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CASE STUDY | SEPTEMBER 2024

Optimising nitrogen

Legume cover crops to optimise nitrogen supply to sweet corn

Background

The Mulgowie Farming Company, a family-owned producer, grows conventional and organic sweet corn and green beans across Australia. Known for its strong focus on innovation and sustainable farming practices, Mulgowie teamed up with Soil Wealth ICP to examine the potential of legumes to effectively supply nitrogen to a sweet corn crop.

Prior to the trial, the crop rotation history of the paddock included beans (2022), wheat (2022), sweet corn (2022-2023), faba beans (2023), and sweet corn (2023-2024). Typically, the region experiences an average annual rainfall of 830mm, predominantly in the summer months. During the trial period from June 2023 to February 2024, the site received 615 mm of rainfall, with 385 mm occurring during the corn season (December 2023-February 2024).

High Johnson grass weed pressure from September to February impacted the trial results, adding an additional layer of complexity to the assessment of the legume cover crop's effectiveness and the timing of nitrogen release.

SITE AT A GLANCE

- **Owners:** Mulgowie Farming Company
- **Location:** Mulgowie, Lockyer Valley, Queensland
- **Trial site:** 16-hectare paddock
- **Soil type:** Black clay cracking soils
- **Irrigation:** Pivot

Hort Innovation

This project has been funded by Hort Innovation using the vegetable and melon research and development levies and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

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KEY RESULTS

- **Cover crop timing of termination:**
  - » Two thirds of nitrogen was removed with harvest of the faba bean grain. Quality of residues was lower at harvest, which led to immobilisation of nitrogen.
  - » Highest quality residues (low C:N) occurred when terminated at flowering.
- **Method of cover crop termination:**
  - » Green vs spray – nitrogen release was quicker via green incorporation than spraying and leaving residues on the surface.
  - » Risks – release too early and it can get lost from the system; release too late and it can penalise crop growth and yield.

TO CONSIDER

- **Measure to manage and choice of cover crop:**
  - » Where possible, measure nitrogen in soil before planting cover crop. High nitrogen may not equate to much nitrogen fixation from a legume. If there is high N in the soil, consider growing a non-legume to mop up nitrogen for later release.
- **In the nutrient budget, consider:**
  - » How much soil available nitrogen is there?
  - » How much nitrogen is being added through legume?
  - » How much nitrogen is being removed at harvest of crops?
  - » What is left over after harvest of a crop and will be cycled into the next rotation?

The trial

The primary objective of this trial was to assess whether a legume cover crop could supply nitrogen to a sweet corn crop.

Differing experimental plots were set up to test which cover crop termination strategies would most effectively release nitrogen to align with the nitrogen demands of the crop.

The soil was prepared by deep ripping twice, followed by broadcast application of a chicken manure-based compost applied at a rate of 6m^3/ha. In preparation for planting of the faba bean cover crop, the seed was inoculated with rhizobia bacteria, then broadcast sown at 200 kg/ha in June 2023, followed by one pass with a speed disc to encourage germination.

Figure 1: Faba bean crop at flowering (August 24, 2023)

Cover crop treatments

The trial area of 1.1 hectares included three different cover crop treatments plus one control. The treatments included (Figure 2):

1. **Green:** Faba bean crop **terminated green at flowering by incorporation** (using a rotary hoe); August 2023
2. **Spray:** Faba bean crop **terminated at flowering by spraying with herbicide** (using Glyphosate and Carfentrazone-Ethyl) and rolling, leaving the residue brown on the soil surface; August 2023
3. **Harvest:** Faba bean crop **grown to maturity and harvested for grain** with stubble left on the soil surface; October 2023
4. **Fallow:** with no faba bean crop (control)

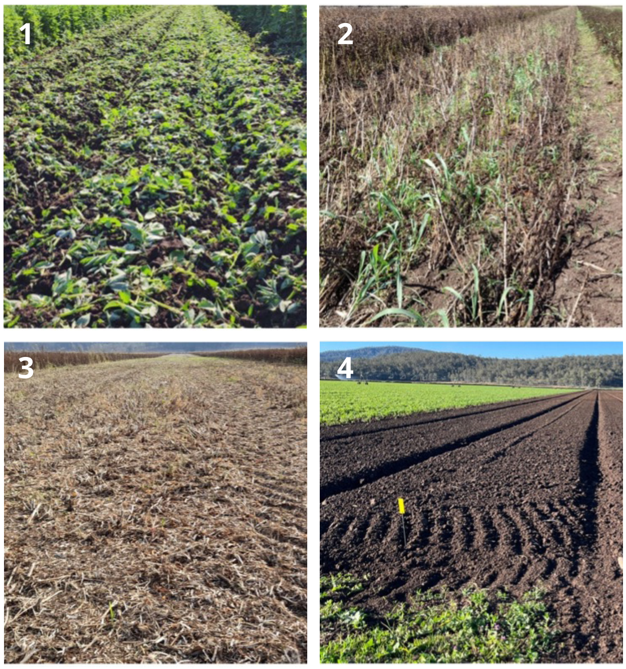

Figure 2: Faba bean termination methods:
1. Termination green by incorporation (August 2023); 2. Termination by spraying with herbicide and rolling (September 2023); 3. Grown to maturity and harvested for grain (October 2023); 4. Fallow (July 2023).

Fertiliser treatment

At sowing of the sweet corn crop (via direct drilling) in December 2023, the trial area was split in half:

- Half of the treatment area **received base fertiliser** (300 kg/ha containing 10.5% nitrogen)
- Half of the treatment area **received no base fertiliser**

Leaving half of the trial area without base fertiliser facilitated an investigation into whether the cover crop alone could supply sufficient nitrogen to the corn crop.

In January 2024, the whole trial area was side dressed at 300 kg/ha, containing 20% nitrogen. The sweet corn crop was commercially harvested in February 2024.

Data collection

Soil nutrients

Soil was sampled in each of the treatment areas to monitor the influence of termination methods on plant-available nitrogen and other parameters.

- Monthly soil testing
  - » Soil collected at 0-30cm from July 2023 to February 2024 (in both the faba bean and sweet corn crops) and tested for available nitrogen
  - » Other nutrients and soil properties (full nutrient analysis (including organic matter and C:N), bulk density and particle size) were also assessed

Other soil parameters

- Soil temperature was measured every three hours at a depth of 10cm, using two thermo button temperature loggers in each treatment area installed between July 2023 and February 2024
- Soil moisture was measured every 30 minutes at depths of 0-15 and 15-30cm, using two single point Wildeye moisture probes, installed between July 2023 and Feb 2024

Soil temperature and soil moisture were monitored to assess the effects of the different treatments on these soil parameters, and subsequently, the potential influence it had on nutrient cycling.

Climate

- Rainfall was collected daily using a rain gauge at the site and was also monitored via Bureau of Meteorology data from nearby weather stations

Plant tissue and biomass

Plant biomass and N% was collected to understand nitrogen cycling and to collect data for preparation of a nitrogen budget, as follows:

- At flowering and harvest of faba bean: tissue testing of above ground biomass for C% and N%
- At flowering and harvest of faba bean: above ground biomass for calculation of t/ha (grain measured separately at harvest)
- At V4 of sweet corn: tissue testing of 5th leaf from tip for full nutrient analysis
- One week prior to sweet corn harvest, testing included:
  - Corn ear leaf for full nutrient analysis
  - Corn above ground biomass (excluding cobs) for N%
  - Corn above ground biomass (excluding cobs) for t/ha
  - Corn cobs for N%
  - Corn cob pre-harvest assessment of quality and yield
  - Johnson grass above ground biomass for t/ha

Steph Tabone from the SWICP team visually assessing the corn cobs

The results and what they mean

How did faba beans contribute to overall nitrogen?

As management of nitrogen can significantly impact crop yield and soil health, one aim of this trial was to understand how much impact faba beans had on available nitrogen levels in the soil before, during, and after the faba bean crop. Nitrogen derived by the legume from atmospheric nitrogen fixation was not measured.

Following compost application (comprising nitrate and ammonia), the available nitrogen in the soil of the fallow treatment (the control) was recorded at 146kg N/ha (Figure 3). On a fallow site, nitrogen can be lost through leaching or denitrification, particularly with heavy rainfall. However, the site experienced no heavy rain between June and November 2023, ensuring the nitrogen remained largely available for subsequent use.

Results from available nitrogen levels in areas with the faba bean crop illustrate the effectiveness of a cover crop to 'mop up excess nitrogen' and store it in their biomass: soil available N was significantly reduced, down to 47 kg N/ha by July.

At the flowering stage, the faba bean crop produced 5t/ha of above-ground biomass (dry matter), containing a total of 242kg N/ha (Figure 4). This included 194kg N/ha in the shoots and 48kg N/ha in the roots, with the shoots exhibiting a carbon to nitrogen (C:N) ratio of 11.4.

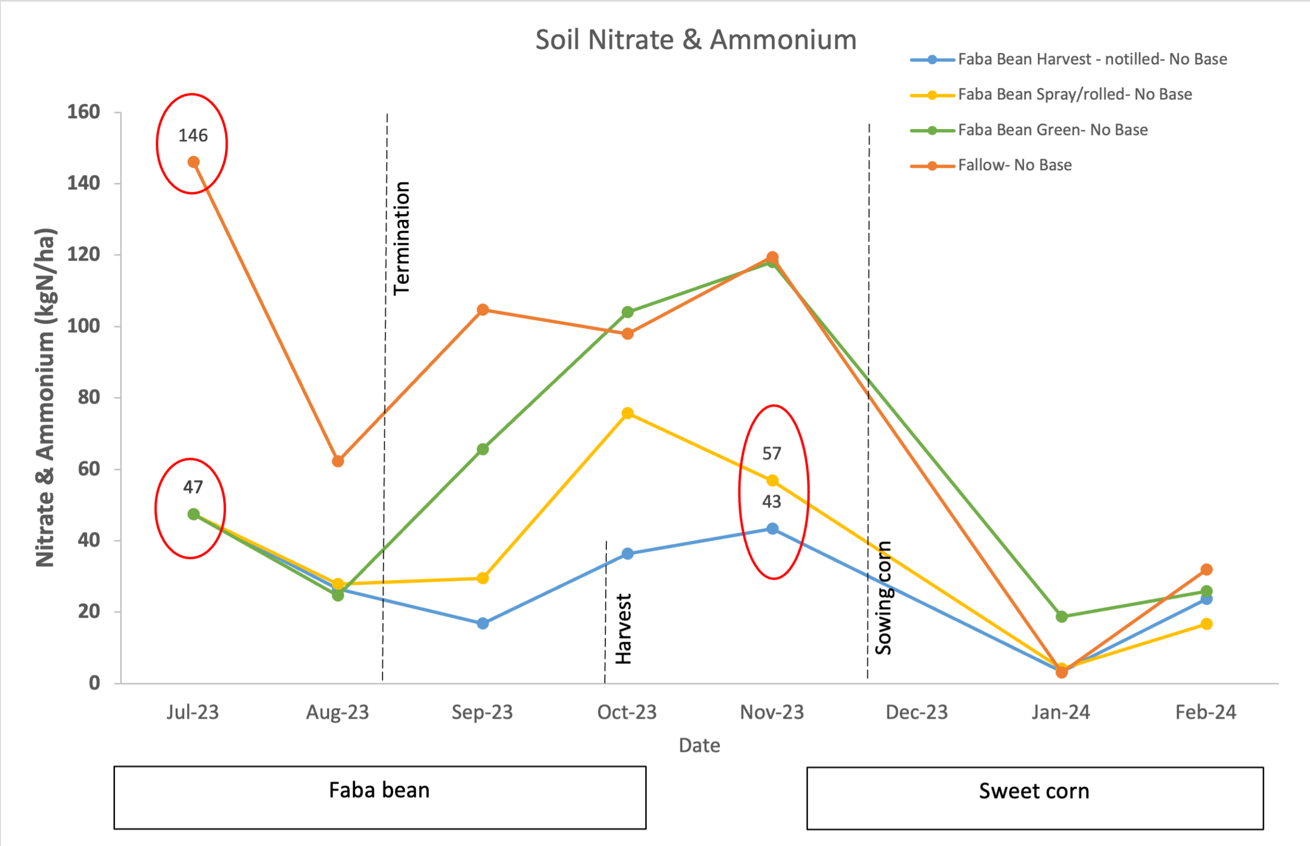

Figure 3: Soil available nitrogen (kg/ha) under different treatments

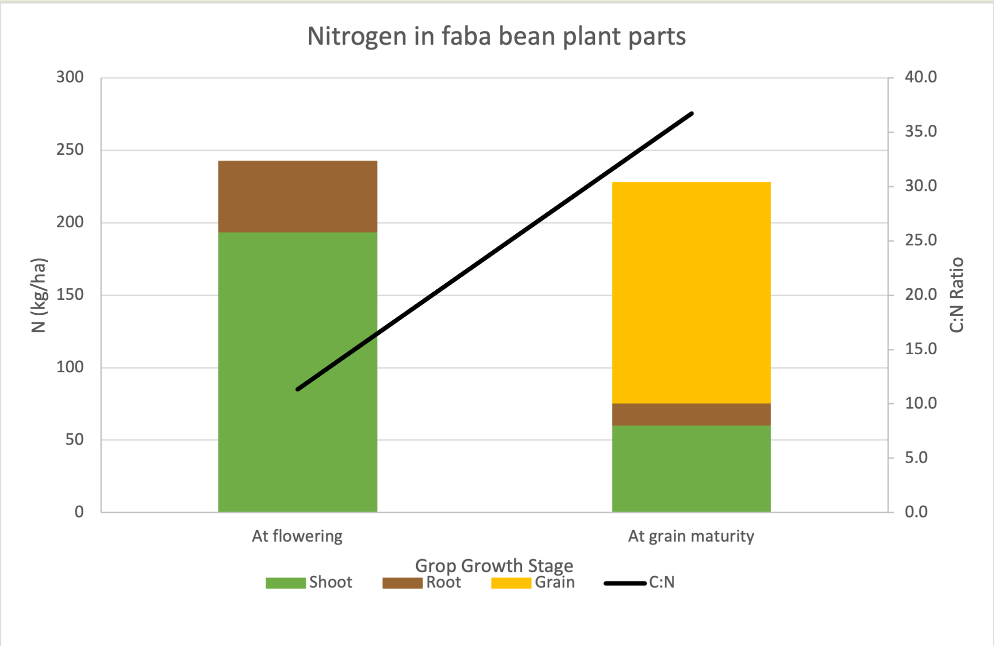

Figure 4: Nitrogen (kg/ha) in different plant parts at flowering and at grain maturity

By harvest, the faba bean crop had increased its above-ground biomass to 5.3t/ha (excluding grain) and yielded 3.5t/ha of grain. The total nitrogen content in the plant was 228kg N/ha, distributed as 60kg N/ha in the shoots, 15kg N/ha in the roots, and a substantial 152kg N/ha in the grain. The C:N ratio of the shoots at harvest was 37.

What is the impact of taking the legume crop through to harvest? Why is it important?

These results show that faba beans absorb nitrogen from the soil, primarily into the shoots, between planting and flowering. As the plant matures, nitrogen is redistributed from the shoots into the grain. Therefore, harvesting the faba bean crop for grain removes two-thirds (152kgN/ha) of the accumulated nitrogen from the system.

Additionally, the C:N ratio increases from 11.4 at flowering to 37 at maturity, altering nitrogen cycling. A lower C:N ratio (11.4) promotes nitrogen mineralisation (release from residues), while a higher C:N ratio (37) causes nitrogen immobilisation (storage). Considering whether to harvest the cover crop or cut it for hay is crucial; harvesting affects residue quality and nutrient cycling and removing products (grain and hay) depletes nutrients. Further it may negatively impact soil physical properties due to the use of heavy machinery.

Did the method of termination of the faba bean crop influence nutrient cycling?

The simple answer is yes.

Soil microbial activity ramped up at the end of August into spring as the soil temperatures rose above 15°C (averages of 17 to 19.5 to 22°C in August, September and October respectively). As the soil microbes aid residue decomposition and nutrient cycling, the rate of nutrient cycling also increases.

As seen in Figure 3, after termination of the faba bean cover crop in August, the **green** incorporated treatment demonstrated a **rapid** release of nitrogen from the residues through September, October and November, while the **spray** terminated treatment released nitrogen at a **slower** rate during the same period.

Cutting up plant residues finely, and incorporating them into the soil encouraged more rapid breakdown of the residues, compared to leaving them intact on the soil surface. Consequently, the speed of nutrient availability was also influenced.

Consideration was also given to the timing of nitrogen demands of the sweet corn crop to assess which termination method of the faba beans could best supply nitrogen to meet the sweet corn's nitrogen demands. Supplying nitrogen too early could risk losses through leaching or denitrification, and supplying nitrogen too late could limit crop development and yield. Literature indicates that nitrogen demand for corn increases rapidly from V6 (6 leaf), with 60% of nitrogen uptake between V6 to R1 (silking) growth stages.

OTHER KEY RESULTS AS SHOWN IN FIGURE 3

- There was a strong uptake of available nitrogen from the soil by the corn after planting in early December.
- The drop in soil available nitrogen in the fallow area in August, and the spray area in November, may be a result of heavy weed pressure.

Corn crop – biomass, yield and nitrogen trends

In late September and October, there was a significant flush of Johnson grass weeds, with a noticeable difference in foliage colour between treatments. The **green** treatment had darker foliage compared to the **spray** treatment. The Johnson grass was sprayed with herbicide in November before planting corn, and the corn crop received a light scuffling in the interrow to manage the weeds. Despite these efforts, Johnson grass pressure remained a problem throughout the crop's growth.

At the tasselling stage of sweet corn, the **green** treatment showed darker and more uniform foliage compared to the **spray** and **harvest** treatments. Due to substantial Johnson grass pressure, data on above-ground biomass of sweet corn was combined with Johnson grass and interpreted as a combined unit (Figure 5). Johnson grass pressure was highest in the spray treatment, followed by the harvest treatment, and lowest in the green treatment, with no pressure in the fallow area. There was a direct correlation between weed pressure and packable yield: increased weed pressure led to a reduction in corn crop size and yield.

Unexpectedly, the total above-ground biomass in areas without base fertiliser was consistently higher than in those with base fertiliser across all termination treatments (Figure 5). The reason for this is unclear.

In the *no base fertiliser* areas, the fallow, green, and harvest treatments returned similar biomass levels, while the spray treatment had significantly more biomass. Late November soil tests showed that the fallow and green areas had significantly more readily available nitrogen (119kg N/ha) just before planting, compared to the spray treatment area (57kg N/ha), potentially giving the crop a growth advantage over the weeds (Figure 3).

It is unclear why the harvest from the *no base fertiliser* area returned similar biomass levels to the green and fallow treatments. However, the

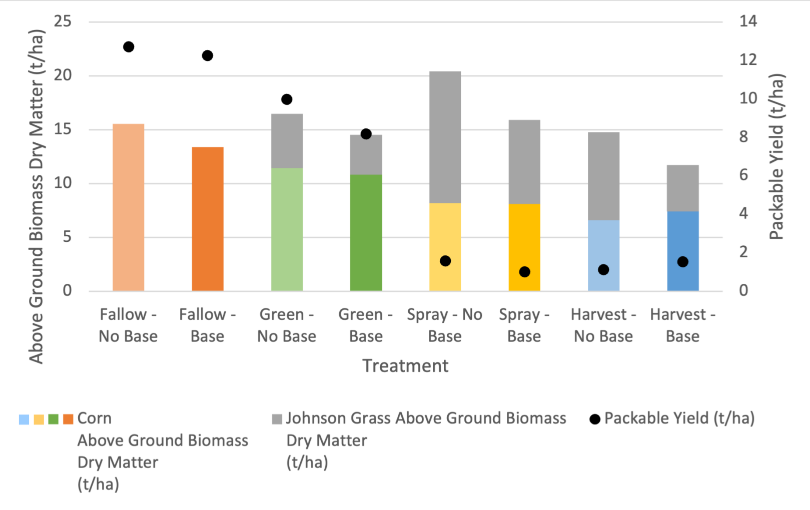

Figure 5: Above ground biomass dry matter of sweet corn and Johnson grass (t/ha, left axis), and packable yield (t/ha, right axis) by treatment, at end of corn crop (Feb 2024)

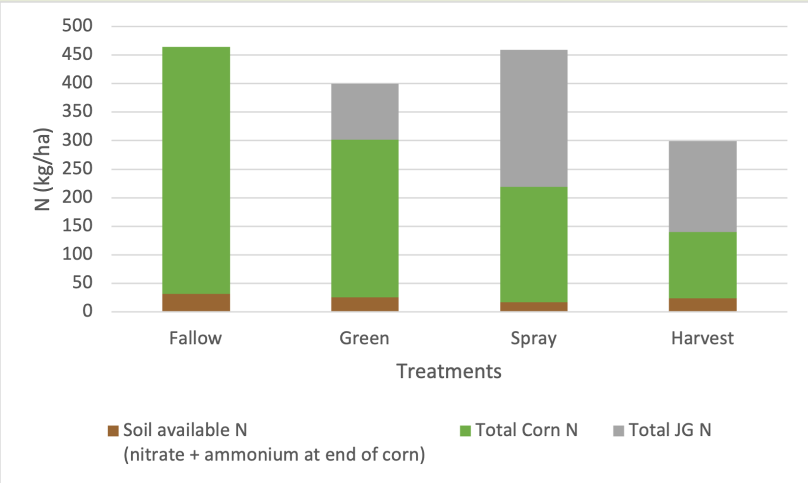

Figure 6: Nitrogen (kg/ha) in soil, and corn and Johnson grass above ground biomass of no base fertiliser areas at end of corn crop (Feb 2024)

harvest *no base fertiliser* area did have lower nitrogen in the above-ground biomass of corn and Johnson grass at the end of the season than the other treatments (Figure 6), likely due to the large amount of nitrogen removed during the faba bean grain harvest.

Nitrogen budgeting

A nitrogen budget can be compared to a financial budget, where the liabilities (nitrogen removed through crop harvest) are subtracted from the assets (soil, crop N) to see how much profit (nitrogen) is remaining. The equity or assets owned (soil organic matter) should also be considered as a safety net as it can be 'liquidated', i.e., mineralised.

Faba bean budget

- The fallow area had a higher level of plant-available nitrogen in the soil (62kg N/ha) compared to the other treatments (25-28kg N/ha), with some taken up by weeds but largely at risk of being lost (Table 1).
- Close to 240kg/ha of nitrogen was added by legume crop (with the estimate that approx. 100kg N/ha was taken up from plant-available nitrogen in the soil, considering the July soil test results)
- 152kg N/ha removed with harvest of faba bean

Table 1: Nitrogen budget for Faba Bean crop.

Note: Soil plant-available N were from samples collected in August before termination. Faba shoots, roots and grain were collected at termination for green & spray treatments, and at harvest for harvest treatment.

Treatment	Fallow	Green	Spray	Harvest
Nitrogen assets	**kg N/ha**			
Soil available N (nitrate-N + ammonium-N in Aug before termination)	62	25	28	26
Faba crop residues - Shoots	0	194	194	60
Faba crop residues - Roots	0	48	48	15
Faba crop residues - Grain	0	0	0	152
Total Nitrogen Assets	62	267	270	254
Nitrogen liabilities	**kg N/ha**			
Crop removal	0	0	0	152
Losses - Denitrification	0	0	0	0
Losses - Leaching	3	1	1	1
Total nitrogen liabilities	3	1	1	153
Net assets	59	266	269	100
Equity	**kg N/ha**			
Annual Nitrogen earnings (SOM mineralised to plant-available N annually to 30cm)	293	265	265	265
Total Retained Nitrogen earnings (SOM Total to 30cm)	5,854	5,291	5,291	5,291

Sweet corn budget

- Relatively low levels of nitrogen remaining in the soil after harvest of corn (17-32kg N/ha) (Table 2)
- Only 5% of nitrogen in the above ground biomass was removed through harvest of corn cobs, with 95% of nitrogen remaining in the paddock in crop residues. The cycling of nutrients from the residues needs to be considered for the next crop planted.
- Nitrogen leaching has been estimated with consideration to the excessive rainfall experienced during the corn crop (384mm).

Table 2: Nitrogen budget for sweet corn crop. Soil and crop data was collected at end of sweet corn crop in Feb 2024.

Treatment	Fallow	Green	Spray	Harvest
Nitrogen assets	kg N/ha			
Soil available N (nitrate + ammonium at end of corn)	32	26	17	24
Corn + JG crop residues - Shoots	353	307	370	225
Corn + JG crop residues - Roots	53	46	55	34
Corn crop residues - Grain	27	21	17	17
Total Nitrogen Assets	465	400	459	300
Nitrogen liabilities	kg N/ha			
Crop removal	27	21	17	17
Losses - Denitrification	0	0	0	0
Losses - Leaching	16	13	8	12
Total Nitrogen Liabilities	43	34	25	29
Net assets	422	367	434	271
Equity	kg N/ha			
Annual Nitrogen earnings (SOM mineralised to plant-available N annually to 30cm)	224	260	260	236
Total Retained Nitrogen earnings (SOM Total to 30cm)	4,475	5,191	5,191	4,710

What can we conclude

Did N availability from legumes match crop demand?

While it is difficult to draw definitive conclusions due to the skewed results from weed pressure, it appeared that nitrogen was more readily available in the green incorporated treatment area. The area where faba beans were terminated by spraying contributed the same amount of nitrogen at termination, yet it became available much more slowly than when it was incorporated green. While the fallow area also showed good results and simplified management, there was a real risk of rapid nitrogen loss with heavy rainfall. Fortunately, the conditions during the trial allowed for nitrogen retention.

Table 3: Summary of key results

	Fallow	Green	Spray	Harvest
Nitrogen added and distribution in plant within faba bean crop	None added	Total 242 kg N/ha added Shoots 194 kg N/ha Roots 48 kg N/ha Grain 0 kg N/ha	Total 242 kg N/ha added Shoots 194 kg N/ha Roots 48 kg N/ha Grain 0 kg N/ha	Total 228 kg N/ha added Shoots 60 kg N/ha Roots 15 kg N/ha Grain 152 kg N/ha
Quality of faba bean residues at termination (C:N)	No residues	Low C:N (11.4)	Low C:N (11.4)	High C:N (37)
Nitrogen removed with harvest of Faba bean crop	None removed	None removed	None removed	152 kg N/ha removed
Speed of nitrogen cycling after faba bean termination	Fast (released from weeds residue)	Fast	Slow	Slow/removed
Nitrogen left in the soil after faba bean crop	119 kg N/ha remaining	118 kg N/ha remaining	57 kg N/ha remaining	43 kg N/ha remaining
Other considerations	No ground cover Risk of soil erosion and nitrogen leaching Reliance on chemistry or cultivation for weed management Ease of operations	Aggressive cultivation, soil structure broken Cultivation helped with weed management	Use of herbicide to terminate cover crop No cultivation, soil structure left intact	Heavy machinery driving on paddocks - impact to soil health Good for cash flow
Corn and Johnson grass above ground biomass	16 t/ha corn 0 t/ha Johnson grass 16 t/ha combined	11 t/ha corn 5 t/ha Johnson grass 16 t/ha combined	8 t/ha corn 12 t/ha Johnson grass 20t/ha combined	7 t/ha corn 8 t/ha Johnson grass 15 t/ha combined
Corn plant N	Total 433 kg N/ha Shoots 353 kg N/ha Roots 53 kg N/ha Grain 27 kg N/ha	Total 276 kg N/ha Shoots 222 kg N/ha Roots 33 kg N/ha Grain 21 kg N/ha	Total 203 kg N/ha Shoots 162 kg N/ha Roots 24 kg N/ha Grain 17 kg N/ha	Total 116 kg N/ha Shoots 86 kg N/ha Roots 13 kg N/ha Grain 17 kg N/ha
Packable cobs and packable yield	45,333 cobs/ha 13 t/ha	39,822 cobs/ha 10 t/ha	8,511 cobs/ha 2 t/ha	5,867 cobs/ha 1 t/ha
Plant available nitrogen remaining in soil at harvest	32 kg N/ha	26 kg N/ha	17 kg N/ha	24 kg N/ha

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Looking ahead to future trials

- Prioritising a site without weed challenges.
- The trial needs to be repeated and replicated over several seasons, as weed pressure significantly skewed the results of this trial.
- Tracking both nitrogen fixation and nitrogen uptake will clarify how much nitrogen the faba beans fixed themselves. This trial demonstrated how much nitrogen could be stored by absorbing plant-available nitrogen from the soil and redistributing it into plant tissues.
- Removing base fertiliser from half of the trial also eliminated other essential nutrients. Future trials should focus on reducing nitrogen only.
- Conducting soil tests before deciding which cover crop to plant and choosing a paddock with initially lower nitrogen levels, lower organic matter, and sandier soil before planting faba beans to encourage more nitrogen fixation by the legume.

ACKNOWLEDGEMENTS

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