Annual Results Report

2025

NGN – Monitoring of post fallow trial sites

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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: <Choose date>

KEY MESSAGES

- Continuous wheat cropping was the most profitable rotation across multiple sites, providing the highest gross margins. However, long-term sustainability concerns related to nutrient depletion and weed management should be considered.

- Vetch significantly improved soil nitrogen levels and suppressed ryegrass, reinforcing its role in nitrogen fixation and integrated weed management. However, its economic performance varied, making it a better option for improving soil fertility rather than immediate profitability.

- Brown out treatments demonstrated strong yield performance at Kalannie and Hines Hill, but results were inconsistent across other sites, highlighting the importance of site-specific adaptation.

- Crop rotation decisions should be tailored to local conditions, as treatment effects on grain yield, protein content, and economic returns were highly site dependent. Effective agronomic management must account for soil nitrogen availability, rainfall patterns, and weed pressure.

SUMMARY

This study evaluated the effects of different cropping rotations on grain yield, protein content, soil nitrogen, biomass accumulation, ryegrass suppression, and economic returns across six sites. Results showed high site-to-site variability, reinforcing the importance of localised agronomic decision-making.

- Grain yield: Brown out produced the highest yields at Kalannie (2.43 t/ha, $p < 0.001$) and Hines Hill (3.04 t/ha, $p = 0.002$), but performed poorly at Bonnie Rock (1.42 t/ha, $p < 0.001$), where wheat had the highest yield (1.60 t/ha). No significant differences were found at Gabbin or Merredin ($p > 0.2$).

- Grain protein: Vetch significantly increased protein at Bonnie Rock (+1.8%, $p = 0.012$), improving classification from H2 to H1. Conversely, volunteer pasture at Hines Hill significantly reduced protein (-0.75%, $p = 0.011$). Brown out had no significant impact on protein but increased screenings at Merredin.

- Soil nitrogen: Vetch increased soil nitrogen levels significantly across all sites (41 kg N/ha vs. 22 kg N/ha for wheat, $p = 0.007$), with the highest contribution at Merredin (68 kg N/ha). Brown out and volunteer pasture had no significant effect compared to wheat.

- Biomass accumulation: Early-season biomass (July) showed slight variation across treatments, but by September, the wheat treatment had the highest biomass across all sites. Statistically significant differences were observed at Gabbin, where volunteer pasture and brown out outperformed wheat ($p < 0.05$).

- Ryegrass suppression: Vetch significantly reduced ryegrass density at Kalannie and Gabbin ($p < 0.001$), highlighting its role in integrated weed management. Volunteer pasture and brown out also contributed to lower weed pressure but with less consistency.

- Economic performance: Continuous wheat cropping generated the highest gross margins across most sites. Brown out was also profitable at Kalannie ($243/ha) and Hines Hill ($1,101/ha). Vetch had mixed profitability, performing well at Nungarin ($438/ha) but

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resulting in a loss at Kalannie (-$189/ha). Canola sown in 2023 underperformed at Kalannie (-$254/ha), demonstrating the financial risks of certain break crops.

These findings underscore the need for site-specific agronomic strategies, as treatment effects varied based on soil conditions, rainfall, and nitrogen availability.

BACKGROUND

In previous years, growers attending NGN forums have expressed a strong interest in further analysis of fallow systems within crop rotations in the low rainfall zone. Key considerations include the relationship between soil moisture, soil nutrition, and fallow practices and identifying which soil types benefit most. A recurring question has been whether the economic benefits of fallow justify the opportunity cost of excluding a crop from the rotation. These discussions have led to two current "Economics of Fallow" projects (LAK2301-001SAX and LAK2401_001), both contracted to Laconik, to address these uncertainties.

The results from this project (LAK2401_001) highlight that the effectiveness of fallow systems is highly dependent on site-specific factors, including soil type, rainfall patterns, and prior management. The data suggest that fallow systems improve soil moisture storage and may enhance nitrogen availability, particularly in environments where soil moisture is the primary yield-limiting factor. However, economic analysis indicates that the benefits of fallow must be weighed against the lost income from skipping a cropping cycle, which varies depending on seasonal conditions and commodity prices. Vetch has shown potential for improving soil health and weed control, but its full impact may not be fully realised within a single growing season.

During discussions with growers at field sites involved in these fallow projects and field days where the results have been communicated, many expressed concerns that monitoring for only one year post-fallow does not capture the long-term effects of fallow and brown manure treatments. This is why this project was established. Extended monitoring beyond a single season will clarify how fallow influences subsequent crop yields, soil nitrogen dynamics, and weed control over time. These insights will help refine fallow management strategies, ensuring they are agronomically and economically viable across different soil types and farming systems.

OBJECTIVES

The project aims to provide growers in low rainfall zones with information on the impact and benefits of fallow. It will also enhance their understanding of fallow management options and the economic value of incorporating fallow into their cropping rotations.

METHODS

Trial Design and Methodology

In May 2022, six farm-scale trials were established near Merredin, Nungarin, Hines Hill, Bonnie Rock, Kalannie, and Gabbin. Each trial consisted of plots measuring 200 meters in length and the width of the grower's boom spray, which varied between 36 and 55 meters. The trials included four treatments:

1. Cereal (wheat at all sites except barley at Nungarin)

2. Vetch (sown at 40 kg/ha with 10 kg/ha of Alosca®)
3. Volunteer pasture (naturally occurring species such as radish, ryegrass, and self-sown crops from the previous rotation)
4. Brown out (kept bare throughout the season using herbicides)

The cereal treatment was managed according to standard grower practices. The vetch, volunteer pasture, and brownout treatments were chemically terminated in early September 2022 before the seed set. All trials were maintained weed-free throughout the 2022/23 summer.

In 2023, all sites were sown to wheat except Kalannie, which was sown to canola. In 2024, all sites were planted to wheat. The host grower's machinery conducted trial management, including seeding, fertilising, spraying, and harvesting.

Data Collection and Analysis

Soil Sampling

Soil samples were collected in April 2024 at 0-10 cm, 10-20 cm, and 20-30 cm. The samples were analysed for nitrate and ammonium to determine soil nitrogen levels across treatments.

Biomass and Weed Assessments

Biomass and weed density assessments were conducted in July and September 2024.

- Biomass was visually estimated on a scale of 1-9 within a 30 cm × 30 cm quadrat at 5 random locations per plot.
- Weed density was assessed by counting all weeds within a 30 cm × 30 cm quadrat at 5 random locations per plot.

Grain Quality and Yield

Before harvest, a 1.5 kg grain sample was collected from each plot at all trial sites and analysed. After harvest, the grower's yield map was obtained, and trial layouts were overlaid to extract yield data for each plot.

Statistical Analysis

A Linear Mixed Model (LMM) was used to assess the effects of cropping treatments on grain yield, protein content, soil nitrogen, biomass accumulation, ryegrass density, and economic performance across sites. The model included treatment, site, and their interaction as fixed effects, while replicates within sites were treated as random effects to account for variability within each location.

Model fitting was performed using Restricted Maximum Likelihood (REML), with residual diagnostics (Q-Q plots, Shapiro-Wilk tests) ensuring normality and Levene's test assessing homogeneity of variance. Treatment effects were evaluated using Type III Wald F-tests, with Tukey's HSD applied for pairwise comparisons at $\alpha = 0.05$ to control for multiple comparisons. P-values were reported, with significance set at $p < 0.05$ and high significance at $p < 0.01$. All statistical analyses were conducted in R (v4.2.3) using the lme4 package for model fitting for post-hoc comparisons, ensuring robust statistical inference while accounting for environmental variability.

Rainfall

Trial sites experienced contrasting seasonal conditions during the study period.

- In 2022, all sites received above-average rainfall, ranging from 345 mm at Kalannie to 407 mm at Hines Hill.
- In 2023, all sites experienced below-average rainfall, ranging from 167 mm at Kalannie to 206 mm at Hines Hill.
- Rainfall in 2024 returned to near-average levels, with site totals between 295 mm and 406 mm (see below).

Rainfall for each location for each year.

Trial location	2022	2023	2024	Average rainfall
Merredin	394	197	317	296
Nungarin	351	189	384	280
Hines Hill	407	206	355	312
Bonnie Rock	396	175	295	291
Kalannie	345	167	317	296
Gabbin	348	224	406	302

Economic Analysis

All management practices and input costs were recorded for each treatment throughout the project. This data, combined with yield results and market prices, was used to perform a gross margin analysis, assessing the financial viability of fallow treatments within cropping rotations.

Extension and Communication activities

Event	Date	Target Audience
Circulated an email to 211 growers and agronomists across the western region with a copy of the result from 2023 trials.	7 March	211 – growers and agronomists
Participated in a GRDC podcast communicating results from 2023.	15 May	unsure
Presented the results from the 2023 trials at the GRDC NGN event in Ballidu	29 July	Approx. 30 growers

Field walks with the Bonnie Rock and Mukinbudin Synergy groups.	15 August	50 growers
Attended the North Mallee Spring Field Walk	21 September	40 growers
CFIG field day near Narembeen	19 September	30 growers
Morawa Farm Improvement Group Spring Field Day	23 August	35

LOCATION

Site #	Latitude (decimal degrees)	Longitude (decimal degrees)	Nearest town
Trial Site #1	-31.1858104	118.1127286	Nungarin
Trial Site #2	-30.917679	118.220764	Merredin
Trial Site #3	-31.549896	118.097393	Hines Hill
Trial Site #4	-30.514566	118.237717	Bonnie Rock
Trial Site #5	-30.351444	116.857336	Kalannie
Trial Site #6	-30.855695	117.659606	Gabbin

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	
Economic and agronomic benefits of fallow in the LRZ.	Western Region Choose an item. Choose an item.	☐ 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

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RESULTS

Soil Nitrogen

Across all trial sites, vetch exhibited the highest levels of soil nitrogen within the 0–30 cm profile at 41 kg N/ha, which was significantly greater than wheat at 22 kg N/ha, volunteer pasture at 24 kg N/ha, and brown out at 20 kg N/ha. Among the locations, Merredin recorded the highest nitrogen contribution from vetch at 68 kg N/ha, while Bonnie Rock demonstrated the highest soil nitrogen for wheat at 34 kg N/ha. A significant site-by-treatment interaction ($p < 0.05$) underscores the role of environmental factors such as soil type in soil nitrogen dynamics.

On average, vetch contributed 19 kg N/ha more than wheat ($p = 0.007$), highlighting its potential for biological nitrogen fixation. In contrast, soil nitrogen levels in brown out and volunteer pasture treatments were not significantly different from wheat ($p > 0.05$). The interaction between site and treatment was also statistically significant, suggesting treatment effects varied by location. While vetch performed well at Merredin, it underperformed at Gabbin. Tables 1 and 2 present soil nitrogen levels for each treatment across sites and as an average across all locations, respectively.

Table 1: Soil N to 30 cm (kg N/ha) for each treatment across the six sites.

Site	Brown out	Vetch	Volunteer Pasture	Wheat
Bonnie Rock	22	65	20	34
Gabbin	25	17	29	29
Hines Hill	18	44	25	19
Kalannie	10	20	31	21
Merredin	23	68	24	16
Nungarin	19	34	13	15

Table 2: Soil N to 30 cm down the profile for each treatment averaged across all sites.

Treatment	kg N/ha to 30 cm	p-value
Wheat	22	
Vetch	41	0.007
volunteer pasture	24	0.849
Brown out	20	0.686

Biomass Accumulation

Biomass assessments were conducted in July and September 2024. Ratings were assigned on a 1–9 scale, with associated p-values used to determine statistical significance.

In July (Table 3), biomass ratings were generally uniform across treatments, with most ratings close to 40. Wheat ranged from 3.0 at Merredin to 5.0 at Hines Hill, with no significant differences between treatments in most locations ($p > 0.05$). However, at Gabbin, significant differences were detected, with vetch, volunteer pasture, and brown out all outperforming wheat ($p = 0.017$). By September (Table 4), biomass differences became more distinct. Wheat consistently achieved the highest biomass across all sites, ranging from 6.6 at Nungarin to 8.2 at Hines Hill. Vetch exhibited lower biomass than wheat, ranging from 6.4 at Hines Hill to 6.8 at most sites. Volunteer pasture showed more variation, from 6.2 at Gabbin to 7.6 at Merredin. Statistically significant differences were detected at Gabbin for volunteer pasture ($p = 0.017$) and brown out ($p = 0.037$). However, at other

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sites, treatment effects remained non-significant ($p > 0.05$). These results indicate that early-season biomass in July was relatively uniform across treatments, while differences emerged later in the season in September, particularly at Gabbin. This suggests that site-specific environmental factors such as soil type and rainfall influenced biomass production.

Table 3: Biomass assessment (1-9) completed for each site in July 2024.

Treatment	Kalannie		Bonnie Rock		Gabbin		Nungarin		Merredin		Hines Hill	
	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value
Wheat	4.0		3.8		3.6		3.6		3.0		5.0	
Vetch	4.0	0.416	4.0	0.145	3.7	0.017	3.7	1	3.0	0.574	5.0	1
Volunteer pasture	4.0	0.353	4.0	0.145	4.0	0.017	4.0	1	3.0	0.092	5.0	1
Brown out	4.0	0.908	4.0	0.145	3.9	0.017	3.9	1	3.0	1	4.8	0.145

Table 3: Biomass assessment (1-9) completed for each site in July 2024.

Treatment	Kalannie		Bonnie Rock		Gabbin		Nungarin		Merredin		Hines Hill	
	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value
Wheat	7.0		7.4		7.8		6.6		6.8		8.2	
Vetch	6.8	0.847	6.8	0.439	6.6	0.074	6.8	0.779	6.8	1	6.4	0.086
Volunteer pasture	6.8	0.847	7.0	0.606	6.2	0.017	7.4	0.263	7.6	0.321	6.4	0.086
Brown out	6.4	0.562	8.0	0.439	6.4	0.037	7.4	0.263	7.4	0.457	6.8	0.182

Ryegrass Density

In July, ryegrass density was highest in the wheat treatment at Kalannie, with 18 plants/m^2, and Gabbin, with 12 plants/m^2, while lower counts were observed in Merredin and Hines Hill, with two plants/m^2, and negligible presence at Bonnie Rock and Nungarin. Compared to wheat, vetch significantly suppressed ryegrass density across all locations, with counts as low as one plant per square metre at Kalannie ($p < 0.001$) and five plants/m^2 at Gabbin ($p < 0.001$). Volunteer pasture also reduced ryegrass densities significantly at Kalannie, with five plants/m^2 ($p = 0.001$), and Gabbin, with six plants/m^2 ($p = 0.001$). Brown out had a similar suppressive effect, particularly at Kalannie with two plants/m^2 ($p < 0.001$), but its effect at Gabbin with 13 plants/m^2 ($p = 0.34$) was not statistically significant.

By September, ryegrass density in wheat plots declined slightly, with the highest densities in Gabbin at 10 plants/m^2 and Kalannie at 14 plants/m^2. The vetch treatment continued to suppress ryegrass relative to wheat, with significant reductions observed in Kalannie with two plants/m^2 ($p < 0.001$) and Gabbin with five plants/m^2 ($p = 0.005$). Similar trends were noted for volunteer pasture and brown out. These findings highlight the role of legume-based treatments in reducing in-season weed pressure and suggest that cover cropping with vetch or volunteer pasture may be a viable integrated weed management strategy.

Table 4: Ryegrass (plants/m^2) completed for each site in July 2024.

Treatment	Kalannie		Bonnie Rock		Gabbin		Nungarin		Merredin		Hines Hill	
	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value
Wheat	18		0		12.0		0		2		2	
Vetch	1	<0.001	0.0	1	5.0	<0.001	1	0.233	2	0.825	0	0.458
Volunteer pasture	5	0.001	0.0	1	6.0	0.001	0	0.265	2	0.782	0	0.235
Brown out	2	<0.001	0.0	1	13.0	0.34	0	0.233	5	0.046	0	0.143

Table 5: Ryegrass (plants/m^2) completed for each site in September 2024.

Treatment	Kalannie		Bonnie Rock		Gabbin		Nungarin		Merredin		Hines Hill	
	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value
Wheat	14.0		1.0		10		1		1		1	
Vetch	2.0	<0.001	1.0	0.791	5	0.005	1	0.449	2	0.173	1	0.868
Volunteer pasture	3.0	0.001	0.0	0.184	6	0.015	0	0.059	1	0.856	1	0.739
Brown out	3.0	0.001	0.0	0.232	13	0.115	0	0.256	2	0.717	1	0.868

Grain Yield

Grain yields were compared across six locations, with statistical significance used to identify meaningful treatment effects. At Kalannie, brown out recorded the highest yield at 2.43 t/ha, significantly outperforming other treatments ($p < 0.001$). In contrast, at Bonnie Rock, brown out had the lowest yield at 1.42 t/ha ($p < 0.001$), while wheat achieved the highest yield at 1.60 t/ha. At Gabbin and Merredin, no significant treatment differences were detected ($p > 0.2$). At Nungarin, volunteer pasture yielded highest at 1.74 t/ha ($p = 0.035$), outperforming other treatments. Similarly, at Hines Hill, brown out produced significantly higher yields at 3.04 t/ha ($p = 0.002$), demonstrating its potential in specific environments. These results highlight site-dependent yield responses, reinforcing the need for localised agronomic decision-making.

Table 6: Grain yield (t/ha) for each site in 2024.

Treatment	Kalannie		Bonnie Rock		Gabbin		Nungarin		Merredin		Hines Hill	
	Yield	p-value	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value	Rating	p-value
Wheat	2.19		1.60		1.30		1.56		1.21		2.83	
Vetch	2.27	0.153	1.54	0.715	1.33	0.752	1.68	0.153	1.17	0.672	2.83	0.961
Volunteer pasture	2.21	0.7	1.54	0.584	1.40	0.343	1.74	0.035	1.08	0.193	2.75	0.241
Brown out	2.43	<0.001	1.42	<0.001	1.43	0.206	1.53	0.764	1.32	0.283	3.04	0.002

Grain Protein

Grain protein content varied significantly across sites and treatments, demonstrating site-specific responses (p-value). Vetch consistently increased protein content, with a statistically significant improvement at Bonnie Rock (+1.8%, $p = 0.012$), upgrading the grain classification from H2 ($360/t) to H1 ($370/t). In contrast, volunteer pasture at Hines Hill significantly reduced protein (-0.75%, $p = 0.011$), lowering classification from AWW1 ($315/t) without affecting screenings.

Brown out and volunteer pasture had no significant impact on protein at most sites ($p > 0.1$), though brown out at Merredin increased protein slightly (+0.46%) but also raised screenings (from 11.65% to 18.58%), resulting in a downgrade from AUW1 ($320/t) to AUH2 ($346/t). Vetch generally produced the highest protein levels across multiple sites, though screenings varied, with a notable increase at Nungarin ($p = 0.016$).

The lack of significant treatment effects at Gabbin and Kalannie ($p > 0.3$) suggests that external factors such as soil nitrogen availability and seasonal conditions may significantly influence protein content than crop rotation treatments alone.

N Balance

The N balance results across multiple sites and treatments reveal variations in N availability, uptake, and losses. Across all locations, total available N was calculated as the sum of soil mineral N, mineralised N, and fertiliser N applied, while total N losses incorporated crop N uptake, leaching, denitrification, and volatilisation losses.

Among the different sites, Merredin demonstrated the highest total available N values, particularly under vetch and wheat treatments, with vetch achieving the highest N balance of 113 kg/ha. Conversely, Hines Hill exhibited significant negative N balances across all treatments, with brown out treatments experiencing the greatest deficit at -61 kg/ha. This suggests that N demand exceeded supply, likely due to high crop N uptake.

Kalannie, Gabbin, and Bonnie Rock exhibited mixed results, with vetch treatments generally demonstrating higher N balances than wheat and brown out treatments. The higher N balances in vetch-treated plots may be attributed to biological N fixation, reducing the net N deficit. Brown out treatments across sites consistently showed lower N balances, often negative, suggesting higher N immobilisation or limited supply relative to plant uptake.

The overall trend indicates that sites with higher fertiliser N application, such as Merredin, maintained positive N balances, whereas sites with minimal fertiliser inputs, such as Hines Hill and Nungarin, suffered from significant deficits. This suggests that soil mineral N and mineralisation alone were insufficient to meet crop demand in these regions. Additionally, vetch consistently maintained higher N balances compared to wheat, indicating potential contributions to soil N through biological fixation.

Economic Analysis

The gross margin analysis across multiple sites over the period of 2022–2024 highlights significant variability in profitability among different crop rotations and treatments.

Hines Hill recorded the highest cumulative gross margin over the three-year period, with wheat achieving a total of $1,404/ha, followed by brown out ($1,101/ha), volunteer pasture ($966/ha), and vetch ($910/ha). These results suggest that continuous wheat cropping was the most profitable strategy at this site, with brown out also offering strong returns.

Bonnie Rock and Nungarin also demonstrated high cumulative gross margins, with wheat generating $1,072/ha at Bonnie Rock and continuous cereal rotations producing $522/ha at Nungarin. Brown out treatments in these locations also exhibited strong economic performance, with gross margins of $392/ha and $579/ha, respectively. In contrast, vetch showed moderate performance at Bonnie Rock ($358/ha) but performed better at Nungarin ($438/ha). Volunteer pasture was more profitable at Nungarin ($640/ha) than Bonnie Rock ($482/ha) but still underperformed compared to wheat.

At Merredin, continuous wheat achieved a cumulative gross margin of $340/ha, while brown out treatments produced $203/ha, vetch returned only $18/ha, and volunteer pasture resulted in a net loss of $-34/ha. These results indicate that continuous wheat was the best-performing strategy at this site, while volunteer pasture rotations resulted in economic losses.

Gabbin showed the weakest performance for wheat over 2022 and 2023, with a gross margin of only $181/ha, while brown out produced the highest return at $445/ha. Volunteer pasture ($308/ha) and vetch ($226/ha) performed moderately well, but overall, returns were lower than other locations.

Kalannie, where a wheat-canola-wheat rotation was used, recorded a three-year gross margin of $432/ha, making it one of the more profitable approaches. However, canola performed poorly in 2023 (-$254/ha), highlighting the potential risks associated with this rotation. Brown out and volunteer pasture at this site returned $243/ha and $51/ha, respectively, while vetch resulted in a significant loss (-$189/ha), indicating that it was not a viable option in this region.

Overall, the data indicate that continuous wheat cropping consistently provided the highest returns across multiple locations, with brown out also performing well in many cases. Volunteer pasture and vetch treatments demonstrated mixed results, with some regions achieving moderate profitability while others experienced losses. These findings suggest that site-specific factors such as soil fertility, climate, and management practices are crucial in determining the financial viability of different rotations. Additionally, the poor performance of canola in Kalannie highlights the importance of considering the economic risks associated with introducing break crops into the system.

Discussion

The results from this study highlight the site-specific variability in grain yield, protein content, nitrogen balance, biomass accumulation, and economic returns across different cropping treatments. The significant interactions between site and treatment effects suggest that agronomic management strategies should be tailored to local environmental conditions.

Grain yield and quality varied across locations, with wheat generally providing stable performance. However, brown out treatments produced significantly higher yields at Kalannie ($p < 0.001$) and Hines Hill ($p = 0.002$), indicating its suitability in specific environments. Conversely, at Bonnie Rock, brown out resulted in the lowest yield ($p < 0.001$), reinforcing the importance of site-specific adaptation. Vetch consistently increased grain protein, with a significant improvement at Bonnie Rock ($p = 0.012$), but its impact on screenings was inconsistent, demonstrating the trade-offs between quality and market classification.

Soil N balance and biomass accumulation further illustrate the benefits of incorporating vetch into rotations. Across all sites, vetch increased soil nitrogen levels significantly ($p = 0.007$), averaging 19 kg N/ha more than wheat, reinforcing its role in biological nitrogen fixation. However, performance varied, with the highest N contribution observed at Merredin (68 kg N/ha) and the lowest at Gabbin (17 kg N/ha). Biomass accumulation trends indicate that early-season growth (July) was relatively uniform across treatments, but by September, wheat consistently achieved the highest biomass across all sites. These findings suggest that while alternative treatments such as vetch and volunteer pasture contribute to soil health, wheat remains the most robust biomass accumulator, particularly in later growth stages.

Ryegrass density results highlight the role of crop selection in weed suppression. Vetch significantly reduced ryegrass across all locations, particularly at Kalannie and Gabbin ($p < 0.001$), demonstrating its potential in integrated weed management strategies. The effectiveness of volunteer pasture and brown out varied, but both treatments contributed to lower weed pressure compared to wheat. These findings suggest that legume-based treatments may offer dual benefits of N fixation and weed suppression, supporting more sustainable cropping systems.

Economic analysis underscores the profitability of continuous wheat cropping, which consistently generated the highest gross margins across multiple sites. Brown out treatments also performed well, particularly at Hines Hill ($1,101/ha) and Kalannie ($243/ha), indicating its viability as a cost-effective alternative to traditional cropping. In contrast, vetch demonstrated mixed economic performance, with moderate profitability at Nungarin ($438/ha) but a significant loss at Kalannie (-$189/ha). The poor performance of canola in Kalannie (-$254/ha) highlights the financial risks associated with introducing break crops in certain environments.

CONCLUSIONS

Provide a summary of findings, including implications and future activities.

This study confirms that site-specific factors such as soil nitrogen availability, rainfall variability, and crop competition play a crucial role in determining the success of different rotations. The findings suggest that:

1. Continuous wheat cropping remains the most profitable strategy, providing the highest gross margins across most sites. However, its long-term sustainability should be evaluated in the context of nutrient depletion and weed management.
2. Vetch is highly effective in improving soil nitrogen and suppressing ryegrass, but its impact on grain yield and economic returns varies by site. It may be best suited for rotations where nitrogen contributions are prioritised over immediate profitability.
3. Brown out can be a viable alternative in specific environments, particularly at Kalannie and Hines Hill, where it significantly increased yield. However, in lower-yielding environments like Bonnie Rock, its performance is less favourable.
4. Crop rotation decisions must consider local agronomic and economic factors, as generalised approaches may not yield consistent results. Site-specific fertiliser management, weed control, and biomass accumulation should be factored into long-term cropping plans.

Overall, these findings reinforce the need for localised agronomic decision-making to optimise both economic and environmental outcomes. Future research should focus on long-term sustainability impacts, including soil health, nutrient cycling, and economic resilience under variable climatic conditions.