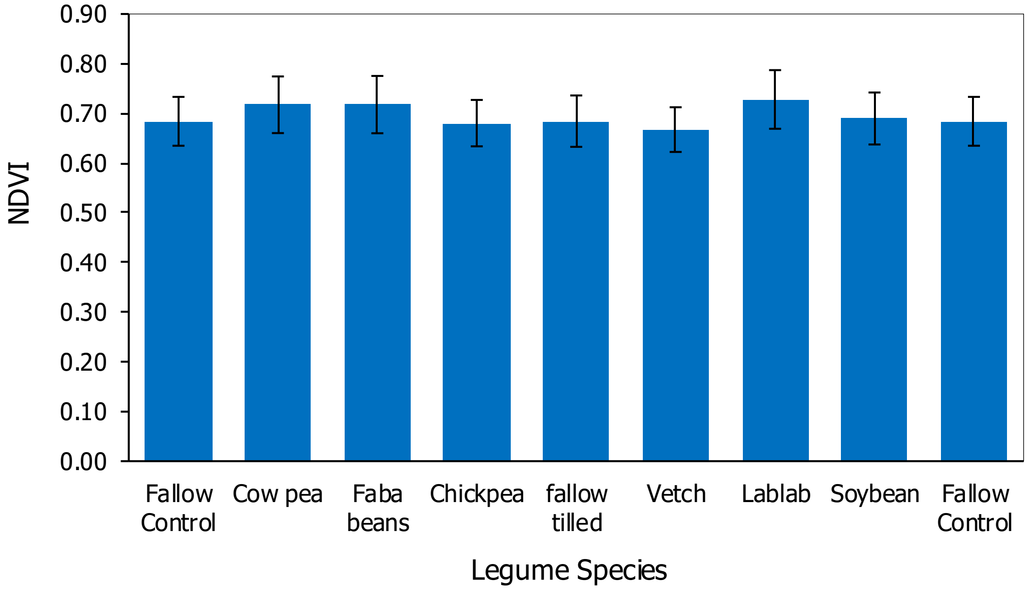


Figure 10: Average NDVI Status of the wheat crop over-sown on each of the previous legume treatments - taken by drone and recorded on the 7 September 2023.

The 2023 wheat crop produced good yields considering the crop received no in-season nitrogen fertiliser. Wheat yields ranged from 3.6t/ha in the tilled fallow treatment, to as high as 5.5t/ha in the soybean plots (Figure 11). There was no significant relationship between grain yield in the winter wheat crop and N production from the prior legume cover crop. However, there is a trend suggesting a link between the better performing legume crops (soybean, faba bean, vetch), and higher wheat yield. There are a couple of aspects that may have influenced treatment effects on grain yield in the 2023 season. Firstly, the dry finish to the 2023 season likely limited the yield capacity across all treatments, and secondly, there is no way to accurately measure the rate of residue breakdown and remineralisation of the legume residue N. Different legume crop types likely broke down at different rates once terminated. Therefore, the extent to which nitrogen from the legume directly drove yield in year one is difficult to measure.

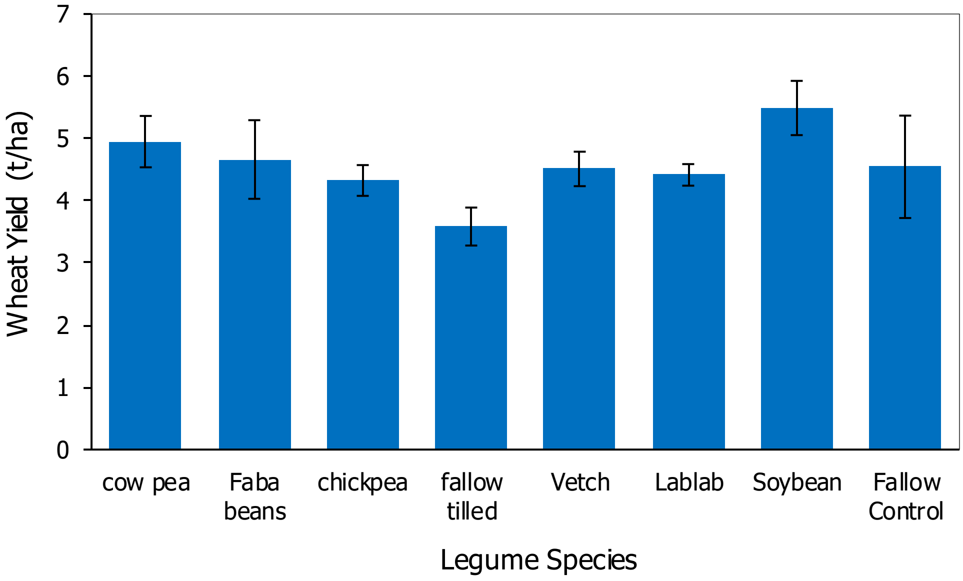


Figure 11: Average wheat yield (t/ha) for the first wheat crop sown over the 2023 legume treatments, 2023.

The wheat protein percentages show relatively even level of protein in response to all legume crop types grown and control treatments (between 10 and 12%) except for the fallow control plots (Figure 12). The protein percentage within the grain would classify the wheat as APW1 across all prior legume crops. The increased grain protein in the fallow control plots was likely due to trial design whereby the two fallow control strips were on edge rows 1 & 9 (small plot seeder practicality) and likely impacted by the farmer's spreader throwing fertiliser into these plots (buffer too small).

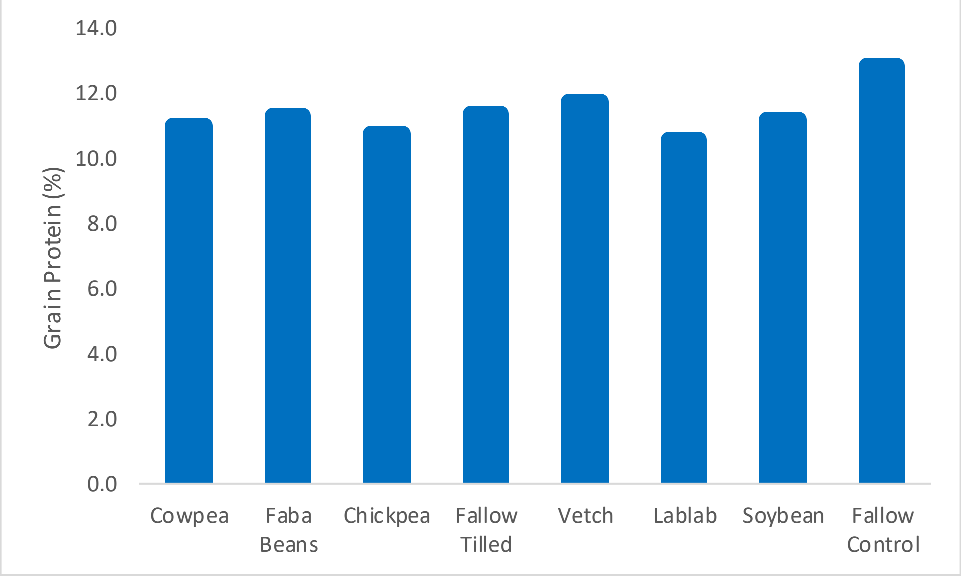


Figure 12: Average grain protein (%) for the first wheat crop sown over the 2023 legume treatments, 2023.

Cereal 2024

The 2024 wheat crop was sown on the 21 May 2024 (Rockstar) over the same plots to investigate the second-year nitrogen benefits of the 2023 summer legume treatments. Crop establishment counts were undertaken on the 28 June 2024 (Figure 13). Plant numbers were somewhat reduced; however, this is representative of many crops in the region due to the very dry and challenging start. The 2024 wheat grain yields were significantly lower than in 2023 and there was no significant difference between yields (Figure 14). The lower yields were likely due to it being the second year without nitrogen fertiliser and the challenging seasonal conditions in 2024. Interestingly, protein % was markedly higher in plots sown over the 2023 faba bean treatments (best performing), showing that there was some legacy impact of the legume (Figure 15).

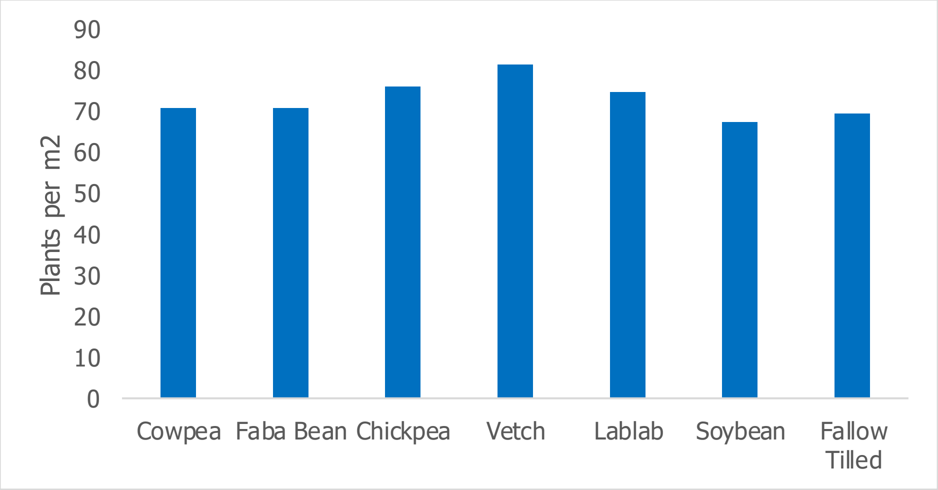


Figure 13: Average crop establishment (plant/m2) for second wheat crop sown over the 2023 legume treatments, 2024.

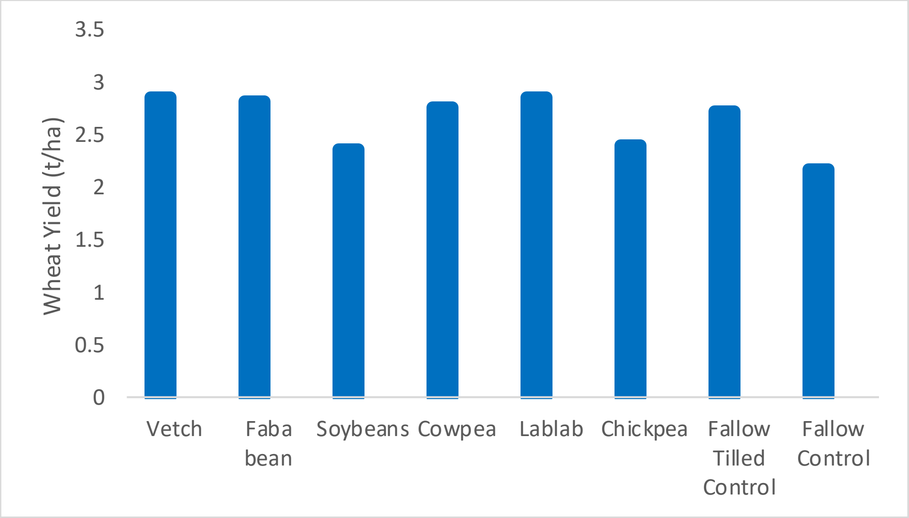


Figure 14: Average wheat grain yield (t/ha) for second wheat sown over the 2023 legume treatments, 2024.

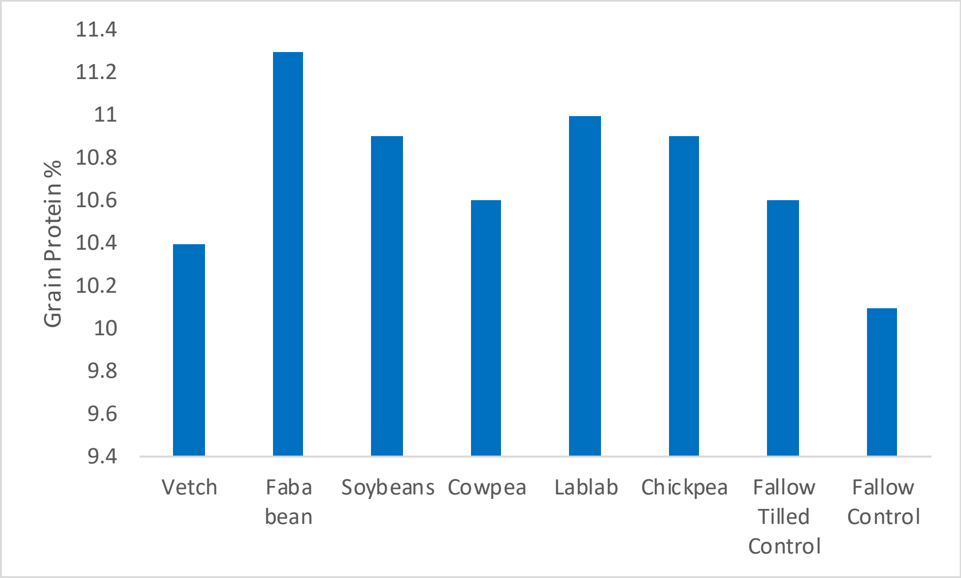


Figure 15: Average wheat grain protein (%) for second wheat sown over the 2023 legume treatments, 2024.

Nitrogen Accounting

Table 2 shows the nitrogen account for the first winter wheat crop. Wheat yield and protein drive the level of N removal from the system. Grain N removal represents nitrogen that is completely lost from the farming system. The nitrogen balance shows the difference between the N provided by the legume plant tissue, in addition to the soil N prior to sowing of the winter crop, minus N removed in grain. This calculation leaves the balance of N from each treatment. It can be assumed that each deficit in the N balance was made up by a combination of mineralisation of prior stubble residues during the 2023 winter cropping season and/or a draw down on organic nitrogen stocks.

Table 2: Nitrogen balance for the 2023 wheat crop sown over the 2023 summer legume trial.

	Vetch	Faba bean	Soybeans	Cowpea	Lablab	Chickpea	Fallow Tilled	Fallow Control
Wheat Yield (kg/ha)	4511	4662	5489	4949	4414	4324	3584	4544
Grain N removal (kg/ha)	125	125	144	128	110	109	96	118
Starting Soil N (kg/ha)	36	64	52	77	21	22	31	39
Above Legume Ground N (kg/ha)	51.5	242	81.7	21.9	58.2	39.9	0	0
N Balance (kg/ha)	-37.5	+181	-9.3	-29.1	-30.8	-47.1	-65	-79

In 2024, the starting N content measured in the soil prior to seeding the 2024 wheat crop (Table 3) did not reflect the adjusted N account after the harvest of the 2023 wheat crop (Table 2). This highlights the potential influence of both mineralisation and N losses over the summer season. The trend in wheat yields and protein in 2024 suggests that starting soil N had a greater influence on crop yield than the amount of nitrogen contributed by the legume biomass grown over the 2022/3 fallow period and that starting soil N did not correlate (in this instance) with the legume biomass grown in 2023.

Table 3: Nitrogen account for the 2024 wheat crop sown over the 2023 summer legume trial (2024 wheat crop only).

	Vetch	Faba bean	Soybeans	Cowpea	Lablab	Chickpea	Fallow Tilled Control	Fallow Control
2024 Wheat Yield (t/ha)	2.86	2.81	2.35	2.76	2.85	2.39	2.71	2.17
Starting Soil N (kg/ha)	104	115	88	83	129	102	101	101
Protein (%)	10.4	11.3	10.9	10.6	11.0	10.9	10.6	10.1
Grain N Removal (kg/ha)	38	51	52	49	56	60	44	37
Soil N Balance (kg/ha)	66	64	37	34	73	43	57	64

Soil Nitrogen – Post Legumes

Soil nitrogen was tested to a depth of 90cm, immediately prior to seeding the winter crop in 2023 and again prior to seeding in 2024, to measure the level of nitrogen available at the end of the summer fallow period. Figure 16 shows the cumulative amount of nitrogen available prior to seeding in 2023, in response to each legume crop type.

The soil test results show there was a variable impact of the legumes on the available N going into the 2023 growing season. It should be noted that all the soil N levels measured prior to seeding the winter crop were lower than the baseline soil N measured prior to planting the legumes. This is likely due to two aspects. Firstly, the legumes are potentially scavenging N from the available soil nitrogen. Although all the legume crops successfully nodulated, the nodule scores were relatively low and populated quite late in the growing season. As a result, the legume crops likely scavenged pre-existing N to build biomass, at least initially. Secondly, the mild and wet lead into the 2022/3 fallow period followed by warm weather likely encouraged the breakdown of existing stubble residue from the 2022 canola crop, and the remaining cereal stubble from the 2021 wheat crop. This would have tied up large amount of soil N during the immobilisation phase of the N cycle.

It should be noted that these figures represent the soil nitrogen available after the fallow period and would, most likely, show minimal impact from the summer legumes given they had only just been terminated and incorporated into the soil.

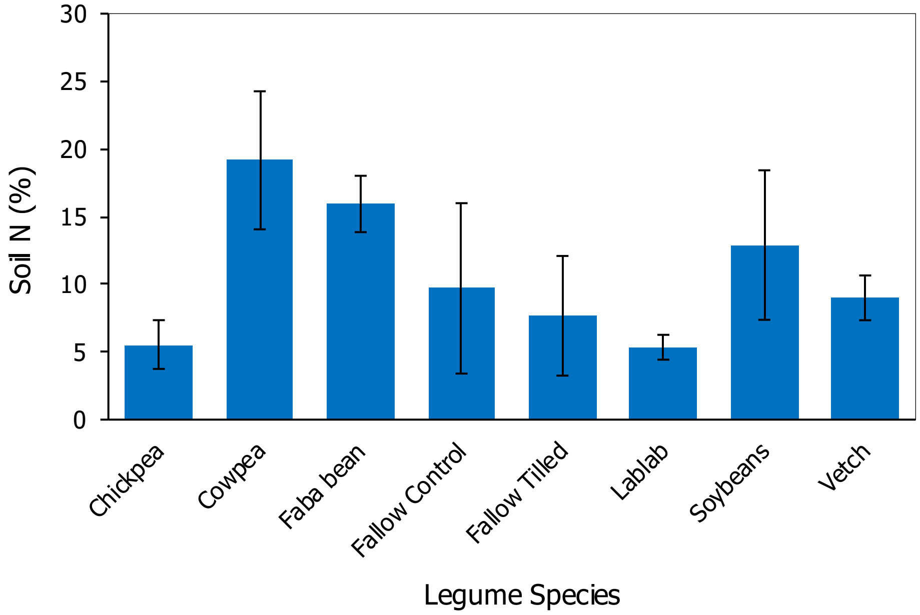


Figure 16: Cumulative soil nitrogen (Nitrate & Ammonium) (kg/ha) available to 90cm prior to seeding of the winter crop, 2023 for intervals 30-90cm.

DISCUSSION – SUMMER LEGUME TRIAL - 2023

The 2023 summer legume trial demonstrated that a range of legume species can be successfully established and can nodulate under limited rainfall conditions, provided an initial moisture event occurs (in this case irrigation to simulate summer rain). Despite receiving only 77 mm of rainfall during the 87 days following sowing, all legume crops produced viable biomass and nodules, indicating that summer legume options are agronomically feasible in the region given suitable establishment conditions. However, strong crop type differences were observed, with faba beans surprisingly producing substantially greater biomass and nodulating better than other legumes.

The substantial variation in biomass production and shoot nitrogen concentration between legume species translated into large differences in estimated above-ground nitrogen contributions at termination. Faba beans clearly outperformed other species, producing close to 250 kg N/ha, driven by both high biomass and high tissue nitrogen concentration. In contrast, slower-growing summer-active legumes such as lablab and cowpea, along with vetch, were likely disadvantaged by the length of the growing season and did not reach their potential biomass or nitrogen fixation capacity before termination. This reinforces that growing season length and termination timing strongly influence realised nitrogen benefits.

Despite large differences in legume nitrogen production, the first wheat crop in 2023 showed no statistically significant yield response to increasing legume nitrogen inputs. Wheat yields were relatively strong across all treatments given no in-season nitrogen fertiliser was applied, suggesting that factors other than legume-derived nitrogen dominated yield outcomes in year one. The dry seasonal finish in 2023 likely constrained grain fill across treatments and limited the crop's ability to respond to additional nitrogen supply later in the season. Furthermore, the rate and timing of nitrogen mineralisation from incorporated legume residues is difficult to quantify and likely varied substantially between crop types due to differences in residue quality and carbon-to-nitrogen ratios. These factors make it challenging to directly link above-ground legume nitrogen at termination with cereal nitrogen uptake and yield, particularly in the following season.

Nitrogen balance calculations highlight the complexity of nitrogen dynamics following summer legumes. While faba beans generated a strongly positive nitrogen balance in 2023, most other treatments showed deficits, indicating that wheat nitrogen uptake exceeded measured soil and above-ground legume nitrogen inputs. This suggests a reliance on in-season mineralisation of existing organic nitrogen pools and remobilisation from prior residues. Importantly, soil nitrogen measured prior to the 2024 wheat crop did not reflect the adjusted nitrogen balances calculated after the 2023 harvest, demonstrating the influence of summer mineralisation, immobilisation and potential nitrogen losses through leaching or volatilisation. These results reinforce that single-point soil nitrogen measurements may poorly reflect longer-term nitrogen cycling following summer legumes.

In the second wheat crop (2024), grain yields were uniformly lower across all treatments, largely reflecting the second consecutive crop grown without nitrogen fertiliser and a challenging seasonal start. However, the elevated grain protein observed in the faba bean treatments indicates a measurable legacy effect of higher nitrogen-fixing legumes, even where yield responses were limited. This perhaps suggests that for this trial mineralisation occurred later than anticipated, not soon enough in 2024 to drive yield but early enough to impact protein.

RESULTS - SUMMER LEGUME TRIAL – 2024

Baseline Soil Nitrogen & Summer Weather Data

Baseline soil nitrogen was taken at the time of seeding of the legume cover crops to 60cm, to determine the level of nitrate N or ammonia that would be potentially available for the legume plants to utilise during the growing season (Figure 17).

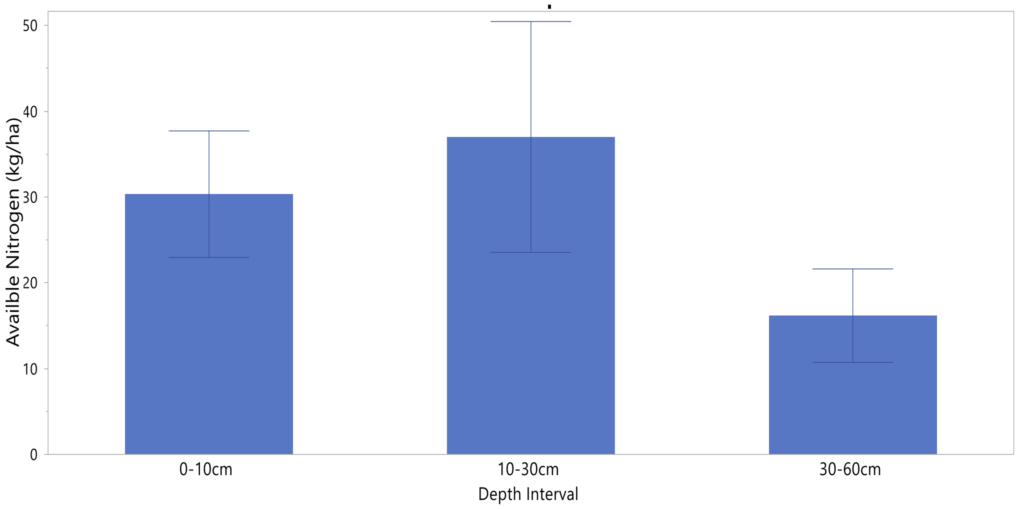


Figure 17: Baseline soil nitrogen results for the legume trial established in January 2024.

The crops received an initial 25mm of irrigation to replicate the conditions in which a farmer would undertake the practice of growing a cover crop (after a summer rainfall event). The crops were irrigated again in February 2024 with a further 15mm and then only received 22.4 mm in rainfall, compared to 80.4 mm received in 2023 (Figure 18), over the same period (prior to termination). It should be noted that it was an extremely dry start to the season in 2024 – with many properties in the region experiencing short-term drought conditions.

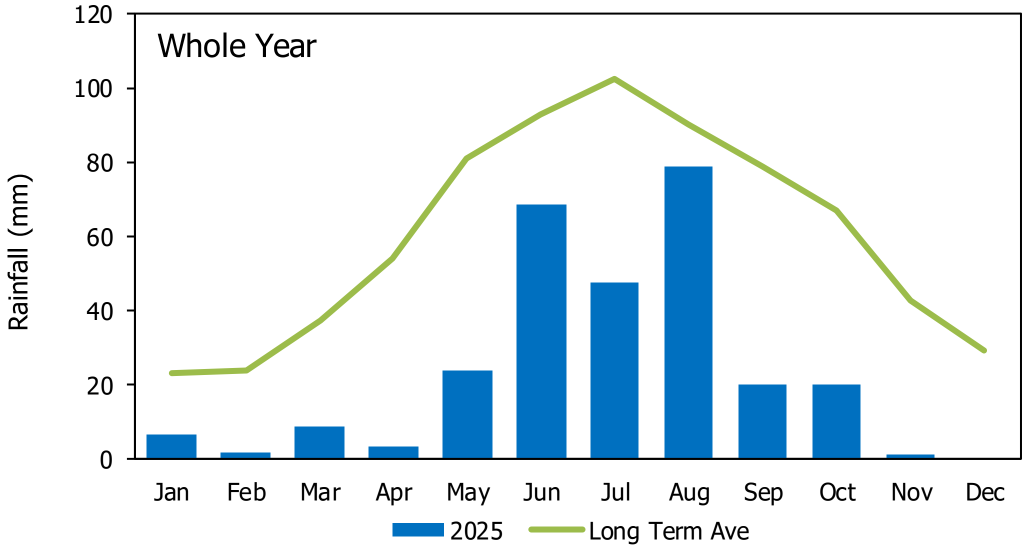


Figure 18: Monthly rainfall (Woogenellup, WA) in 2024 against the long-term average (BOM, Mount Barker).

Legume Establishment & Nodulation

Plant counts were taken at termination to reflect the plant survival over the summer period (Figure 19). There was a large amount of variability between the treatments, largely reflecting the difficulties with establishment early in the growing season. The faba beans and vetch notably suffered from the hot and dry conditions present at the time of sowing. This was somewhat surprising given the success of the faba beans in 2023.

All the legume species were inoculated at seeding with the assigned inoculant group. Legume nodulation scores were assessed at time of chemical termination (Figure 20). Cowpea recorded the highest nodulation followed by vetch and faba beans.

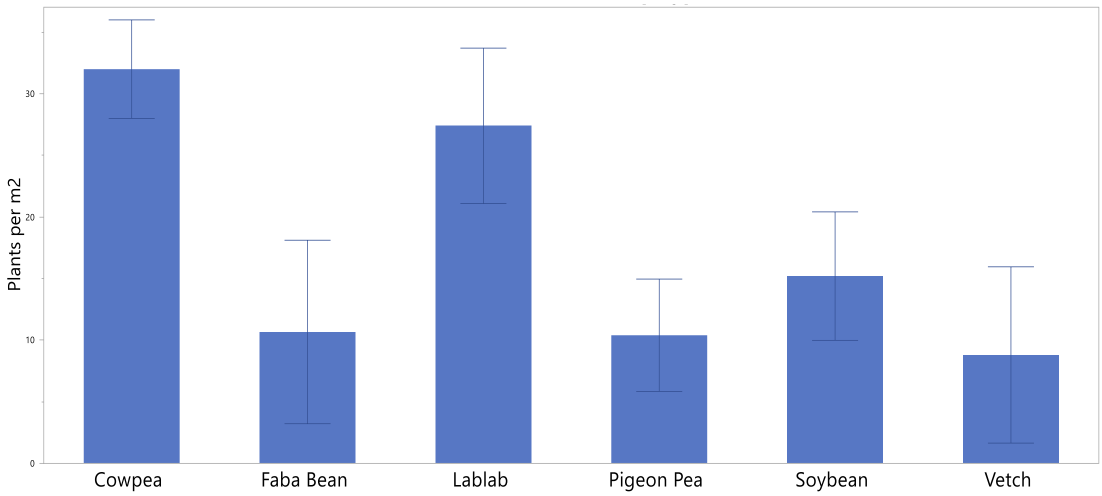


Figure 19: Average legume plant counts at termination (plants/m2), 2024.

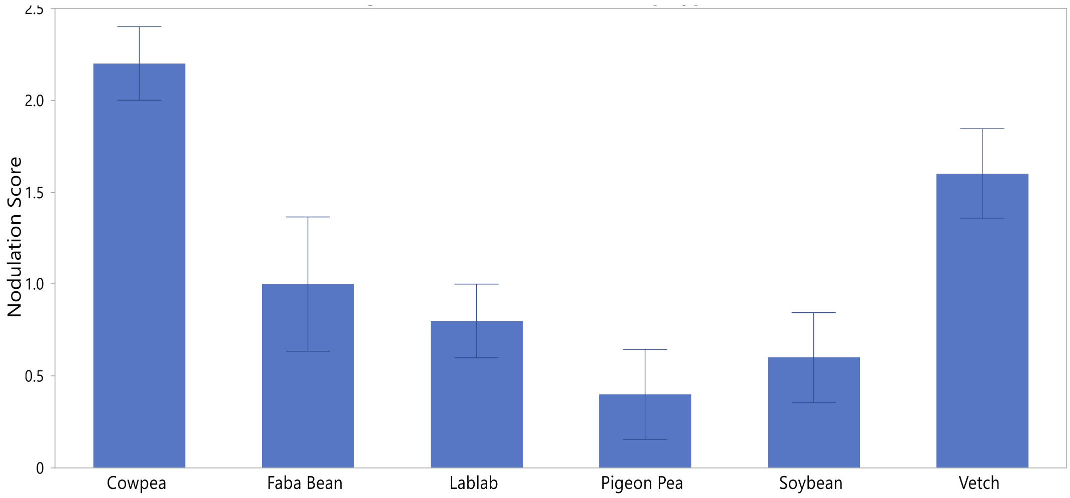


Figure 20: Average nodulation scores at time of termination for each legume treatment, May 2024.

Legume Biomass & Shoot N% Content

Plant biomass cuts were taken prior to chemical termination (Figure 21). The results (dry matter t/ha) clearly indicate that soybean produced the highest biomass at 2.75 t/ha. Given the summer growing season, this was a good result. Soybean was followed by cowpea and lablab. The limited vetch and faba bean legume biomass was driven by two factors, a later/staggered germination, reducing the time in which the plants had to produce biomass, as well as the low plant numbers compared to the other crop types.

Plant tissue samples were taken at time of termination and analysed for percentage nitrogen concentration (Figure 22). In 2024, vetch recorded the highest nitrogen concentration and faba bean the lowest (note: faba bean was highest in 2023). This shoot nitrogen percentage is driven by a range of factors such as plant physiology, crop growth stage and the plant's nitrogen demand curve, as well as the level of nodulation and nitrogen fixation. In the case of faba beans in 2024, the delayed crop stage at termination quite likely played a role in it's lower shoot N%.

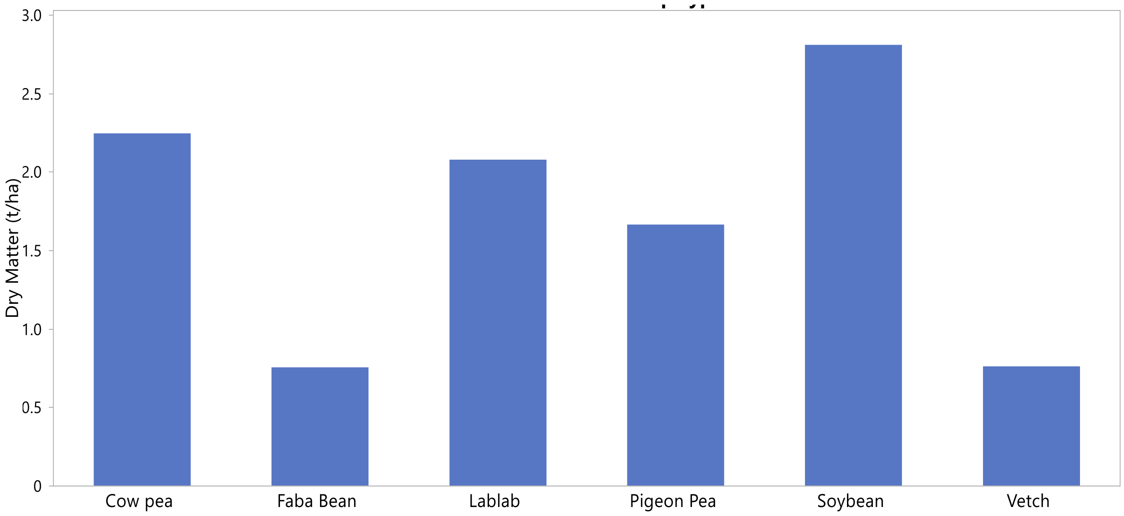


Figure 21: Average legume biomass (dry matter t/ha) for each legume treatment, May 2024.

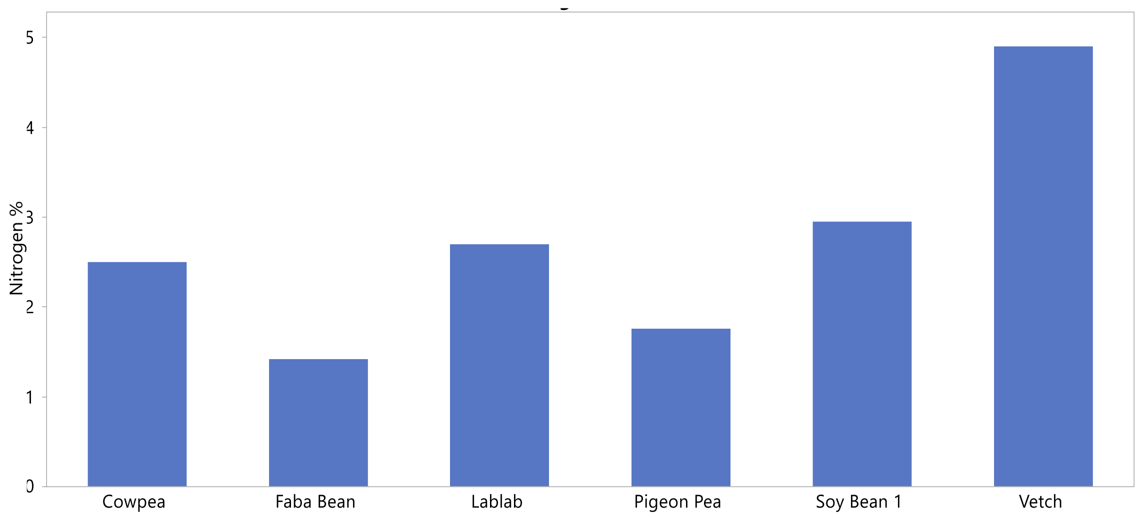


Figure 22: Average plant tissue nitrogen content (%) for each legume treatment, May 2024.

Total N Contribution at Termination

A calculation of above ground nitrogen was determined using plant biomass (t/ha) and plant tissue nitrogen % results (Figure 23). It shows that the plant biomass drove the above ground nitrogen with the soybean (80 kg/ha) outcompeting the other legumes (highest plant biomass also). Lablab and cowpea were relatively similar at 55 kg/ha and the lowest result was in the faba bean treatment which produced only 10 kg/ha. This is compared with over 250 kg/ha for faba beans in the 2023 trial, most likely due to better initial germination in 2023.

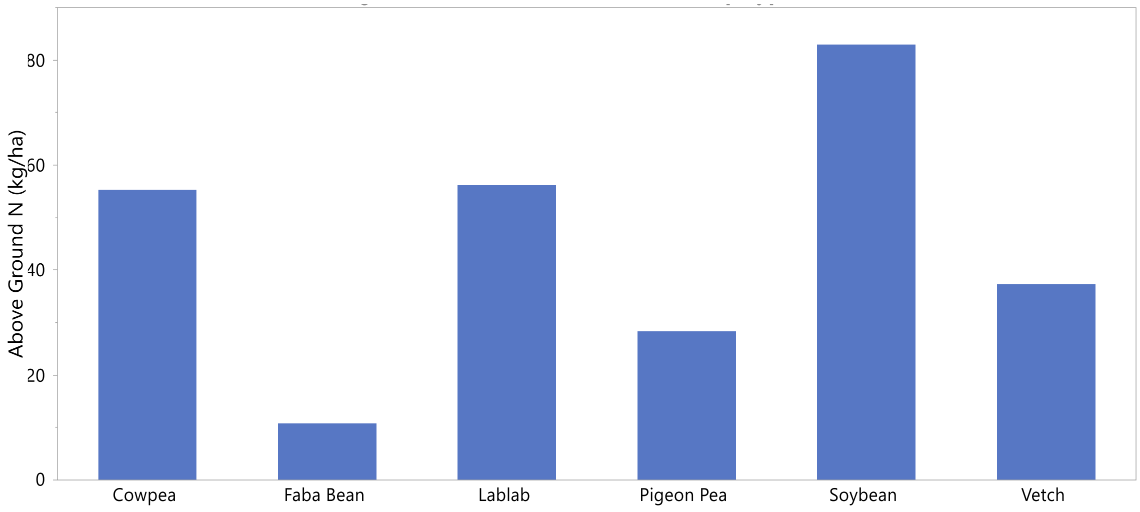


Figure 23: Average above-ground nitrogen (calculated from plant biomass & plant tissue N%) for each legume treatment, 2024.

Cereal -2024

The summer legume plots were chemically terminated on the 7 May 2024. The plots were left for a period of ten days before being tilled into the ground on the 17 May 2024. The trial was then over-seeded on the 21 of May (14 days after termination). The seeding date of the winter crop was delayed allowing the summer legume to maximise biomass production.

The winter cereal (Rockstar Wheat) was sown over the summer legume and control treatments on the 21 May 2024. The wheat was sown into good soil moisture (after a long dry autumn) however, germination was slow after seeding and somewhat staggered across both trial sites.

Establishment counts were undertaken on the 28 June 2024 and are shown in Figure 24. Plant numbers were somewhat reduced; however, this is representative of many crops in the region due to the very dry and challenging start.

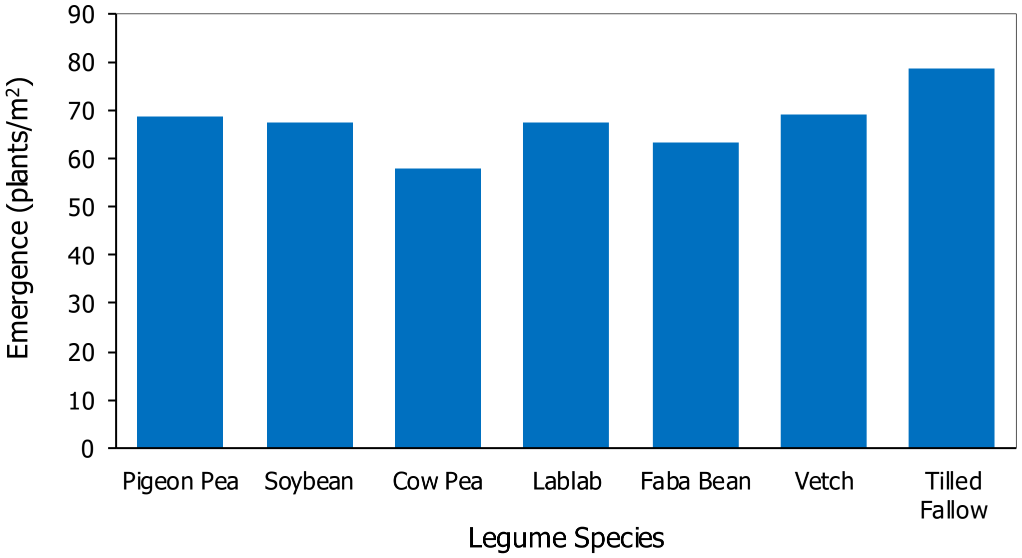


Figure 24: Average plant counts (plants/m2) for wheat crop sown over the 2024 summer legume plots, June 2024.

The yields of the wheat grown directly after the summer 2024 legume & control treatments were somewhat higher in the legume plots (with the exception of Pigeon Pea), compared to the two control plots (Figure 25). Although not a significant difference, the highest yielding average wheat yield was over the previous soybean plots, with soybean also the being the best performing legume. Grain protein was slightly higher in the previous vetch treatment plots and all other treatments very similar (Figure 26).

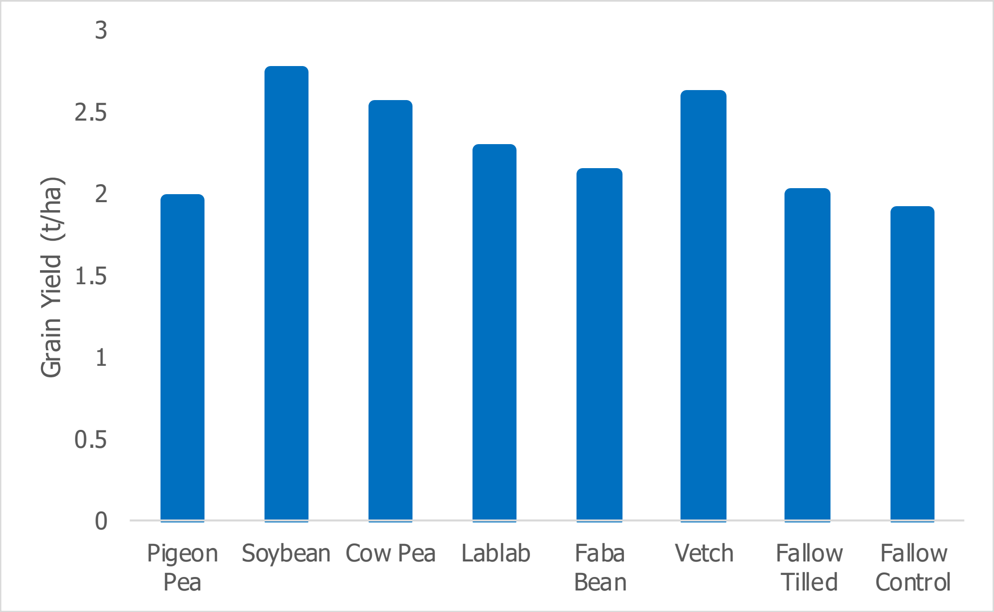


Figure 25: Average grain yield (t/ha) for wheat sown over each of the 2024 summer legume treatments, 2024.

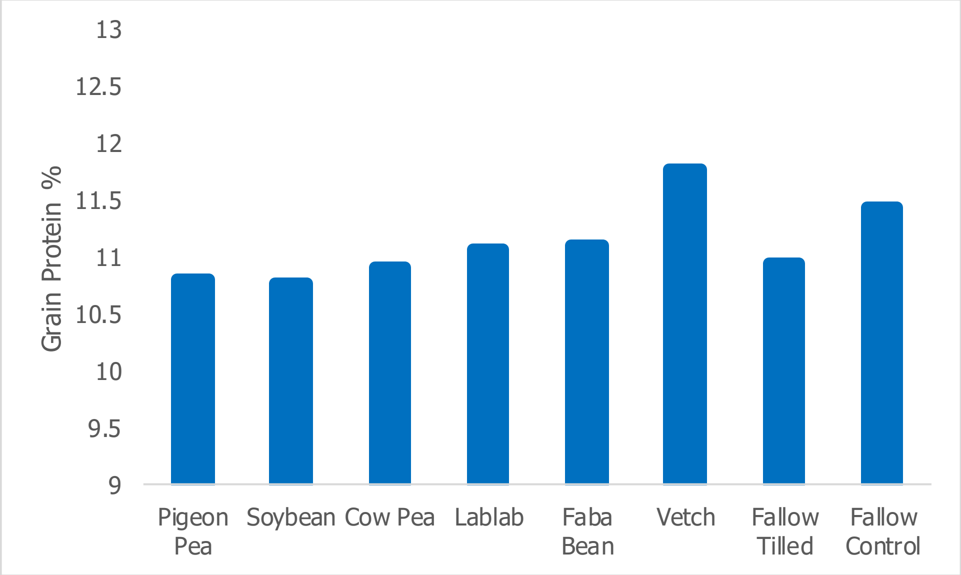


Figure 26: Average grain protein (%) for wheat sown over each of the 2024 summer legume treatments, 2024.

Nitrogen Accounting

When the starting soil nitrogen was adjusted to include the contribution of the legume nitrogen, the highest nitrogen amount was in the soybean treatment (Table 5). This may have contributed slightly to yield of the following wheat crop but had no impact on protein. Overall, as a result of the nitrogen produced by the legumes and the lower wheat yields, the soil N balance for this trial was positive.

Table 5: Nitrogen balance for the 2024 wheat crop sown over the 2024 summer legume trial.

	Pigeon Pea	Soybean	Cow Pea	Lablab	Faba Bean	Vetch	Fallow Tilled Control	Fallow Control
2024 Wheat Yield (t/ha)	1.95	2.74	2.53	2.26	2.11	2.6	1.99	1.88
Starting Soil N (kg/ha)	85	87	74	85	86	87	108	86
Legume N (kg/ha)	28	83	55	56	54	20	0	0
Adjusted Starting N balance (kg/ha)	113	170	129	142	140	108	108	86
Protein (%)	10.8	10.8	10.9	11.1	11.1	11.8	10.9	11.4
Grain N (%)	1.86	1.86	1.88	1.91	1.91	2.03	1.88	1.97
Grain N removal (kg/ha)	36	51	48	43	40	53	38	37
Soil N Balance (kg/ha)	77	119	82	98	100	55	71	48

The soil test results show there was a variable impact of the legumes on the available N going into the 2023 growing season. It should be noted that all the soil N levels measured prior to seeding the winter crop were lower than the baseline soil N measured prior to planting the legumes. This is likely due to two aspects. Firstly, the legumes are potentially scavenging N from the available soil nitrogen. Although all the legume crops successfully nodulated, the nodule scores were relatively low and populated quite late in the growing season. As a result, the legume crops likely scavenged pre-existing N to build biomass, at least initially. Secondly, the mild and wet lead into the 2022/3 fallow period followed by warm weather likely encouraged the breakdown of existing stubble residue from the 2022 canola crop, and the remaining cereal stubble from the 2021 wheat crop. This would have tied up large amount of soil N during the immobilisation phase of the N cycle.

It should be noted that these figures represent the soil nitrogen available after the fallow period and would, most likely, show minimal impact from the summer legumes given they had only just been terminated and incorporated into the soil.

Soil Nitrogen – Post Legumes

Soil nitrogen levels prior to seeding of the wheat crop in May 2024, were slightly higher than the baseline test results (samples taken prior to seeding of the summer legumes). Prior to seeding the wheat, total nitrogen was highest in the 'tilled fallow control' plots and lowest in the cowpea plots (Figure 27). This didn't correlate to performance of the legumes, and it should be again noted that these figures would, most likely, show minimal impact from the summer legumes given they had only just been terminated and incorporated into the soil.

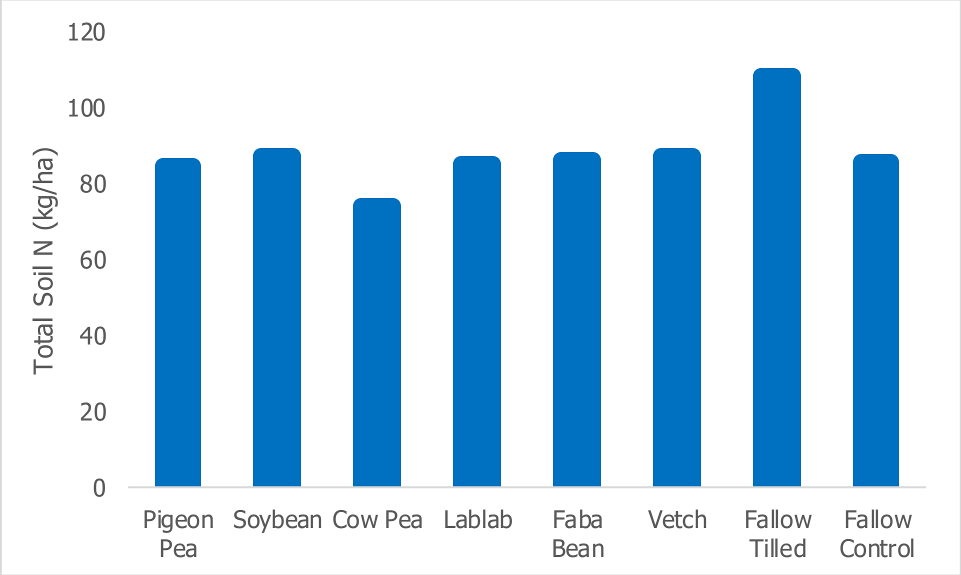


Figure 27: Average soil nitrogen (Nitrate & Ammonium) (kg/ha) available to 90cm for each of the 2024 summer treatment plots prior to seeding of the wheat crop, May 2024.

DISCUSSION – SUMMER LEGUME TRIAL - 2024

The 2024 summer legume trial highlighted the high sensitivity of summer legume performance to seasonal conditions, particularly at establishment. Compared to 2023 (which was also somewhat dry), much lower rainfall and hotter conditions during and immediately following sowing had a strong influence on plant establishment, nodulation, biomass accumulation and ultimately nitrogen contribution. Despite the application of irrigation twice (25mm followed by 15mm) to simulate summer rainfall events, subsequent rainfall was considerably lower than in the previous season, limiting growth potential. This resulted in much greater variability between legume species and a shift in which crops performed best relative to 2023. As an example, faba beans were far and beyond the best performing legume in 2023 and then the poorest performing legume in 2024. This reinforces that outcomes from summer legume crops are highly season-dependent.

Good establishment was key to success in 2024, playing a major role in shaping biomass and nitrogen outcomes. Faba beans and vetch, which performed strongly in 2023, struggled under the hotter, drier sowing conditions in 2024, resulting in lower plant counts, delayed growth and reduced biomass accumulation. In contrast, soybean performed consistently well (both in 2023 and 2024), producing the highest biomass and the greatest above-ground nitrogen contribution in 2024. Cowpea and lablab also performed reasonably well under the summer conditions, reflecting their suitability to warmer environments. These results confirm that species selection for summer legumes must consider not only nitrogen fixation potential, but also establishment reliability and tolerance to heat and moisture stress.

Nodulation patterns differed from biomass production, with cowpea recording the highest nodulation scores despite soybean contributing more total nitrogen due to greater biomass. This highlights that nodulation alone is not a reliable indicator of nitrogen contribution, particularly where growing periods are short or growth is constrained. The relatively low nodulation observed across several species, combined with delayed nodulation timing, suggests that legumes likely relied initially on scavenging existing soil nitrogen to support early growth. Soil nitrogen prior to sowing of the wheat also showed limited immediate response to legume biomass, as much of the fixed nitrogen most likely remained contained within plant residues that had only recently been incorporated into the soil.

The wheat crop sown immediately following the 2024 summer legume treatments showed modest yield benefits over the control treatments, although differences were not statistically significant. The highest wheat yields were observed following soybean, consistent with its higher above-ground nitrogen contribution. However, grain protein levels were largely similar across treatments, indicating that while additional nitrogen may have supported yield to some extent, it was insufficient or inadequately timed to drive strong protein responses. The delayed mineralisation of incorporated residues, combined with a challenging start to the 2024 season, likely limited or delayed the availability of legume-derived nitrogen.

Nitrogen balance calculations demonstrated that, unlike in 2023, the system remained nitrogen-positive across all treatments in 2024 due to lower wheat yields and modest grain nitrogen removal. While adjusted starting nitrogen was highest in the soybean treatment, soil nitrogen measurements prior to wheat sowing did not clearly reflect overall performance of other legumes, again emphasising the dynamic nature of nitrogen cycling. These findings suggest that the value of summer legumes may lie more in contributing to medium-term nitrogen supply and buffering system nitrogen over multiple seasons, rather than delivering immediate, predictable benefits to the first subsequent cereal crop.

Overall, the 2024 results reinforce that summer grown legumes can contribute nitrogen, but outcomes are highly dependent on seasonal conditions, establishment success and residue breakdown dynamics. The contrasting results between 2023 and 2024 underline the importance of multi-year data in evaluating the role of summer legumes and caution against drawing strong conclusions from single-season responses. For growers, these results suggest that summer legumes should be viewed as a strategic, opportunistic tool for nitrogen management rather than a year-in-year-out fertiliser replacement strategy.

RESULTS – AUTUMN LEGUME TRIAL – 2025

Weather Data

Following a quite warm summer period in 2024, the average daily temperatures recorded at Woogenellup in 2025 were much cooler (Figure 28). Rainfall values were, however, quite low for the start of the year, with approximately 20mm recorded between 1st January and the end of February (Figure 29). The season officially broke on 13 March, when 29mm of rainfall was recorded across the day on a weather-station located near to the trial site. A second significant rainfall event was recorded on the 3 April with a further 20mm of rainfall being captured. This resulted in favourable soil conditions throughout legume seeding, leading to successful legume germination throughout the trial plots.

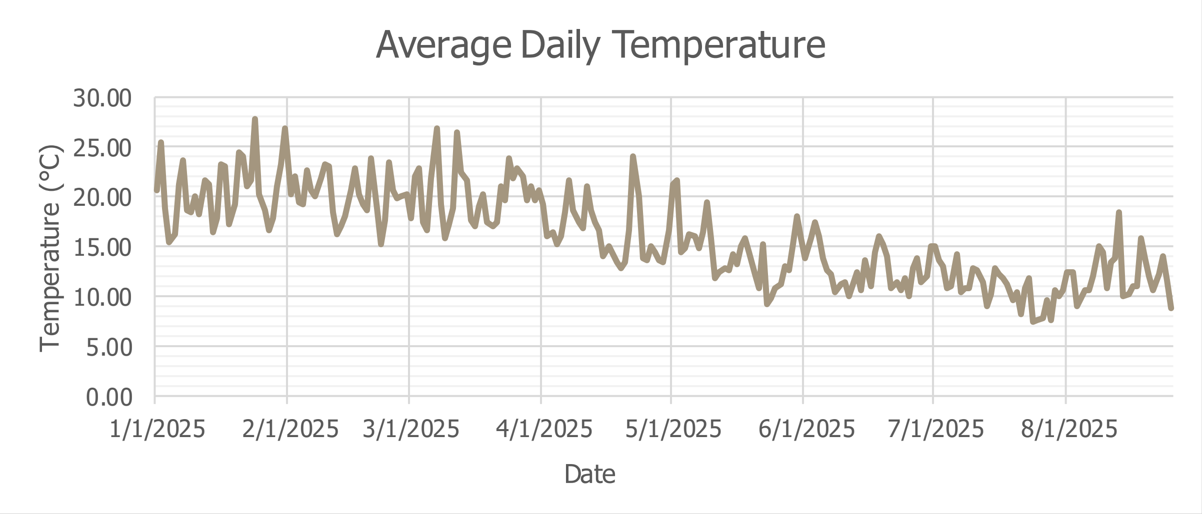


Figure 28: Average daily temperatures recorded for Woogenellup between January & August 2025.

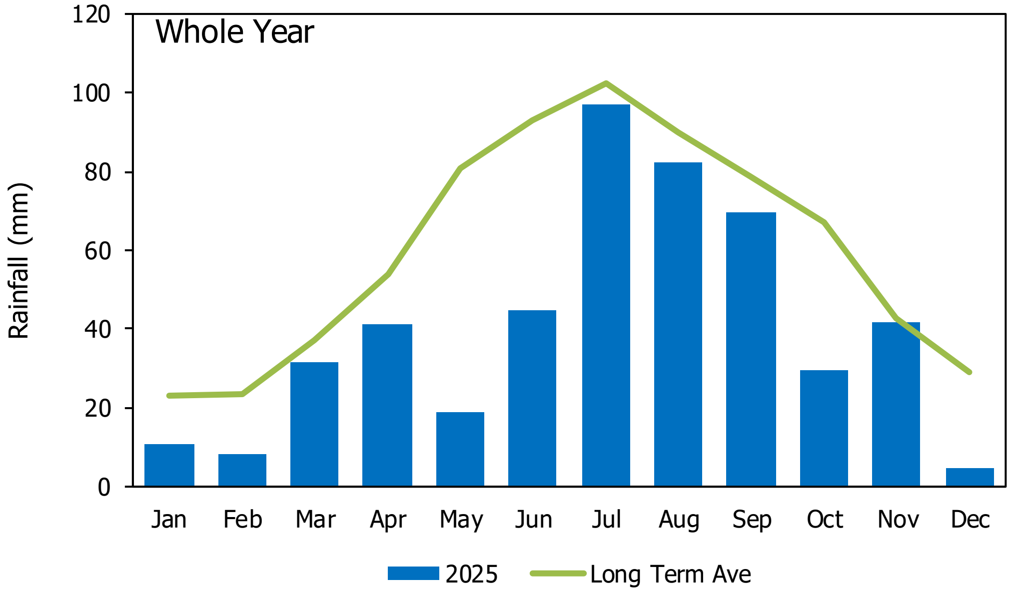


Figure 29: Monthly rainfall (Woogenellup, WA) in 2025 against the long-term average (BOM, Mount Barker).

Legume Establishment & Nodulation

The autumn legume trial site was sown on the 8 April 2025 and seeding conditions at the time were noted as ideal, with excellent soil moisture at the time of sowing. The seedbed was an existing canola stubble with an approximate 10-20% stubble loading.

Initial plant establishment counts were undertaken on 14 May 2025 in the field, with average plant counts graphed by crop type in Figure 30 below. Although establishment (germination) was successful across all plot treatments, high levels of spatial variability were seen across all plots. Table 6, below, represents the minimum and maximum values seen for each plant count undertaken (3 measurements per plot) and the total average plant counts observed across all plots combined.

Establishment/viability counts were measured again at termination to reflect plant survival over the summer/autumn period (Figure 31). For the most part, later counts were close to the initial counts with the exception of chickpea. At the time of termination, there were only a handful of chickpea plants scattered through the plots. Chickpea is not commonly grown across the region and it is likely that the cold/wet conditions were not conducive to plant survival.

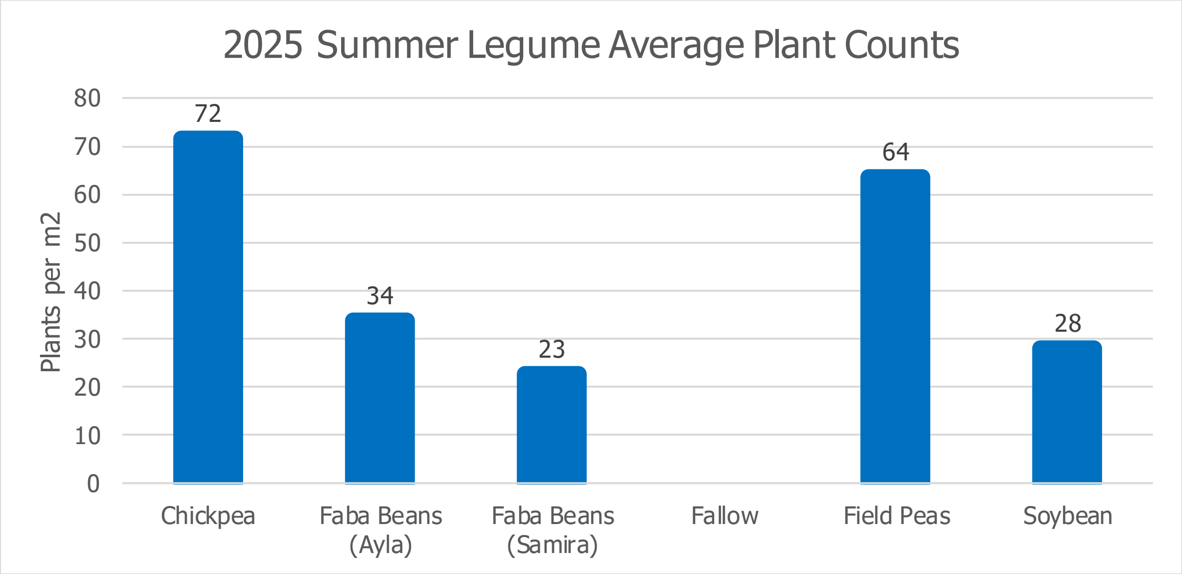


Figure 30: Average plant counts per square metre, measured across the 2025 Summer/Autumn legume plots grown at Woogenellup.

Table 6: Recorded minimum, average and maximum plant counts measurements observed within trial plots.

Crop-Type	Plant Counts (plants/m2)		
	Minimum	Average	Maximum
Field Peas	32	64	112
Faba Beans (Samira)	8	23	40
Chickpea	40	72	128
Fallow	-	-	-
Soybean	8	28	80
Faba Beans (Ayla)	16	34	64

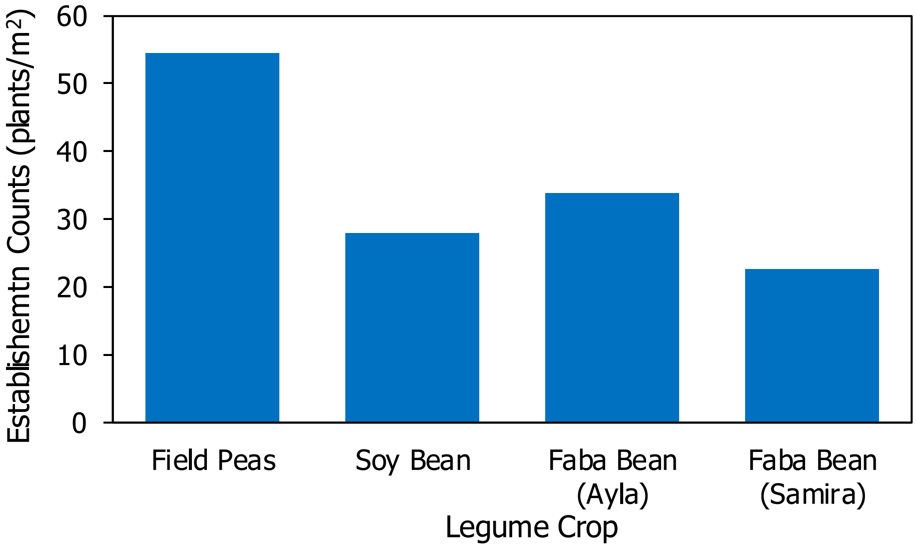


Figure 31: Average legume establishment (plants/m2) for each legume treatment, May 2025.

In terms of nodulation, the faba beans (both varieties) produced the most nodules (Figure 32). Soybean nodulation was noticeably lower compared to field peas and faba beans. Soybean nodulation was the highest overall in the 2023 summer trial (score 4) suggesting that it might require warmer temperatures to nodulate well.

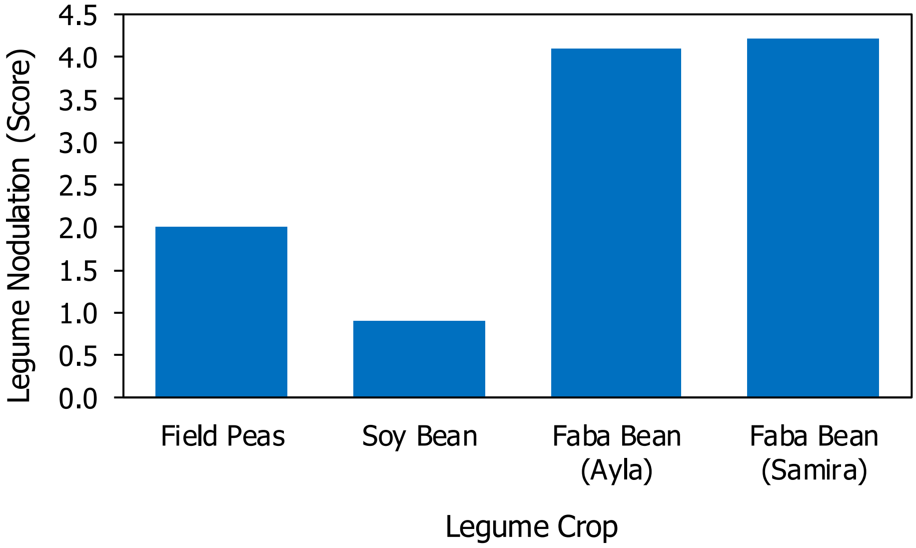


Figure 32: Average nodulation scores for each legume treatment at time of termination, 2025.

Legume Biomass & Shoot N% Content

Average legume biomass (dry matter t/ha) for each time of termination (2 weeks apart) in Figures 33 and 34. The 10-day delay in termination (essentially lengthening the growing period) resulted in the following increases/decreases in average biomass production:

- Field peas + 0.2 t/ha
- Soybean – 0.5 t/ha
- Faba bean (Ayla) + 0.4 t/ha
- Faba bean (Samira) + 0.5 t/ha

The decrease in biomass produced in the soybean due to the later harvest is likely due to the unsuitable growing conditions as winter progressed (summer active legume). Soybean is sensitive to frost and prefers daytime temperatures above 20 degrees.

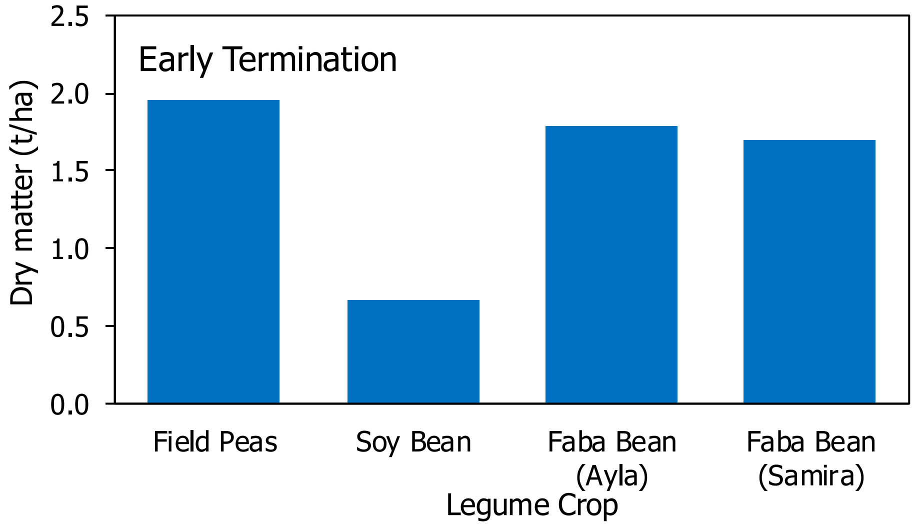


Figure 33: Biomass (dry matter t/ha) at time of Block 1 early termination – 18 July 2024 - for each autumn legume treatment.

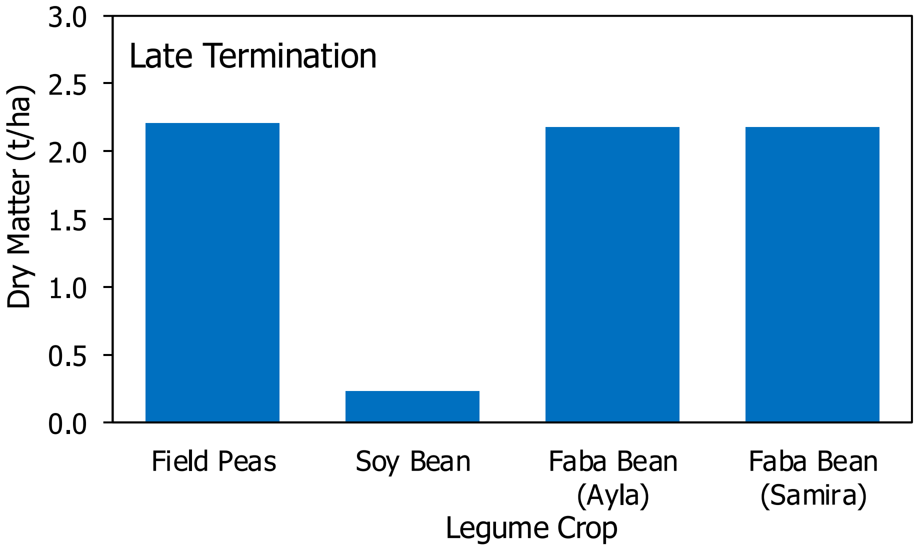


Figure 34: Biomass (dry matter t/ha) at time of Block 2 later termination – 29 July 2024 - for each autumn legume treatment.

Interestingly, tissue test results showed the field peas and soybean to have a higher tissue N% in the later termination (compared to early termination timing), whereas the beans had a slightly lower tissue N% in the later timing (Figures 35 & 36). Overall, tissue N% was significantly higher in the faba beans compared to other treatments for both times of termination.

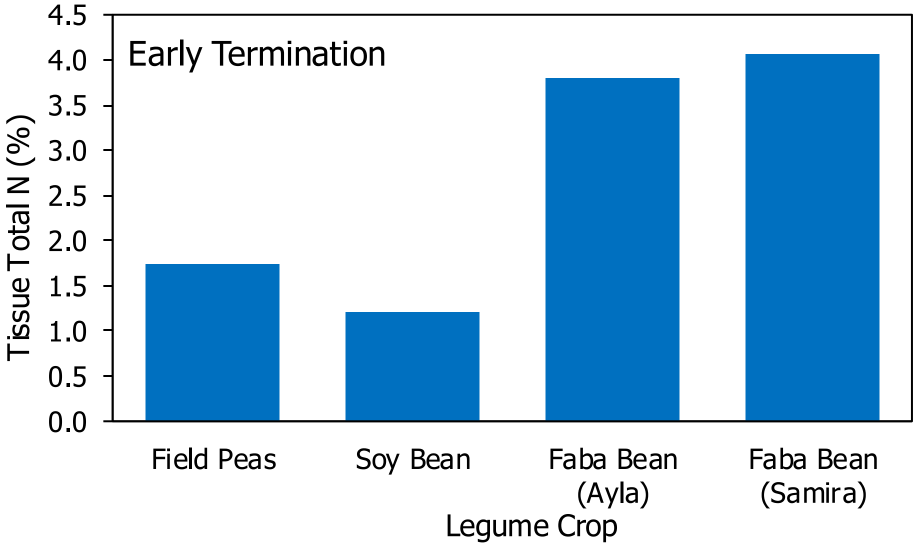


Figure 35: Plant tissue nitrogen (%) at time of Block 1 early termination – 18 July 2024 - for each autumn legume treatment.

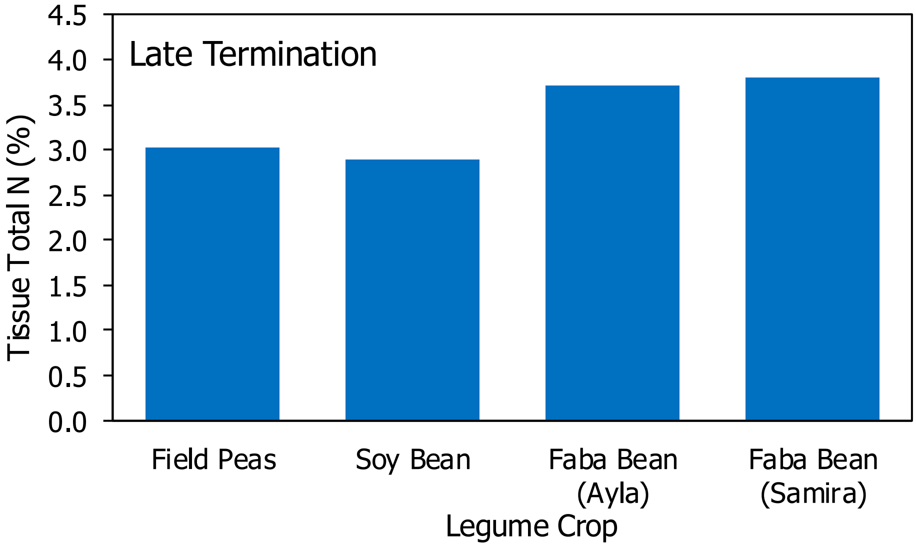


Figure 36: Plant tissue nitrogen (%) at time of Block 2 later termination – 29 July 2024 - for each autumn legume treatment.

Total N Contribution at Termination

Above ground nitrogen contribution for each of the legume treatments across both times of termination are shown in Figure 37. Late terminated faba beans contributed the highest amount of nitrogen to the system, followed by the early terminated field pea. Soybean struggled to grow enough biomass to contribute meaningful nitrogen to the system.

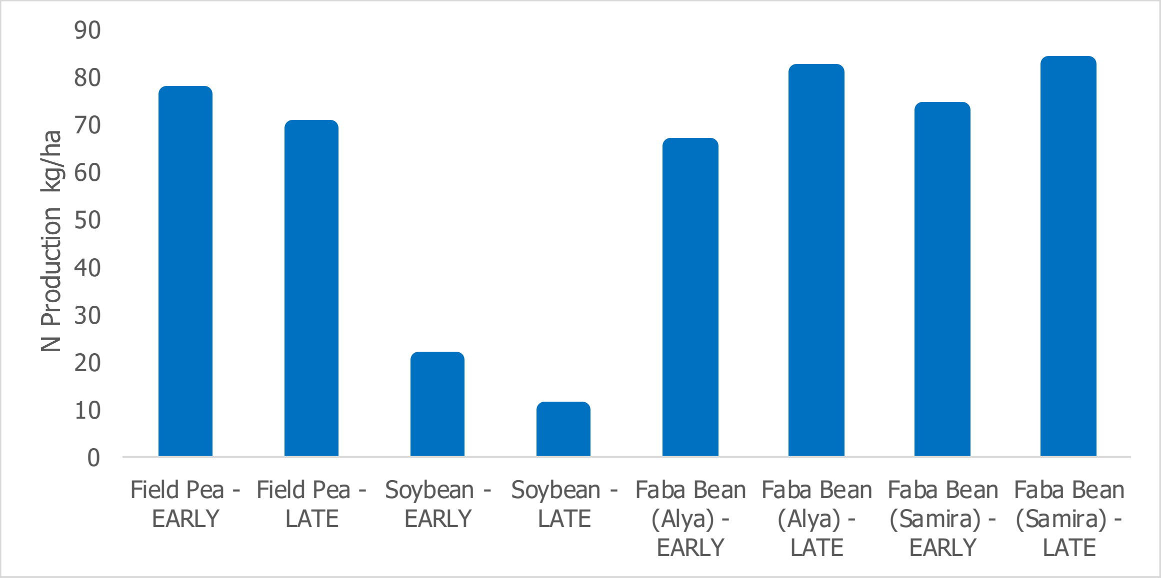


Figure 37: Average above-ground nitrogen (calculated from plant biomass & plant tissue N%) for each autumn-sown legume treatment, 2025.

Cereal - 2025

In July 2025, all legume plots were chemically terminated. Block 1 was terminated on July 18, and Block 2 was terminated on July 29. All legume-based plots were tilled in utilising a rotary tiller, and the plots were then over sown with Maximus Barley at a rate of 100kg/ha and half rate farmer practice fertiliser blend (35kg/ha MAP, 15kg/ha MOP, 20kg/ha Urea and 25kg/ha SOP). No further nitrogen was applied to the barley crop. Block 1 was sown on the 30 July 2025, and block 2 sown on 11 August.

Germination was even across all plots and there were no visual responses to treatments (Figures 38 & 39).

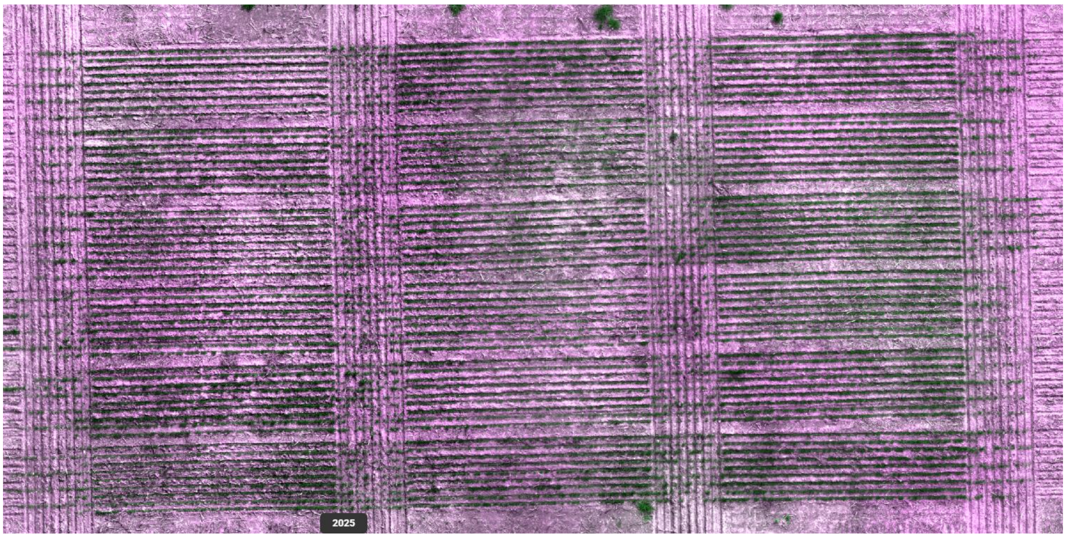


Figure 38: False Colour image of Block 1 (middle), identifying event germination across the trial site. UAV Capture date: 10th September 2025

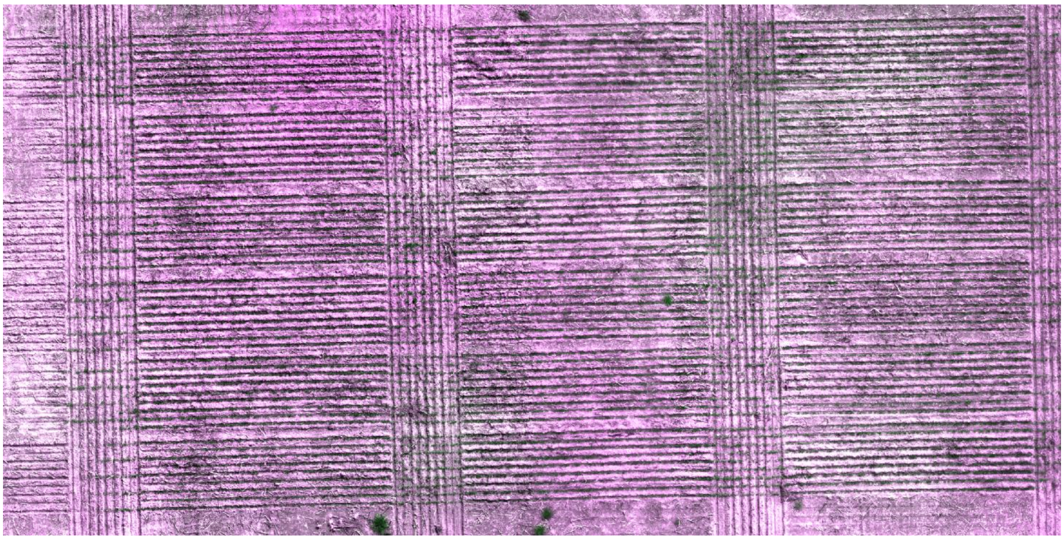


Figure 39: False Colour image of Block 2 (North), identifying event germination across the trial site. UAV Capture date: 10th September 2025.

Harvest yields were significantly lower in the fallow treatments across both times of termination compared to the faba bean (PBA Samira plots), where yields were the highest (Figure 40). Barley yields over all other legume treatments were relatively even, including the failed chickpea and low biomass producing soybean treatments. This suggested that there may have been a tillage effect.

Grain protein levels across all treatment were similar except for in barley grain over the early terminated faba bean (PBA Alya) and field pea plots (Figure 41).

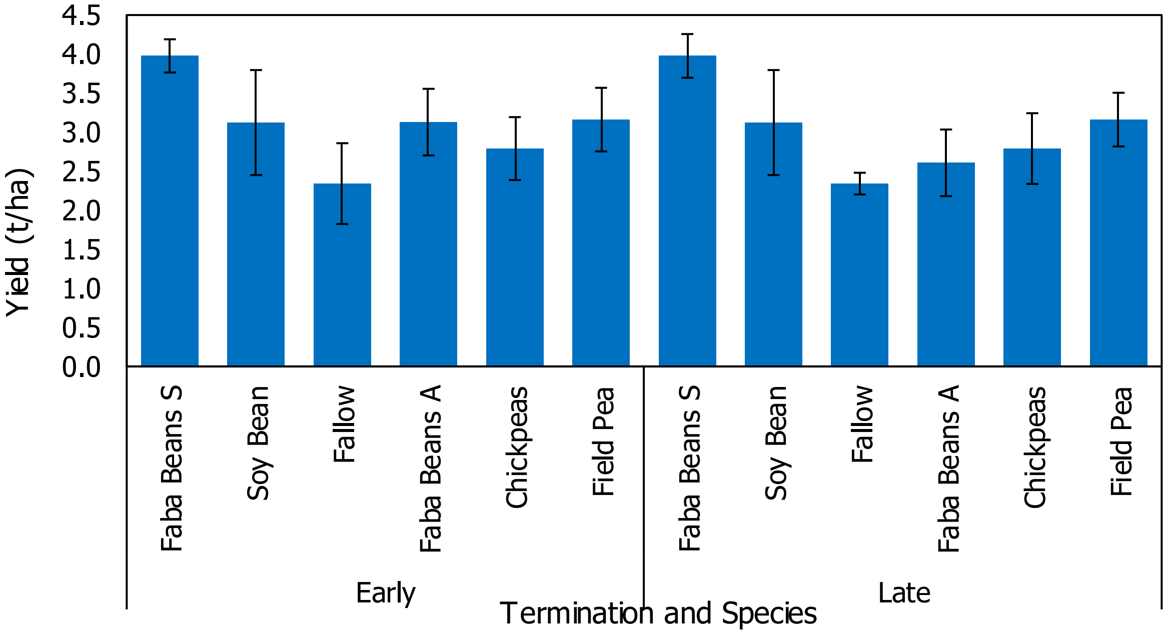


Figure 40: Average barley grain yield (t/ha) for each of the plots sown over autumn trial treatments, Dec 2025.

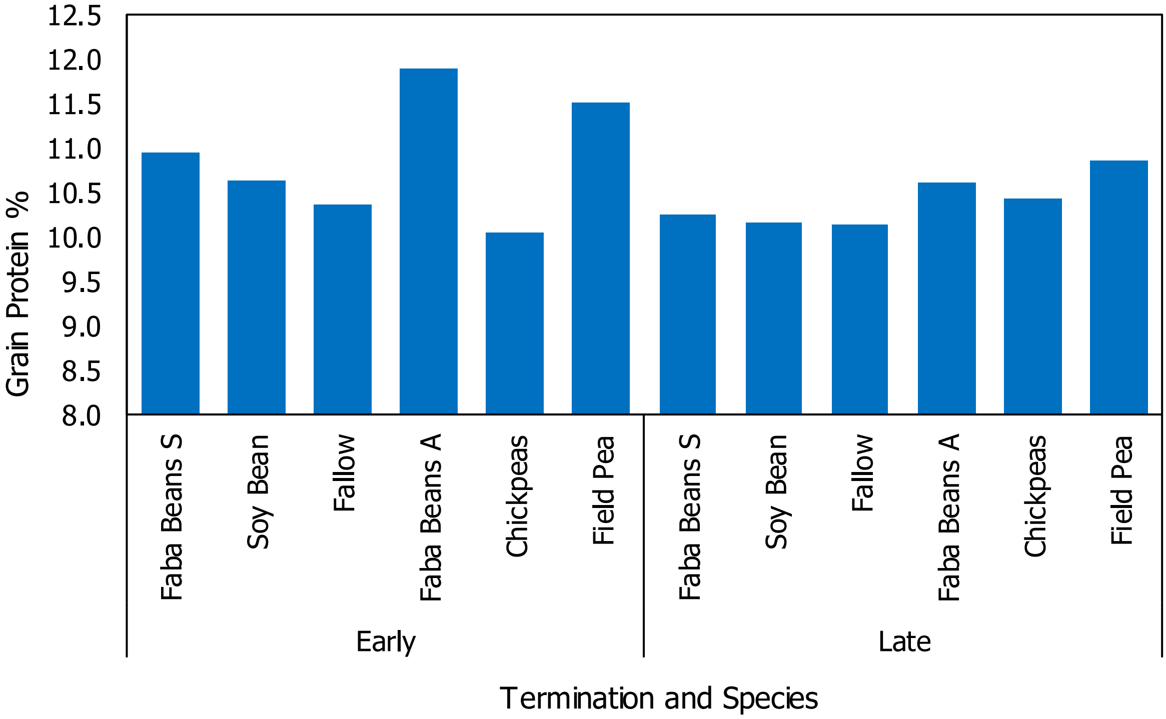


Figure 41: Average grain protein (%) for each of the plots sown over autumn trial treatments, Dec 2025.

Soil Nitrogen – Post Legumes

Interestingly post-harvest 2025, the combined soil nitrogen levels to a depth of 1m (ammonium N and nitrate N), were higher in the fallow and the chickpea autumn treatments (Figure 42). Barley harvest yields were lower in these treatments, particularly the fallow treatment so potentially nitrogen use by the previous crop played a role. Again, these results reinforce that single-point soil nitrogen measurements may poorly reflect the complexities of longer-term nitrogen cycling.

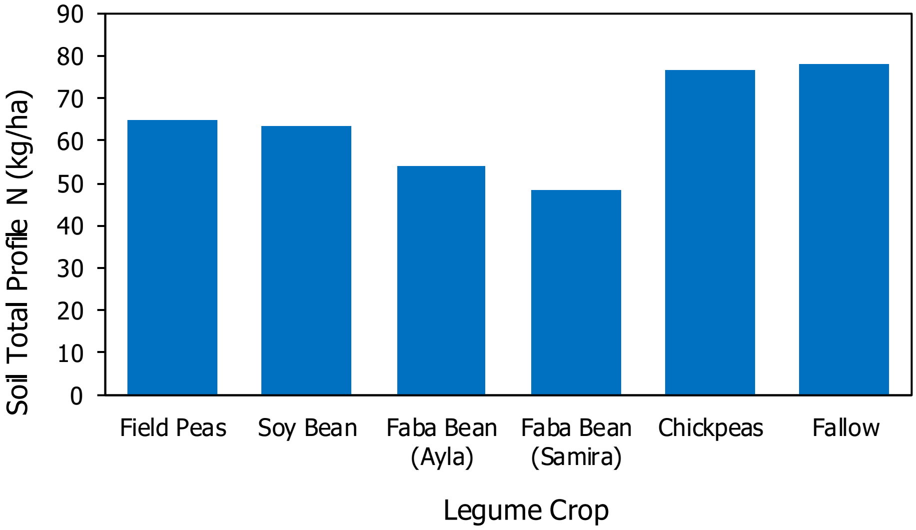


Figure 42: Average total post-harvest soil nitrogen, ammonium and nitrate (kg/ha) to 1m depth, across each of the treatments for both termination timings, Jan 2026.

DISCUSSION – AUTUMN LEGUME TRIAL - 2025

The 2025 trial contrasted strongly with the previous two seasons and provided important insight into how temperature, timing and legume type influence nitrogen outcomes and subsequent cereal performance. Cooler average temperatures during early 2025, combined with well-timed rainfall events in March and April, created favourable soil moisture conditions in early autumn for legume sowing and establishment. Unlike the summer-dominant systems tested in earlier years, these conditions supported reliable germination across all treatments, demonstrating that autumn establishment of legumes may offer a more robust opportunity for biomass and nitrogen production under southern Western Australian conditions.

Legume establishment across the trial was generally successful, although substantial spatial variability was observed, reflecting inherent soil variability and the challenges of small-plot experimentation. Chickpea survival was notably poor despite acceptable early establishment, highlighting the sensitivity of this species to cold and wet conditions and reinforcing its limited suitability for the region. In contrast, faba beans (both varieties) and field peas demonstrated better survival and nodulation, confirming their adaptability to cooler autumn conditions. Soybean nodulation and biomass production was comparatively low, supporting the hypothesis that this crop type requires warmer temperatures, consistent with its stronger performance in the warmer 2023 and 2024 summer trials.

Termination timing had a species-specific influence on biomass accumulation and nitrogen contribution. Extending the growing period increased biomass for field peas and both faba bean varieties, while soybean biomass declined under later termination, likely due to cold temperature sensitivity and its summer-active growth habit. These results emphasise the importance of aligning legume species with seasonal temperature profiles and selecting termination timing that matches species-specific growth dynamics. Tissue nitrogen concentrations varied with termination timing, but faba beans consistently maintained the highest shoot nitrogen levels.

Differences in biomass production and tissue nitrogen concentration translated into clear differences in above-ground nitrogen contribution. Late-terminated faba beans contributed the greatest amount of nitrogen, indicating that autumn-sown, cool-season legumes can deliver meaningful system nitrogen when establishment is successful and growing conditions and season length allow sufficient accumulation of biomass. In contrast, soybean contributed relatively little nitrogen, confirming that while it can perform well in warmer summer conditions, it is less suited to cooler late-autumn or winter environments.

Barley yield responses in 2025 further supported the value of productive autumn legumes. Yields were consistently lowest in fallow plots and highest following faba bean treatments, particularly PBA Samira. However, yields over other legume treatments, including those with limited nitrogen contribution, were relatively similar, suggesting that a tillage or stubble incorporation effect may have contributed to improved barley performance beyond nitrogen supply alone. Grain protein responses were modest and inconsistent.

Post-harvest soil nitrogen levels were highest in fallow and chickpea treatments, which also produced lower barley yields. This further illustrates the difficulty of interpreting single-point soil nitrogen measurements and suggests reduced nitrogen uptake driven by lower biomass production rather than enhanced nitrogen supply. These findings reinforce observations from earlier years that soil nitrogen testing alone provides an incomplete picture of system nitrogen dynamics following legume phases.

Overall, the 2025 results demonstrate that autumn-sown legumes, particularly faba beans, can contribute meaningful nitrogen benefits and yield advantages when seasonal conditions align.

OVERALL CONCLUSIONS

This project demonstrated that legume cover crops can contribute biologically fixed nitrogen to high-rainfall grain systems in southern Western Australia, but outcomes are highly dependent on season, species selection, and establishment success. Large differences were observed between years, reinforcing that currently legumes are not a guaranteed short-term substitute for fertiliser nitrogen.

Key findings from the three seasons include:

- Legume establishment and performance were strongly season-dependent. Summer legumes were viable under warm conditions with reliable establishment moisture (2023), but performance was highly constrained under hot, dry conditions (2024). In contrast, autumn-sown legumes performed well under cooler conditions with well-timed rainfall (2025), highlighting the importance of aligning legume type and sowing time with seasonal conditions.
- Species selection was critical. Faba beans consistently demonstrated strong nodulation, high biomass production under suitable conditions, and the greatest above-ground nitrogen contribution, particularly in 2023 and 2025. Soybeans performed well in warmer summer conditions (2023 and 2024) but were poorly suited to cooler autumn environments (2025). Chickpeas showed limited suitability across seasons, particularly under cold and wet conditions.
- Large differences in above-ground nitrogen production did not consistently translate into first-year cereal yield or protein responses. In several instances, cereal responses were muted by seasonal constraints (dry finishes or poor establishment) and possibly by the timing of nitrogen mineralisation relative to crop demand. This indicates that legume-derived nitrogen may contribute more to medium-term system nitrogen supply than immediate yield gains.
- Soil nitrogen measurements taken immediately prior to cereal sowing or post-harvest did not reliably reflect legume performance or nitrogen contribution. Results across all seasons reinforced that single-point soil nitrogen testing poorly captures the complexity of nitrogen cycling, immobilisation and mineralisation following incorporation of legumes into a system.
- Cereal yield responses were more consistently influenced by overall system effects (seasonal conditions, tillage, residue incorporation and background soil nitrogen) than by legume nitrogen supply alone. However, higher grain protein observed in some treatments (notably following faba beans) suggests legacy nitrogen effects may accumulate over time.

At this stage, the research indicates that summer-sown or autumn-sown legumes should be viewed as a flexible, opportunistic component of nitrogen management rather than a direct substitute for fertiliser nitrogen in the short term. Their value lies in contributing to longer-term nitrogen supply, improving system resilience and reducing reliance on fertiliser nitrogen over multiple seasons, particularly when species selection and sowing timing are well matched to seasonal conditions. It also shows that longer-term monitoring and multi-year evaluation are essential to fully capture the benefits of legumes in grain-based farming systems.

Collectively, the outcomes of both project phases (summer-sown & autumn-sown) have increased grower understanding of how and when legume cover crops may be successfully integrated into high-rainfall rotations to improve system nitrogen supply. By 2025, growers in the high rainfall zone have gained practical, region-specific knowledge on the use of both summer-active and autumn-active legumes, including their limitations, risks, and potential benefits, enabling more informed decisions about opportunistic legume use to support long-term nitrogen management without disrupting traditional cereal-based rotations.

IMPLICATIONS

This research has important implications for nitrogen management in Australian high-rainfall grain systems where fertiliser nitrogen inputs are high and price exposure is significant.

- The project demonstrates that legumes can reduce nitrogen risk by contributing biologically fixed nitrogen to farming systems, particularly where establishment conditions are favourable and species are well matched to season.
- For context, at a current 2026 very high urea price of approximately $1,500/t (equivalent to $3.26/kg of nitrogen), the faba bean crops that produced around 250 kg N/ha in 2023 and 80 kg N/ha in 2025 represent an indicative fertiliser nitrogen value of approximately $800/ha and $260/ha, respectively, noting that the proportion of this nitrogen available to subsequent crops depends on mineralisation timing and seasonal conditions.
- However, outcomes were inconsistent across seasons, highlighting that legumes should be deployed opportunistically rather than year-in-year-out.
- Costs associated with legumes include seed, sowing, termination and incorporation, which are comparable with, but not always offset by, short-term fertiliser savings.
- Longer-term benefits—including residual nitrogen carry-over, reduced fertiliser reliance over multiple seasons and improved system resilience — represent the most realistic pathway to economic return.
- The project reduces adoption risk by providing evidence-based guidance on species selection, sowing timing and seasonal suitability.

Overall, the industry benefit lies in improved nitrogen decision-making and reduced exposure to fertiliser price volatility rather than complete substitution of legumes for synthetic N.

RECOMMENDATIONS

The findings of this project demonstrate that legume cover crops can play a strategic role in nitrogen management for high-rainfall grain systems; however, their effectiveness is dependent on controllable (i.e., species selection) and uncontrollable (weather) variables.

This research suggests that autumn-sown legumes are potentially a more reliable 'regular fit' in this region, after the highly variable success of summer-sown legumes. Considering other constraints to profitable crops in the HRZ (i.e., disease resistance), autumn-sown legumes strategically inserted into tight canola-cereal rotations could play a role in future years. The very current global fertiliser and fuel price rise shortage issues put novel management practices, such as these, even more in the spotlight. SCF and local farmers/agronomists are interested in continued investment into research and development of autumn-sown legumes and would recommend further field scale trials to provide local farmers with more confidence and knowledge to successfully implement this management strategy

The limitations observed in using single-point soil nitrogen measurements to assess legume contribution further reinforce the need for systems-based approaches to nitrogen management. Future research would benefit from longer-term monitoring of nitrogen dynamics, including residue breakdown, mineralisation timing and interactions with soil organic nitrogen pools, to better quantify cumulative benefits and improve predictive capability. This is across legumes in general, not just legume cover crops.

GLOSSARY AND ACRONYMS

Below is a sample abbreviations and acronyms list. Be sure to include all abbreviations and acronyms that appear in the report.

BOM	Bureau of Meteorology
Ha	Hectares
N	Nitrogen
t	tonnes

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