Northern Farming Systems – long-term strategies and their legacy impact on nitrogen and phosphorus

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Take home message

- Incorporating more frequent legume crops boosted system gross margins at some sites, although grain nitrogen and potassium uptake and export is increased.
- Farming system yield improvements due to growing higher frequency of grain legumes are variable across the research sites.
- A higher nutrient strategy boosted mineral N levels post harvest compared to the Baseline system and also saw increased cycling of N in subsequent fallows meaning most of (i.e. > 50%) the additional N was recovered.
- High cropping intensity restricts the accumulation of mineral N, forcing a decline to critical levels, especially when multiple crops are grown back-to-back.
- Higher cropping intensity systems need more robust nutrient application strategies to maintain fertility and crop nutrient supply.
- Long fallow lengths, even during low rainfall periods, allow the build-up of mineral N, boosting yield potential and offsetting the need for fertiliser N inputs.

Introduction

Farming systems need to evolve to manage the challenges of climate variability, increasing soil-borne pathogens, herbicide resistance and problem weeds, declining soil fertility and increasing reliance on costly fertiliser inputs. A major challenge for our farming systems is to match crop nutrient supply and demand under variable growing conditions and maintain our soil's underlying fertility in the long-term. The northern farming systems project investigated long-term implications of several farming strategies that are likely to influence these processes. Particularly how different fertiliser application strategies and using more legumes in the farming system affect requirements for N inputs.

The project investigated the performance of various system modifications compared to the local 'best management practice' (*Baseline*) at seven research sites spanning the northern grain growing region. The modifications included the application of more nitrogen and phosphorus fertiliser, incorporating greater frequency of grain legumes (growing legumes every second crop) and varying degrees of cropping intensity (planting crops with more or less stored water; *Lower intensity* and *Higher intensity).* These modifications followed base rules, where crop selection was triggered on planting soil water, previous crop type and sequence, and current disease levels (determined by soil predicta B and plant diagnosis).

Experiments commenced in 2015 at seven locations: a core experimental site comparing 38 farming systems at Pampas near Toowoomba, and a further six regional sites that included six to nine locally relevant farming systems at Emerald, Billa Billa and Mungindi in Queensland and Narrabri, Spring Ridge and Trangie covering red and grey soils in NSW.

This paper will focus on three farming systems research sites – Billa Billa, Narrabri and Spring Ridge- and compare the following farming systems treatments and their impact on nutrient balance and system fertility.

1. *Baseline* – derived to represent local best management practice where the selection of crops and their management were designed in partnership with local grower panels and analysed as the control treatment. Crops were planted at or above soil moisture of 50% plant available water (PAW) and fertiliser N and phosphorus (P) rates were applied to meet the demand of a 50th percentile crop yield.
2. *Higher nutrient system* — contains identical crop sequence to *Baseline* but with higher N and P fertiliser rates applied to meet the demands of a 90th percentile crop yield.
3. *Higher legume* system where at least 50% of planted crops are legumes, crops were planted at or above 50% PAW. Legume crops did not have N fertiliser applied and P fertiliser rates were calculated to meet export rates, and fertiliser N and P rates were applied to meet the demand of a 50th percentile crop yield for non-leguminous crop.
4. *Higher cropping intensity* – planting frequency determined by soil water. This system is activated when soil water is 30% or higher.
5. *Lower cropping intensity* – planting trigger is determined by greater soil water levels (80%). High value crops are selected to ensure greater economic returns are achieved from optimum planting water triggers.

Over the six years of the project (2015 to 2021), seasonal conditions at regional experiment sites have varied, including extremes of drought and local flooding, as well as 'average' and 'favourable' seasons. The research sites selected had varied starting characteristics, as Billa Billa began with around 300 kg N/ha, while Narrabri's available mineral N was 145 kg N/ha (Table 1). Billa Billa also had the highest organic carbon (OC) content with 1.25% (0-10 cm depth) compared to Spring Ridge (1.09%) and Narrabri (0.83%).

Table 1. Starting soil characteristics at the three focus sites

Site	**Mineral N (kg/ha)**	**% Clay**		**Organic Carbon (%)**		**pH ($CaCl_2$)**	
	0 – 90 cm	*0–10 cm*	*10–30 cm*	*0–10 cm*	*10–30 cm*	*0–10 cm*	*10–30 cm*
Billa Billa	366	34	44	1.25	0.70	6.4	7.6
Spring Ridge	199	58	60	1.09	0.66	6.2	7.4
Narrabri	145	50	53	0.83	0.55	7.5	8.1

Long-term system trends

1. Incorporating 'more' legumes into our systems

Grain legumes have become an important crop option for northern grain farming systems. The benefit of improved agronomy and breeding resulted in exceptional yields, reducing the reliance on fertiliser use and the periodic high commodity prices have contributed to incorporating legumes in current cropping sequences. The Farming System project investigated this further by growing a legume crop every second crop or 50% of total planted crops in the *Higher legume* system. The *Higher legume* system achieved similar system yields to the *Baseline* system at the majority of farming systems sites.

Generally, there was an economic benefit with the *Higher legume* system over the *Baseline* system, especially at Narrabri and Spring Ridge. This is attributed to the good legume grain yields and higher grain values of pulse crops, often surpassing the gross returns from cereals in the same season. One note is that input costs were slightly increased due to additional seed costs and greater requirements for crop protection (e.g. fungicide applications). However, the economic risk of growing legumes (such as chickpea and fababean) in modern cropping systems is low and potential economic returns are high compared to systems based solely on cereals.

The *Higher legume* system had higher plant N compared to the *Baseline* system, reflecting their higher N content. However, we have struggled to find a significant improvement in available soil mineral N prior to subsequent crops and thus fertiliser budgets for most cereal crops post a legume crop were equivalent to the *Baseline* system. Compared to *Baseline*, N export in grain was higher for the *Higher legume* system, and N left in plant residues (i.e. above ground Plant N - Grain N exported) was lower in *High Legume* systems. This was a function of the high harvest indexes achieved with good agronomy and modern cultivars for most legume crops. The approach for N budgeting here involves using mineral soil N (nitrate-N and ammonium-N) as the basis for crop fertiliser budgets, however, a more complex budgeting tool that includes crop uptake and export may improve fertiliser recovery and better account for the legume organic material (Dowling, 2023). Of the three sites reported in this paper, Billa Billa, did have sampling dates where the Higher legume system trended with higher amounts of soil mineral N compared to the *Baseline* system. These spikes in mineral N were attributed to a higher accumulation of mineral N during the fallow periods, resulting in differences of up to 150 kg N/ha.

Higher legume systems elevated nitrogen use efficiency (NUE) at the system scale, calculated as the accumulated exported N against the change in soil mineral N and fertiliser inputs. The *Higher legume* system resulted in a mean NUE of 1.81 kg grain per kg of N across the three sites, compared to the *Baseline* system (1.43 kg grain/kg N). The improvement in the system NUE was attributed to the N fixation of the legumes, and the high conversion of plant N to grain N (N harvest index). Highlighting that although the project did not reduce fertiliser N application rates, there is still improved N use efficiency within the *Higher legume* system.

Table 2. Farming system productivity, nutrient balance and efficiencies at Narrabri, Spring and Bill Billa between 2015 and 2022

	Narrabri					Spring Ridge					Billa Billa				
System	**Baseline**	**Higher Nutrient**	**High Legume**	**High Intensity**	**Low Intensity**	**Baseline**	**Higher Nutrient**	**High Legume**	**High Intensity**	**Low Intensity**	**Baseline**	**Higher Nutrient**	**High Legume**	**High Intensity**	**Low Intensity**
Productivity															
Grain yield (t/ha)	19.8 ±0.6	20.3 ±0.5	21 ±0.7	22.8 ±0.4	11.1 ±0.7	27.3 ±0.8	27.1 ±0.8	23.8 ±0.4	26.1 ±0.6	13.4 ±0.7	24.8 ±0.6	24.7 ±0.6	17.6 ±0.5	20.9 ±0.4	13.3 ±0.8
Dry matter (t/ha)	55.6 ±1.2	52.9 ±1.4	59.0±1.5	77.5±0.9	31.0 ±1.9	77.3 ± 0.9	76.4 ±0.9	75.2 ±1.9	76.6 ±1.1	35.5 ±0.9	67.1 ± 1.4	69.9 ±1.4	51.5 ±1.2	67.9 ±1.1	47.9 ±1.6
Gross margin (S/ha) 2015-21	3775	3097	3269	4049	5801	4994	4812	5454	5903	6318	5246	4972	4201	2831	1714
Nitrogen use															
N fertiliser (kg N/ha)	234	533	234	437	138	301	440	321	330	181	29	84	30	29	21
Exported N (kg N/ha)	451 ±13	453 ±14	578 ±21	486 ±5	319 ±25	586 ±15	606 ±15	708± 24	603 ±17	377 ±12	522 ±29	552± 24	406±18	326 ±17	285±17
Plant N uptake (kg N/ha) 2019-22	601 ±17	639 ±24	701 ±55	698 ±11	417 ±44	530 ±11	476 ±27	890 ±71	711 ±18	376 ±21	444 ±24	475 ±28	356 ±30	551 ±25	367 ±51
System N balance (kg N/ha)	-217	80	-344	-49	-181	-285	-166	-387	-273	-196	-493	-468	-376	-297	-264
Nitrogen use efficiency															
System N use efficiency (kg grain N/kg N)	1.36	0.77	1.86	0.92	3.30	1.31	1.04	1.68	1.38	1.28	1.61	1.74	1.89	1.02	1.32
System N use efficiency ($/kg N)	16	6	14	9	42	17	11	17	18	35	181	59	140	98	82
Phosphorus use															
Applied P (kg P/ha)	42	66	48	59	39	50	52	44	61	39	47	82	51	44	34
Exported P (kg P/ha)	61 ±1.4	65 ±1.7	79 ±2.4	81 ±1.2	52 ±3.7	74 ±2.5	76 ±2.6	75 ±2.7	72 ±2.4	41 ±3.1	92 ±6.3	92 ±6.6	64±5.6	55 ±4.1	46 ±4.4

Note: exported N (or P) = grain dry weight x grain N (or P) %, system N balance = applied N - exported N, system NUE = exported N/applied N + change of mineral N, system GM NUE = gross margin/ applied N + change of mineral N.

2. Applying higher amounts of fertiliser to maximise yield

The *Higher nutrient* system aimed to test the long-term implications of fertilising each crop to maximise its yield potential and how this translates into fertiliser use and soil fertility. The *Higher nutrient* system is identical to the crop choice and sowing date of the *Baseline* system, with the only difference being that crops are fertilised to meet a 90-percentile yield expectation rather than the 50^{th} percentile for the *Baseline* system. The distinct fertiliser strategies in crop budgeting led to differing application rates between the two systems. On average across the three sites, the *Higher nutrient* system applied double the amount of fertiliser N compared to the *Baseline* system, with the cumulative system rates ranging between 299 (Narrabri) and 55 kg N/ha (Billa Billa).

In the *Higher nutrient* systems, the fertiliser inputs balanced or exceeded crop requirements in most seasons for both Narrabri and Spring Ridge. This resulted in a positive or neutral system N balance (where system inputs matched systems outputs) and maintained higher soil mineral N status over this time. We found the application of extra nitrogen fertiliser could take up to two cropping seasons to develop a significant difference in soil mineral N from the *Baseline* system, but once that difference was established, it was maintained until it was used by a high-yielding crop. It is unclear if additional N was lost from the system by denitrification due to extreme weather events, but there was one notable event at Spring Ridge (September 2019) where mineral N levels decreased significantly during a fallow which received heavy rainfall.

We found no additional grain yield between the Baseline and Higher nutrient systems over the first 6 experimental years at the three sites. This was across various seasonal conditions, including seasons with above average rainfall where yield potential was high and drier seasons where crop demand was low. Other factors may contribute to the lack of crop response to the additional fertiliser, including inherited soil fertility and even underlying soil constraints, such as subsoil sodicity (present at the Narrabri and Billa Billa sites).

3. Higher cropping intensity impact on soil fertility

Increasing levels of cropping intensity, also impacted soil fertility, soil N dynamics and fertiliser use. *Higher intensity* systems involved planting crops with a lower soil water as the trigger for sowing (e.g. 30% of a full profile), compared to the *Baseline* which required a moderate threshold (e.g. 60% of a full profile).

The main influence of these cropping intensity effects were: 1; the higher cropping intensity reduced the fallow period, therefore less time to accumulate mineralised N between crops, hence there was a greater reliance on fertiliser N to balance the crop nutrient budget, and 2; the higher cropping intensity, because of growing more crops and biomass had greater drawdown (use) of soil mineral N due to higher overall crop nutrient uptake, and greater export of N.

Because the cropping decisions are driven by soil water accumulation, the ultimate cropping intensity will naturally vary due to environments and seasonal weather conditions. During the project life, we have witnessed severe drought conditions through to growing seasons with rainfall exceeding 90^{th} percentile levels. Generally, mineral N has continuously accumulated during dry conditions with the longer fallow periods, building soil fertility for crop use when the seasons allow. In contrast, when conditions improved and the *Higher intensity* system implemented several back-to-back crops, mineral N was utilised by crops preventing significant soil mineral N accumulation within the system.

Additionally, when the *Higher intensity* system increased to 1.5 to 2 crops per year during high rainfall periods, the export rates of nutrients outweighed the system's potential to maintain mineral N levels. Even with greater application of fertiliser N and phosphorus (P) the export rates of nutrients were higher, and the mineral N declined drastically during these periods. Further pressure on this system was the stratification of mineral N and P, as the subsoil became 'mined' and deficient in plant available nutrients. The implication is that to counter this problem, subsoil application of fertiliser is required, but the *Higher intensity* system has minimal fallow time in which to perform the operation without impacting the next crop.

An early observation of the Higher intensity system is the greater production of plant biomass and lower harvest index. At Narrabri, there was a 22 t/ha extra dry matter production in the *Higher intensity* compared to the *Baseline* system, and 46 t/ha extra in the *Higher intensity* than the *Lower intensity* system over the same period. This extra biomass may benefit building soil organic carbon, and at Narrabri we have seen OC content increase from 0.76% to 0.91% since 2015 in this system. The higher turnover of organic material may aid the system's soil health long term and will increase the rate of N mineralisation and, therefore N available to future crops.

4. Greater mineral N accumulation within the Lower cropping intensity system

The *Lower intensity* system employed higher water planting triggers (> 80% of a full profile) that forced longer fallow periods and less time in crop. The advantage of the longer fallow was the system's ability to cycle, retain and accumulate higher levels of mineral N. This led to less need for fertiliser to meet crop nutrient budgets, reducing the system's reliance on nitrogen fertiliser application. The potential downside of this is that the extra nutrients available to crops comes at the expense of soil organic carbon breakdown to provide this mineral N. This was observed at Billa Billa, where the OC decreased from 1.25% in 2015 to 1.1% in 2019, while the *Baseline* and *High intensity* systems maintained OC at 1.25%

When production is optimised, similar to what happened at Narrabri, nitrogen use efficiency (NUE) is improved in the *Lower intensity* system compared to the *Baseline* (Table 2). When high value crops are grown to take advantage of the ideal growing conditions into the cropping sequence, such as at Narrabri and Spring Ridge, the *Lower intensity* doubled the economic NUE ($/kg N) over the Baseline system.

This general improvement of NUE provides greater scope for reducing input costs and reducing the potential losses of environmentally harmful gaseous emissions due to high fertiliser application. For western farming systems that inherently contain numerous 'dry' periods where planting varies and soil moisture accumulation may take longer than expected, these findings show that low intensity systems can adapt to variable seasonal conditions. While there might be long fallow periods (while producers wait for soil moisture to accumulate), when planting triggers are reached, soil fertility is high and the system is primed to produce high yields without the reliance of large applications of fertiliser.

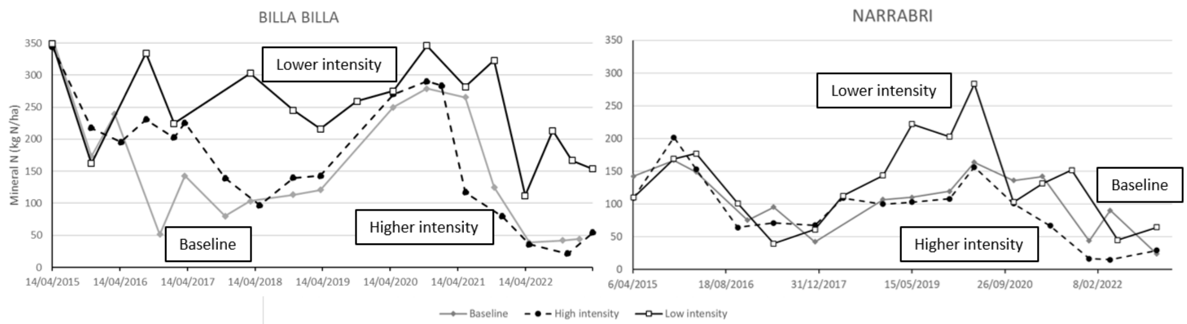

Figure 1. Time course dynamic levels of mineral N (nitrate-N and ammonium-N) at Billa Billa and Narrabri for the Baseline (grey line), Higher intensity (broken black line) and Lower intensity systems (black line).

Conclusion

Ensuring adequate soil fertility and health is paramount to maintaining sustainability and long-term farming system productivity. The project identified trends and legacies of implementing a number of nutrient management strategies and cropping scenarios across sites in the northern grains' region. Implementing these strategies resulted in various legacies from increased legume frequency with greater system N use, but a declining trend for soil mineral N. While higher cropping intensity led to higher grain productivity but at the expense of high fertiliser use and again, reduced soil mineral N.

The variability in weather conditions and seasonal outlook means Australia's grain producers need to implement a dynamic farming system that includes flexibility and resilience to a changing environment. The project implemented modified farming systems to improve industry understanding of the legacies and impacts of our systems to improve productivity and sustainability.

References

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