GOA trial site report

Quantifying the legacy impacts of a range of alternate break crops on subsequent crop performance- Parkes 2021-2023

Project Name	Validation and extension of farming system sequences to maximize WUE in low rainfall sandy soils of Southwest NSW
GRDC Investment Code	GOA2106-002RTX
GOA Trial Code:	GPMA01022-1, GPMA01023-1
Season/Year:	Winter 2022 and 2023
Location:	Goonumbla, North Parkes Mine
Trial Partners:	Nathan Border
Trial Establishment Date:	Winter 2021 (with various pulse species)

Keywords

Pulses, chickpeas, faba beans, vetch, field peas, lupins, lentils, nitrogen, protein, PredictaB, soil moisture, Parkes, Goonumbla, GPMA01022

Take home messages

- High biomass pulse crops can fix large amounts of N
- 20 – 55% of this N is exported in grain or hay- but it varies widely depending on crop type (and is effectively nil for vetch manure)
- Theoretical N remaining following pulse crops is often not reflected in soil testing for nitrates, nor crop responses.
- Soil moisture at this site was relatively unaffected by break crop option- most likely due to wet conditions In higher rainfall/eastern environments, summer fallow rainfall may be enough to overcome legacy moisture differences between pulse crops
- Soil borne disease levels can be impacted by break crop option, and maybe a consideration in disease effected paddocks and for minimising risk in the subsequent crop
- The legacy effect of pulses can have positive responses in subsequent crops, however similar results can also be achieved t with added fertiliser N in a non-pulse system

Background

The term “break crop” is often attached to crops other than wheat or other cereals. This probably stems from previous eras of farming that generally had little crop diversity and crop rotations were largely nonexistent. To be adopted as part of a cropping system or rotation is not unreasonable to expect the crop needs to be profitable and sustainable in the year of growing them. However, break crops have also been suggested to provide additional, ongoing benefits to the farming system such as disease or weeds breaks to minimise their impacts and in the case of pulse crops, they may build on soil N reserves compared to other non-leguminous crop options. This in turn may reduce the need or reliance of fertiliser N in subsequent crops which may offer some savings or increased crop performance. There could also be benefits in regards capture, usage or storage of soil water.

The GRDC Funded, NSW Pulse Project (BRA2105-001RTX)[1] specifically focused on the performance of pulse options as break crops. The project looked at range of common pulse crops and varieties and quantified their performances. The project however was not able to quantify the potential legacy benefits of the various options tested.

GRDC funding under this project GOA2106-002RTX however specifically set out to quantify some of the potential influence that several alternate break crops options would have on subsequent crop performance. It aims to focus on four key areas-

- Soil mineral N prior to sowing of subsequent crops
- Soil water prior to sowing of subsequent crops
- Soil borne disease
- Subsequent crop performance in terms of yields and grain quality

To achieve this, the trials undertaken in the Pulse project trial sites were continued to be managed, sampled and analysed for soil N, water and disease and the trial areas then sown to winter crop in the season following to quantify the impact on crop performance. This report details the findings of this work.

Site details

Location – Goonumbla

Soil type – Chromosol

Crop chronology- 2021- Various pulse and break crops

2022- Wheat

2023- Wheat

Growing conditions – 2021 Was characterised as a wet year, faba beans yielded very well, while broad leaf lupins and lentils were significantly damaged or dead due to waterlogging.

2022 The site started with a full moisture profile following on from 2021 and was followed by above average in crop rainfall.

2023 Soil moisture at sowing of the 2023 crop was quite full from the previous wet years. In-crop rainfall was low however yields were relatively high most likely due to stored soil moisture.

[1] Development and extension to close the economic yield gap and maximise farming systems benefits from grain legume production in New South Wales

Table 1. Trial site rainfall[2] in 2021, 2022, 2023 and the long-term average (LTA).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2021	79	96	119	1	24	79	74	64	58	31	171	61	857
2022	123	16	101	161	75	9	67	95	104	129	162	40	1082
2023	62	22	70	44	4	35	30	14	8	20	114	75	498
LTA	53	49	47	40	41	45	42	42	37	47	53	48	544

Treatments – the base treatments that are referred to throughout the rest of this report relate to the break crop options sown in 2021 winter season. These broadly consisted of five pulse species each with 2 varieties of each. One non legume break crop option in canola was tested, and it had two contrasting nitrogen application rate strategies applied to its management- a high and low. Wheat was also sown in this trial as a non-break crop option, this also had two N management strategies applied. One final non cropped option tested was a fallow treatment in 2021, under this treatment weeds were continuously excluded for all the 2021 winter season and subsequent fallow period leading up to sowing in 2022. In both the wheat and canola options, N rates were applied in only in 2021 and 2022, no N was applied in 2023 due to the dry seasonal conditions and yield outlooks. For the fallow treatment no N was applied in 2021, but differing rates of N was applied in the subsequent crop year of 2022.

Details of the base treatments, including species, variety and N rates applied are detailed in (**Table *2***).

Table 2. Break crop species and varieties tested in year 1 and N rates applied

Description	2021 N (kg/ha)	2022 N (kg/ha)	2023 N (kg/ha)	Total N (Kg/ha)
Canola - Trophy - High N	120	96	0	216
Canola - Trophy - Low N	40	11	0	51
Chickpea - Captain				
Chickpea - Hattrick				
Faba - Nasma				
Faba - Samira				
Fallow - High N	0	85	0	85
Fallow - Low N	0	0	0	0
Lentil - Hallmark				
Lentil - Kelpie				
Lupin (broad) - Murringo				
Lupin (narrow) - Bateman				
Vetch - Studenica - Brown manure				
Vetch - Studenica - Hay				
Wheat - Mustang - High N	120	101	0	221
Wheat - Mustang - Low N	40	3	0	43

[2] Gridded data from: Access Gridded Data | LongPaddock | Queensland Government

Results

Summary of the 2021 pulse crop results (for yield and dry matter results see **Table 3**):

- Faba beans had the highest grain yield (5.3 and 6.3 t/ha for Nasma and Samira respectively) and produced remarkably high biomass (12.1 and 15.1 t/ha for Nasma and Samira respectively).
- The high biomass indicates a high amount of nitrogen fixed but the beans also had remarkably high removal in the grain with an average removal of 262 kg N/ha at Parkes.
- Faba beans outyielded both canola and wheat, even with high N input.
- Biomass of lupins was lower than fababeans (3.0 and 7.9 t/ha for Murringo and PBA Bateman respectively). The broad leaf Murringos suffered from waterlogging (as did the entire site) much more than the sweet lupins (or other species at this site with the exception of the Lentils). Grain yield followed a similar trend with low yield for Murringo (0.8 t/ha) and moderate yield for PBA Bateman (2.6 t/ha).
- The dry matter production from vetch was low however vetch was cut at an earlier growth stage (before podding) to simulate hay cut timing.
- CBA Captain chickpeas had low biomass compared to faba beans, with moderate grain yield (2.6 t/ha). CBA Captain chickpeas yielded more than lentils at both sites. Lentils (like Murringo albus lupins) suffered from waterlogging at Parkes and had low biomass and yield.
- Lupins had the highest seed N content, removing 90% more N than chickpeas (lowest seed N content) per tonne of grain produced.

For more details see the 2021 Summary of field trial results (https://grdc.com.au/__data/assets/pdf_file/0042/577977/2021-Pulse-reports-book.pdf)

Table 3. Dry matter production, yields, calculated nitrogen fixed and nitrogen balance, 2021. N balance calculated as starting soil N 2021 (assume all treatments the same level ~138 kg/ha) plus fertiliser N and N fixed by legumes minus N exported in grain

Species -variety/treatment	Dry matter (t/ha)	Yield (t/ha)	Calculated N fix (kg/ha)	N Balance (kg/ha)
Chickpea - Captain	9.0	2.6	330	379
Chickpea - Hattrick	8.2	2.3	320	379
Faba - Nasma	12.1	5.3	447	343
Faba - Samira	15.1	6.3	552	407
Lentil - Hallmark	3.9	0.7	88	197
Lentil - Kelpie	2.4	0.2	49	176
Lupin - Bateman	7.9	2.6	319	324
Lupin - Murringo	3.0	0.8	98	187
Vetch - Brown manure	4.7		199	337
Vetch - Hay	4.7	4.7*	66	204
Canola - High N	9.3	2.4	0	177
Canola - Low N	8.2	2.1	0	113
Wheat - High N	9.1	3.8	0	176

Wheat - Low N	7.8	3.8	0	100
Fallow - High N			0	138
Fallow - Low N			0	138
Lsd	3.4	0.97		

*Yield is a hay yield

Break crop contribution to residual nitrogen prior to planting of 2022 crop

For the pulse options tested in 2021 the amount of N fixed was calculated by measuring the peak biomass of the crop and determining the portion of the N that was derived from the atmosphere, i.e. that what is fixed by rhizobia. **Table *3*** details the amount of N fixed by the respective pulse crop options. As can be seen the higher biomass of the faba beans resulted in very high levels of N fixed of up to ~550kg N/ha.

However, of the total amount of N fixed by the respective crops some will be exported in the grain. If the grain removal is subtracted from the amount of N fixed that results in the final N balance. As can also be seen in **Table *3***. N content of the various grain crops also varied significantly which impacts on the final N balance. Lupins had nearly double the N concentration than chickpeas (data not presented).

Calculated nitrogen fixed in 2021 varied from 552 kg/ha for Samira faba beans to 49 kg/ha for the Kelpie lentils (lentils severely retarded by wet conditions). Chickpeas, faba beans sweet lupins and brown manure vetch had a calculated N balance at over 200 kg/ha at the conclusion of the trial.

The N balance of the non-pulse species is also shown. As a non-pulse they cannot fix any N and draw their requirements from soil reserves or added fertiliser. As can be seen in the **Table *3*** even under the higher N strategies the net N budget theoretically was lower following harvest. The low N fallow, wheat and canola treatments had less than 50 kg/ha of calculated N balance. The high wheat and canola treatments had over 150 kg/ha of calculated residual N.

Figure 1 below illustrates the residual mineral N present just prior to sowing of the 2022 crop and the 2023 crop. As can be seen residual N is higher in the first year (2022 testing) following the pulse break crop options than the non-pulse options, under both N strategies. However, the additional mineral soil N levels do not reflect the significant amounts of N theoretically fixed and left following the various pulse break crop options when compared to the non-pulse options despite theoretical additions from the pulses of >200kg/ha.

Overall soil mineral N is much lower ahead of sowing of the 2023 crop and the appears to little difference between any of the break crop treatments despite differences in N balances of more than 200kg/ha.

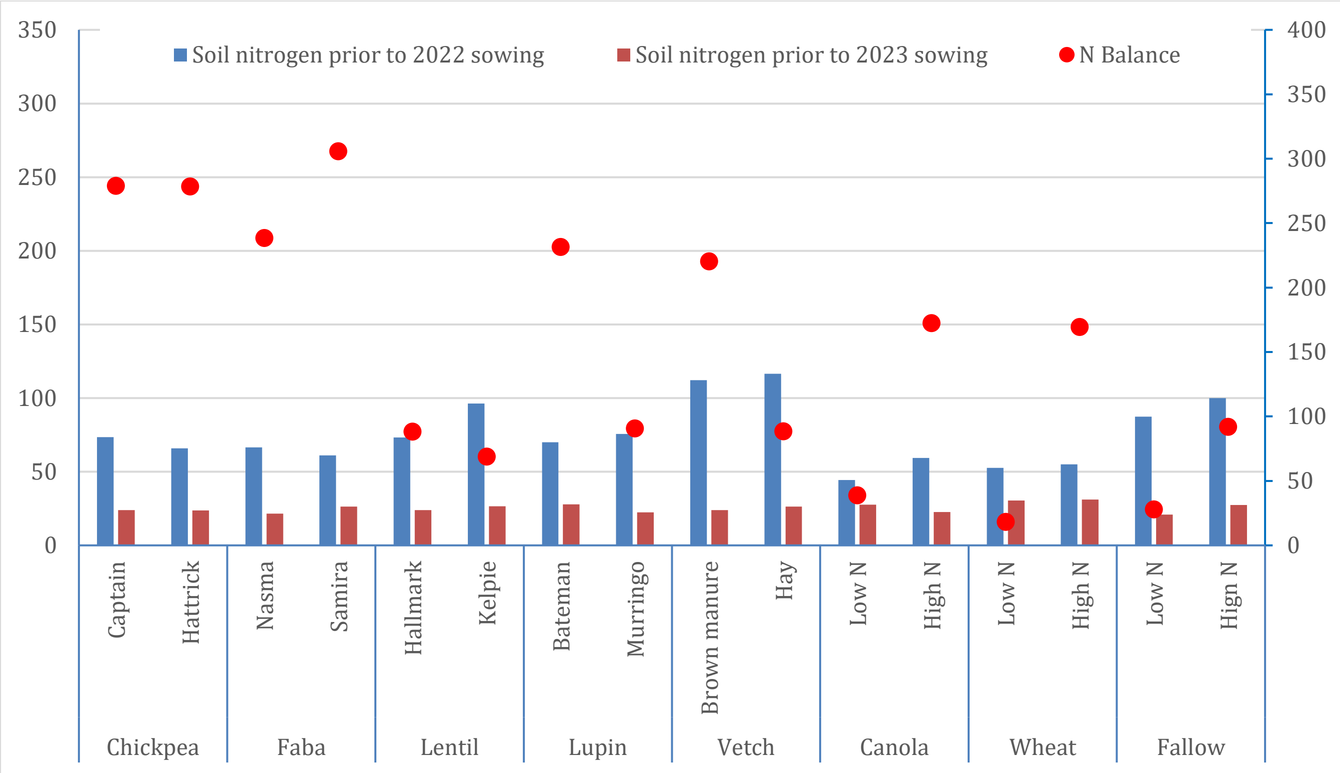

Figure 1. N balance following the sequence crops planted in 2021, 2022 and 2023 and soil N as tested prior to sowing the 2022 and 2023 winter crops. Note that selected canola, wheat and fallow treatments had additional N added in the 2022 winter crop (see treatment list). N balance calculated as starting (2021) soil N (~138 kg/ha) plus fertiliser N and N fixed by legumes – N exported in grain in all 3 years.

Impact on soil borne disease as tested by PredictaB testing prior to sowing of the 2022 crop

The trial site was sampled and analysed by PredictaB testing at sowing time in 2022.The result of this testing is presented in **Table 4** below. NB- Not all break crop species and varieties were tested due to cost.

Table 4. Results from PredictaB testing conducted prior to sowing the 2022 wheat crop

Species; variety or treatment.	Phytophthora megasperma clade	Phytophthora medicaginis	Long Fallow Disorder (AMFa)	Long Fallow Disorder AMFb	Bipolaris	Fusarium culmorum / graminearum	Pratylenchus neglectus	Pratylenchus thornei	Sclerotinia sclerotiorum/ S. minor
	pgDNA copies/g	pgDNA copies/g	kDNA copies/g	kDNA copies/g	pgDNA copies/g	pgDNA copies/g	nematodes /g soil	nematodes /g soil	kDNA copies/g
Lupin- Murringo	3152	0	16.2	2.6	0.8	0.3	0	0	0
Canola - Low N	0	0	10.9	1.2	0.0	0.8	0.49	0.38	264
Chickpea- Captain	4502	0	79.7	14.9	1.1	0.8	0.00	0.90	3
Faba- Nasma	540	0	115.9	25.2	1.8	0.0	0.04	0.17	0
Fallow	0	0	12.0	0.6	2.3	0.5	0.05	0.27	0

Vetch- Studenica (hay)	0	0	28.2	4.4	0.5	0.0	0.00	0.12	0
Lentils- Kelpie	2632	0	44.3	4.8	1.9	1.0	0.09	0.11	0
Lupin- Bateman	1514	0	22.7	4.9	2.6	0.0	0.00	0.04	2059
Wheat - Low N	0	0	104.0	10.2	8.8	5.3	0.11	0.08	0

Impact on soil water as prior to sowing of the 2022 crop

Soil water was assessed by EM38 methods prior to planting the 2022 crop. However as evidenced in **Table *1*** the very wet conditions through the fallow period leading up to testing saw soil moisture reach saturation and largely overwhelming any potential impacts of the various break crop options (data not shown).

Ahead of sowing the 2023 crop soil samples were also taken and gravimetric water content calculated by oven drying methods. The results are illustrated in Figure 2 below. Although there are some differences between break crop options/varieties all results fell within the tight range of 20-23.5%. This tends to suggest that any impact of the break crop treatment may not last beyond the following crop.

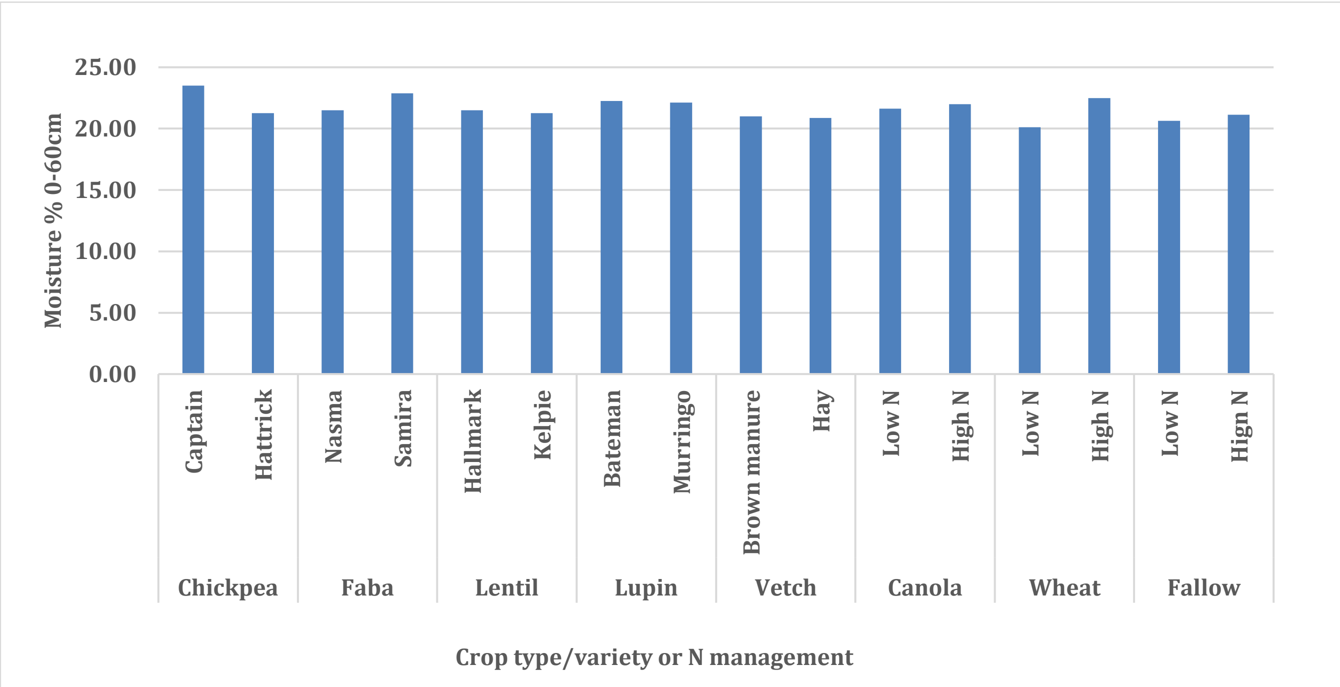

Figure 2. Soil moisture content measured prior to sowing of 2023 crop in response to break crop options grown in 2021.

<u>Summary of 2022 wheat performance (first year after break crop options)</u>

The average yield of the wheat at the site was 3.6 t/ha. The yields following the various break crop options are illustrated in *Figure 3* below. Wheat following fallow with added N fertiliser had the highest yields (4.3 t/ha), following canola with no add N fertiliser had the lowest yields (2.7 t/ha). Wheat following vetch had the highest yields where it was wheat on pulse rotation (4.1-4.2 t/ha) with wheat following lupins the lowest yields (regardless of variety), 2.9 and 3.1 t/ha for Bateman and Murringo, respectively. Adding fertiliser N to wheat following wheat improved yields from 2.8 to 4 t/ha, whereas adding fertiliser N to wheat following canola improved yields from 2.7 to 3.6 t/ha.

The average protein at the site was very low at 9.4%, the highest protein of 10.8% was wheat following fallow with added N fertiliser which also had the highest yield as well. Wheat following vetch had the highest protein where it was wheat on pulse rotation (~9.8%) and wheat following Bateman lupins had the lowest protein (8.4%)

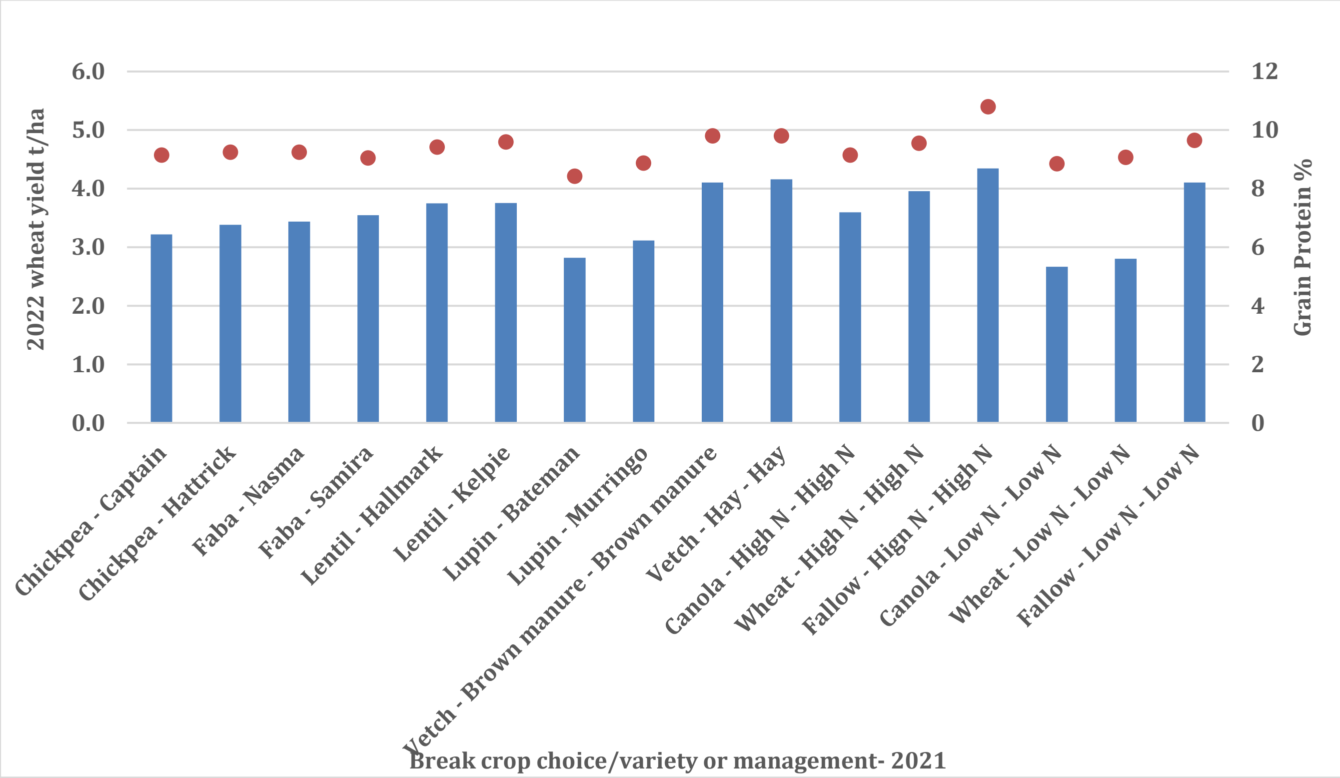

Figure 3. 2022 Wheat yields and grain protein following various break crop treatments sown in 2021.

<u>Summary of 2023 wheat performance (second wheat crop after break crop options)</u>

The average yield of the wheat at the site was 3.3 t/ha. Overall, the differences between crop sequences were not large (~0.5 t/ha) as can be seen in Figure 4. Wheat following two previous crops of wheat, or canola followed by wheat, without N at 3.1t/ha and 3.17 t/ha, respectively. Where N was added in 2022 but not 2023 yields increase slightly to 3.2 t/ha and 3.26t/ha, respectively. Wheat followed by wheat following fallow with added N yielded 3.57 t/ha which was the highest yield in the trial, higher than where no N was added, at 3.17 t/ha.

Wheat following narrow leaf lupins had the highest yields in the site with 3.64 t/ha, Wheat following wheat and Nasma faba beans and Captain chickpeas both yielded close to 3.5 t/ha.

The average protein was 7.8% at the site with less than 0.5% variance between treatments.

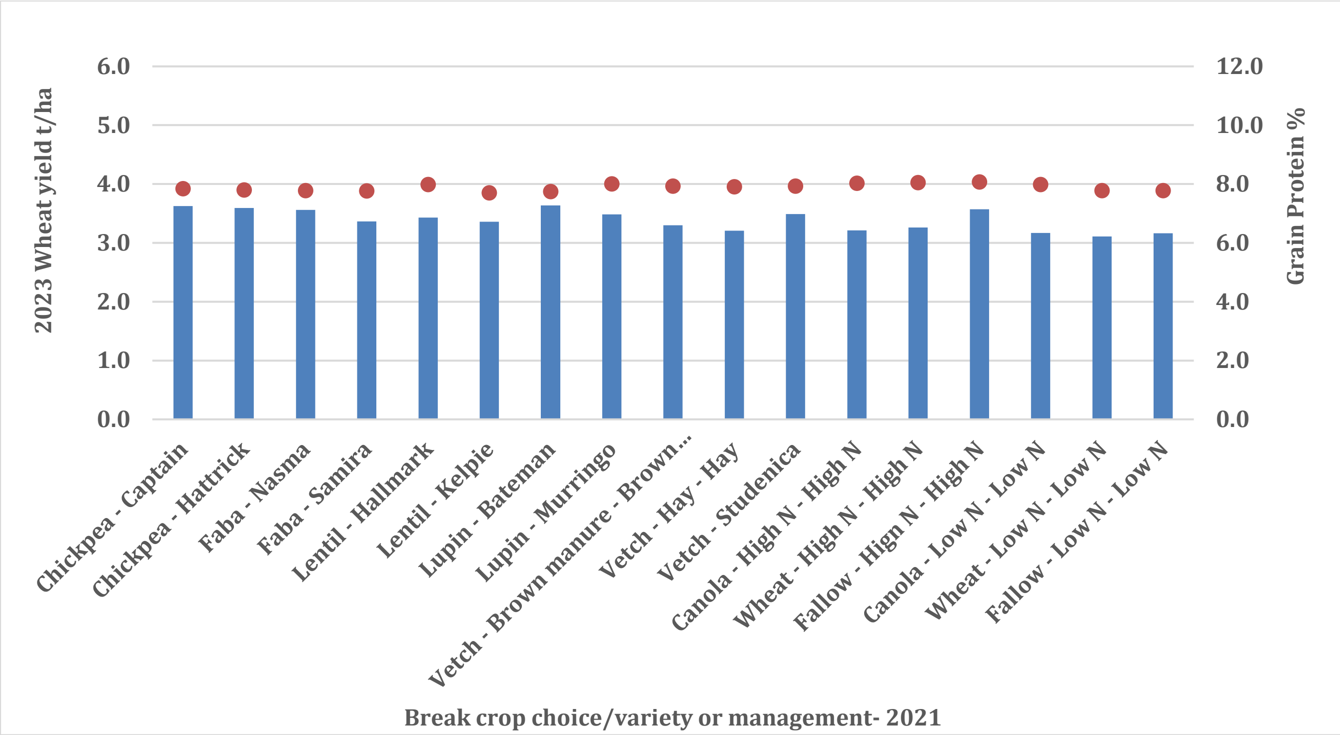

Figure 4. 2023 wheat yields and grain protein following various break crop treatments sown in 2021.

Cumulative 2-year wheat yields are shown in Figure 5 (2022 wheat and 2023 wheat). Wheat and canola with no added N had the lowest cumulative yields (<6t/ha), but wheat and canola with additional N increase cumulative yields by 1.4 and 0.9 t/ha. Cumulative yield over the two years following vetch at >7t/ha and was the highest yield other than following fallow with added N at 7.8 t/ha. Following chickpeas and faba beans yields were ~ 6.8 – 6.9 t/ha, following lupins ~ 6.5 t/ha.

Protein levels in both years were low, resulting in a bin grade of ASW or less. All treatments were below 10% protein in 2022, apart from the high nitrogen fallow, while all treatments were below 8% for the 2023 crop (Figure 6) and there was in practical terms, no difference between treatments.

Figure 6 below illustrates the closing N balance for the crop sequences tested at this site. As can be seen the highest N balances exist following the chickpea and faba bean break options. followed by lupins and vetch brown manure. The low N, non-pulse options tested had the lowest closing N balances at only 18—39 kg/ha of N remaining. Where N was applied to the non-pulse options the closing N balance is higher but not as high as many of the pulse options.

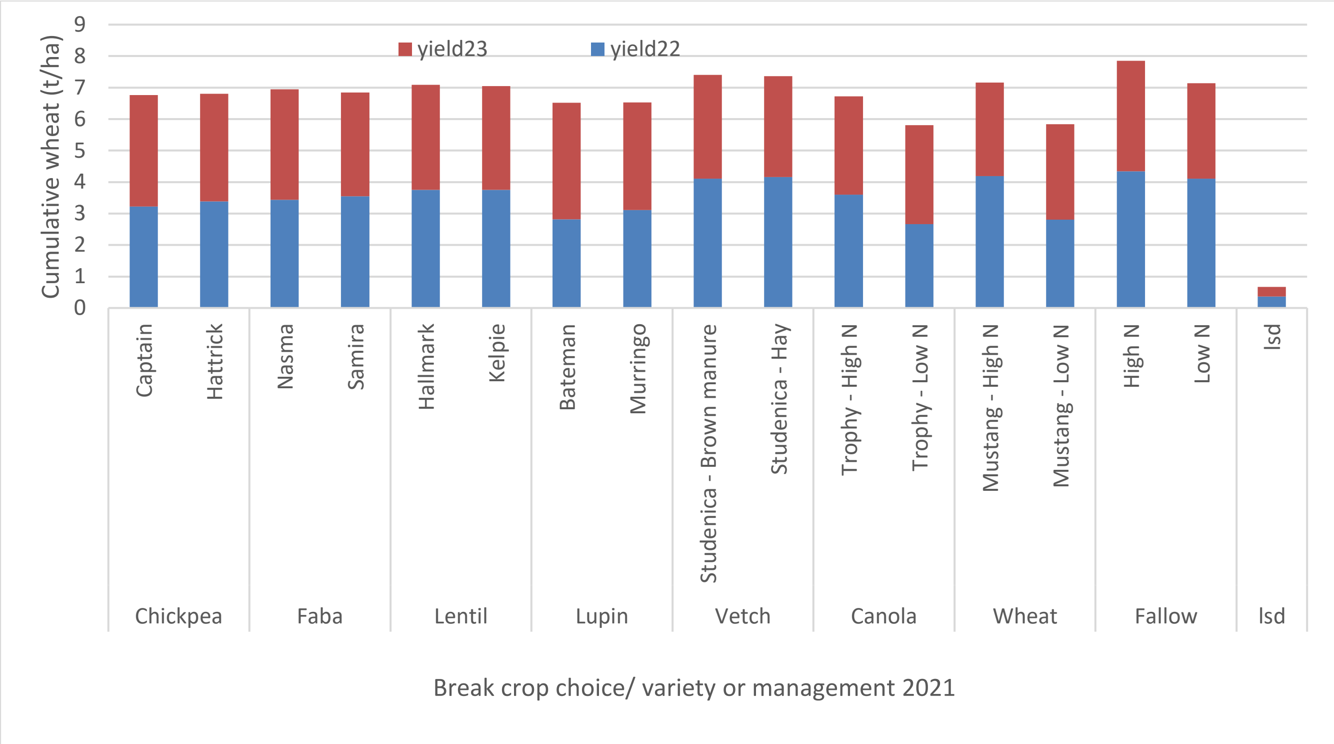

Figure 5. Wheat yields (t/ha) in 2022 and 2023 following crops planted in 2021

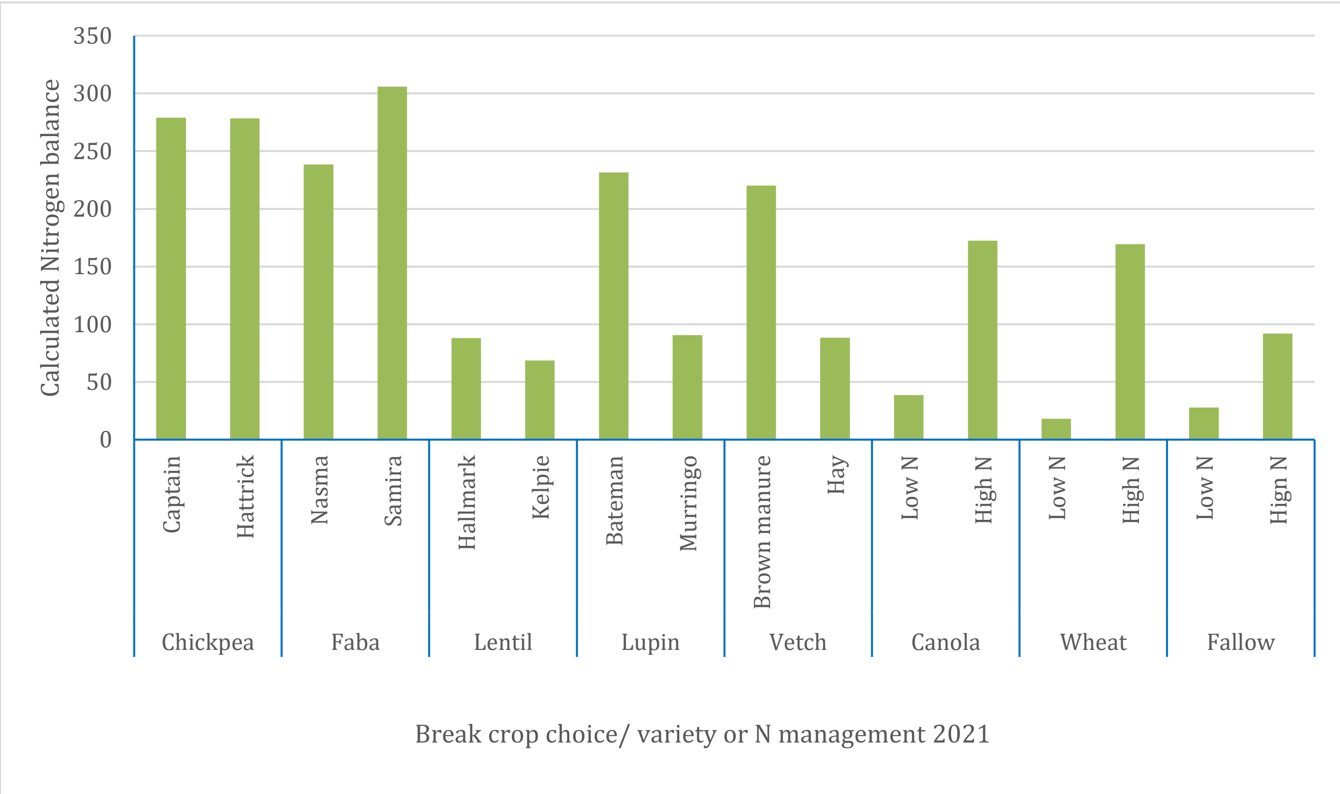

Figure 6. Calculated N balance at the conclusion of the project.

Discussion

Calculated N fix (portion of nitrogen fixed from the atmosphere) and subsequent N balances were high for higher biomass pulses such as the faba beans, lupins, and chickpeas. However, this N was not able to be detected to the expected levels with soil testing. It is reasonable to expect that that much of the fixed and remaining N was tied up in organic matter or crop resides.

The site was N responsive, looking at the cumulative yields (wheat 2022 and 2023) following non-pulse crops or a fallow in 2021 the additional of N to the system increased yields in the range of 0.7 to 1.4 t/ha. Wheat proteins in both years were also very low suggesting yield was N limited. Yet the crop response to the theoretical N additions from the pulses was not reflective of the amount of N fix and remaining in the system by the pulse crops. The residual effect of the pulses on subsequent wheat yields was only similar to the response to the application of nitrogen fertiliser.

There was a noticeable yield improvement from the fallow treatment, reflecting soil tests that showed higher availability of mineralised N. It may have also had more stored soil water, though remembering that these were very wet years, and it is possible that saturation occurred in the fallow periods between crops (close to the annual rainfall ~500 mm fell in the 2021/22 fallow).

Pulses such as albus lupins and lentils performed very poorly in the winter of 2021 due to waterlogging and/or disease, parts of some plots were completely dead. However still had residual soil nitrogen levels (and subsequent wheat yields) not dissimilar to those following faba beans which had very high biomass and high calculated fixed N and N balance. It is possible that there was more mineralisation in these treatments (not completely dissimilar to the fallow treatments).

When looking at the 2-year cumulative wheat yields there was a legacy yield benefit from the pulses that improved yields when compared to the where no nitrogen was applied to conventional crops, however the improvement was not necessarily better than where N fertiliser was applied. Increases to the cumulative yields was also largely driven by response in the first year following the pulse break crops with larger differences, and yield responses in the second year quite small. The low protein levels in both years may suggest that the N demand for yield was not met apart from the high N fallow treatment in 2022, which had 11% protein and the highest yield that year (4.3 t/ha). Suggesting that N demand may not be reached even when growing high biomass pulses without further addition of N fertilisers.

The results of PredictaB testing confirm that pulses can play an important role is crop disease management. Faba beans reduced the levels of crown rot in the soil to almost below detection levels.

The effects on soil moisture where harder to ascertain and likely mitigated by the relatively wet conditions experienced during this series of trials.

Conclusions

The legacy nitrogen following a pulse crop improved yields in 2 subsequent wheat crops, however this improvement was not necessarily better than the use of fertiliser or a non-pulse crop sequence.

Soil testing prior to sowing gave a better indication of the available N than calculated N balances. Crop performance also better matched the N levels detected with soil testing than theoretical calculations of N balance. This does leave the question of how to unlock or access the fixed N by pulse crops. If this could be better achieved it would clearly improve the value of pulses in the cropping systems promote their wider adoption.

Acknowledgements

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