The impact of farming systems with more legumes and nutrient inputs on nitrogen, phosphorus and potassium inputs and use

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Abstract

Farming systems are currently underperforming in terms of yield, due to challenges that include declining soil fertility, herbicide resistant weeds and increasing soil pathogens. Farming system changes are required to maintain and improve productivity. In 2014 long term farming systems research began at seven sites located throughout Queensland and northern New South Wales. These experiments assessed the impact of nine farming systems with respect to numerous measures, including system production and economics, resource use efficiency, pathogen loads/populations, weed populations and soil health. Changes included modifying farming systems to include more legumes and applying fertiliser rates aimed at higher yield potential. The farming system 'modifications' impacted several facets of nutritional results. By applying nutrients via fertiliser (nitrogen (N) and phosphorus (P)) to meet the demands of 90th percentile grain yield potential (*higher nutrient* system), nutrient exports and inputs were balanced, resulting in stable mineral N when compared to current growers' practice (*baseline* system) at 10 of the 11 sites. The higher frequency of legumes (*higher legume* system) increased N and potassium export from the system at most sites (9 of 11 sites), but there was no legacy benefit to plant available N (nitrate and ammonium) for the following grain crops compared to growing non-legume crops. Longer-term examination of farming systems may lead to greater differentiation between systems and geographical location, providing greater insights into the impact different farming systems have on nutrient balances and long-term soil fertility.

Key Words

Farming systems, soil, nutrition, nitrogen, phosphorus, potassium

Introduction

While advances in agronomy and improved performance of individual crops have helped grain growers to maintain their profitability, current farming systems are underperforming; with only 30% of the crop sequences in the northern grains region (from Emerald to Dubbo) achieving 75% of their water limited yield potential (Hochman *et al.* 2014). Growers are facing challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. Changes will be needed to meet these challenges and to maintain the productivity and profitability of our farming systems. Consequently, Queensland Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and Commonwealth Scientific and Industrial Research Organisation are collaborating to conduct an extensive field-based farming systems research program, focused on developing farming systems to better use the available rainfall to increase productivity and profitability, with the question; *Can systems performance be improved by modifying farming systems in the northern region?* The following paper will examine how farming systems compared in terms of their requirements for nutrient inputs and their long-term impacts on soil nutrient status and cycling whilst other papers will explore impacts on pathogens, soil water and systems water use efficiency.

Methods

Experiments were established at seven locations; Pampas, Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (red & grey soils). Research sites were selected to represent a range of climatic conditions, soil types, nutritional status and paddock history. Each site was comprehensively soil tested at the beginning of the project.

Farming System Descriptions

This paper focuses on system comparisons between the following systems across all experimental sites:

1. *Baseline* – an approximation of common farming system practice (growers' practice) in each district: dominant crops only used; sowing crops on a moderate soil water threshold to approximate common crop intensities (often 0.75-0.8 crops per year); crops were fertilised (N and P) to meet the demands of a 50th percentile yield. All yield percentiles were established using APSIM (simulations were conducted at each trial site mean from the last 100 years.

2. *Higher legume frequency* – crop choice aims to have every second crop a legume across the crop sequence and using high biomass legumes (e.g. faba bean) when possible. crops were fertilised to meet the demands of a 50th percentile (no fertilsier N applied to legume crops)3. *Higher nutrient supply* – increasing the fertiliser budget for each crop to meet the requirement of 90th percentile yield potential; same crop choice and planting water thresholds as *baseline*.

Experimental procedures included measuring soil mineral nitrogen (nitrate and ammonium), both pre-sowing and post-harvest for each crop planted over the past four years. Grain content was also analysed for nitrogen (N), phosphorus (P) and potassium (K). Exported nutrients were calculated using grain nutrient content and dry weight grain yield.

Results

How does increasing legume frequency impact on system N, P and K inputs and use?

Results indicate there was little impact in the requirement of N fertiliser when legume intensity was increased. Some sites did reduce the required fertiliser N, e.g. Emerald with a reduction of 83 kg N/ha while other sites, such as Trangie (grey soil) and Pampas, the *higher legume* system increased N fertiliser required in subsequent crops by 25 kg N/ha compared to the local *baseline* system. These findings can be explained by the *higher legume* exporting more N (avg. 30 kg N/ha) from the cropping system (through grain harvest) than *baseline* (8 of 11 sites) (Table 1). This was also reflected in total system N use (soil mineral N depletion plus fertiliser N inputs), with only six of the 11 *higher legume* systems reducing total N use compared to *baseline*, with the largest reduction being 88 kg N/ha at Emerald.

Table 1. Cumulative nitrogen dynamics for the *baseline* and *higher legume* systems (2015 to 2018)

Site	N export (kg/ha)		Applied N (kg N/ha)		Δ mineral N (kg N/ha)		System total N use (kg N/ha)	
	Baseline	Higher legume	Baseline	Higher legume	Baseline	Higher legume	Baseline	Higher legume
Billa Billa	220	259	12	17	249	194	261	211
Emerald	227	249	91	8	52	47	143	55
Mungindi	79	80	54	54	-22	-6	32	48
Narrabri	177	227	127	127	43	36	170	163
Spring Ridge	227	305	211	211	25	35	236	246
Trangie (grey)	113	106	54	80	-213	-221	-167	-141
Trangie (red)	108	117	84	78	-31	-38	53	40
Pampas (mod int.)	271	309	13	39	248	257	261	296
Pampas (high int.)	249	303	101	108	285	280	386	388
Pampas (summer)	237	233	78	109	288	231	366	340
Pampas (winter)	287	347	42	17	275	274	317	291

Note: Total N use is calculated from applied fertiliser and the mineral N balance - (ammonium and nitrate N) prior to sowing 2015 minus the mineral N post the 2018 harvest

Phosphorous export was variable across sites (Table 2). However, the *higher legume* system increased the amount of K exported across all sites relative to *baseline* (avg. 14 kg K/ha), with Pampas (moderate intensity) exporting 31 kg K/ha more from the *higher legume* compared to the *baseline* (2015 to 2018).

Table 2. Cumulative phosphorus and potassium removal for the *baseline* and *higher legume* systems (2015 – 2018)

Site	P export (kg/ha)		Applied fertiliser P (kg N/ha)		K export (kg K/ha)	
	Baseline	Higher legume	Baseline	Higher legume	Baseline	Higher legume
Billa Billa	41	34	27	36	57	66
Emerald	29	32	22	21	56	63

Mungindi	12	14	7	7	24	25
Narrabri	26	34	24	24	42	54
Spring Ridge	32	35	33	33	53	64
Trangie (grey)	15	14	35	35	19	22
Trangie (red)	17	19	35	35	23	26
Pampas (mod int.)	37	42	23	20	53	84
Pampas (high intensity)	41	41	25	29	59	87
Pampas (summer)	40	33	21	21	45	70
Pampas (winter)	40	46	18	22	66	95

What are the consequences of increasing fertiliser inputs on system nutrient balance and use?
As predicted, the *higher nutrient* system increased the amount of N fertiliser applied at each site over the cropping sequence (avg. 83 kg N/ha extra) between 2015 and 2018 relative to *baseline*. Results show that applying N fertiliser to aim for a 90th percentile yield potential may reduce the mining of soil available N, especially in soils with high fertility (e.g. Billa Billa). Also significant amounts of additional N applied remained in the mineral N pool, hence becoming available in subsequent crops. The additional applied N in the *higher nutrient* system resulted in an increase of exported N at seven of the 11 sites. This was highlighted at Trangie (red soil) which exported 49 kg N/ha more than the *baseline* system (Table 3). However, there were a few cases where providing these additional nutrients produced a positive yield advantage.

The additional N applied in the *higher nutrient* system reduced the depletion of background soil mineral N status at ten sites. On average across all sites the *higher nutrient* system had 43 kg N/ha more soil mineral N than the *baseline* – i.e. about 55% of additional N applied was found in the mineral N pool. However, this recovery varied greatly across sites, ranging from full recovery (e.g. Billa Billa, Pampas-summer) to recovery of less than 10% (e.g. Mungindi and Pampas-winter). This value is highly dependent on the timing of sampling and previous crop, residue loads and types, and soil moisture conditions.

The additional P applied to *higher nutrient* systems did not influence grain P export. Similarly, there was no difference between K export compared to the *baseline* systems at all sites. This was not unexpected as we did not see significant yield responses to the higher nutrient application strategies.

Table 3. Cumulative nitrogen dynamics for the *baseline* and *higher nutrient* system (2015 to 2018)

Site	**N export (kg N/ha)**		**Applied N (kg N/ha)**		**Δ mineral N (kg N/ha)**		**System total N use (kg N/ha)**	
	Baseline	**Higher nutrient**	**Baseline**	**Higher nutrient**	**Baseline**	**Higher nutrient**	**Baseline**	**Higher nutrient**
Billa Billa	220	253	12	62	249	190	261	252
Emerald	227	246	91	147	52	33	143	180
Mungindi	79	86	54	125	-22	-26	32	99
Narrabri	177	158	127	201	43	15	170	215
Spring Ridge	227	235	211	316	25	-2	236	314
Trangie (grey)	113	96	54	160	-213	-174	-157	-14
Trangie (red)	108	157	84	261	-31	-225	53	36
Pampas (mod int)	271	257	13	89	248	229	261	318
Pampas (high int)	249	278	101	209	285	193	386	402
Pampas (summer)	237	243	78	116	288	235	366	351
Pampas (winter)	287	277	42	100	275	267	317	367

Note: Total N use is calculated from applied fertiliser and the mineral N balance - (ammonium and nitrate N) prior to sowing 2015 minus the mineral N post the 2018 harvest

How do different crops impact N cycling and fallow mineralisation?
Given the diversity of crops grown across the sites in this project comparisons can be made between the mineral N dynamics in-crop and also in the fallow period after harvest for wheat and chickpea across multiple seasons and locations. In three of four comparisons between chickpea and wheat (Emerald 2015 and 2016, Pampas 2016) there was no additional N accumulation after chickpea compared to wheat during the subsequent fallow after harvest. Where higher mineral N was recorded after a chickpea crop, it was associated with higher N at sowing (Table 4).

Table 4. Comparisons of wheat and chickpea influence on soil N use and subsequent fallow N accumulation across multiple sites and seasons

Site Season	Crop	Sowing mineral N (kg N/ha)	Harvest mineral N (kg N/ha)	End of fallow mineral N (kg N/ha)	Subsequent fallow mineral N accumulation (kg N/ha)
Emerald 2015					
	Wheat	105	59	153	94
	Chickpea	78	32	126	94
Emerald 2016					
	Wheat	126	12	114	102
	Chickpea	153	23	141	118
Pampas 2015 – long fallow					
	Wheat	184	117	179	62
	Chickpea	203	68	168	100
Pampas 2016 – short fallow					
	Wheat	83	17	61	44
	Chickpea	93	34	76	42

Note: Total N use is calculated from applied fertiliser and the mineral N balance - (ammonium and nitrate N) prior to sowing 2015 minus the mineral N post the 2018 harvest

Conclusion

Overall these results indicate that across our farming system sites the implementation of additional legume crops in the crop sequence has not reduced N fertiliser input needs nor reduced soil N use. The legumes are utilising soil mineral N to the same extent as cereal crops and have higher N export which offsets N fixation inputs. This result is consistent across a wide range of starting soil N conditions, from very high to low mineral N status where legumes would require to N fixation to meet their needs. These results significantly challenge the commonly held assumption that grain legumes will reduce N fertiliser needs in the crop sequence. We believe that this shows that as our capacity to grow high yielding grain legumes has increased so too has our nitrogen harvest index and hence the ratio of N removed in the grain to that left in biomass, thereby diminishing the contributions of residual N after the crop. Phosphorous export was variable across sites, however, the *higher legume* system increased the amount of K exported across all sites relative to *baseline*. Although this is not unexpected as legume seed has more than double the K content of cereal grains. In situations where K deficiency may be an emerging issue or where levels are marginal, this greater export under a higher legume system may mean that nutrients will need to be replaced sooner or a higher level of replacement will be required. It must be noted that in the first four years of the project there was generally only one extra legume crop grown in the majority of *higher legume systems*.

The first four years of the farming system project showed that modifying crop systems through higher nutrients balanced the net export of all nutrients (N, P, K) relative to the inputs in several cases. However, there were a few cases where providing these additional nutrients produced a positive yield advantage.

Future comprehensive soil analysis across all sites will investigate changes in other parameters such as total N and organic carbon levels. Longer-term examination of cropping systems may lead to greater differentiation between systems and geographical location, providing greater insights into the impact different farming systems have on nutrient balances and long-term soil fertility.

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References

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