Nitrogen cycling and management decision making in Central Queensland farming systems – N availability and recovery across the farming system – N impacts on productivity – implications for management in CQ

David Lester[1], Darren Aisthorpe[2], Lindsay Bell[3], Doug Sands[2], David Lawrence[1], Michael Bell[4]

[1] Queensland Department of Agriculture and Fisheries, Toowoomba
[2]. Queensland Department of Agriculture and Fisheries, Emerald
[3]. CSIRO, Toowoomba
[4]. The University of Queensland, Gatton

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DAQ2303-006RTX - Understanding the nitrogen contribution of chickpea in Qld
UQ00063 MPCNII - Regional soil testing guidelines for the northern grains region
DAQ2307-001RTX NGN - Understanding the long-term residual benefit of deep placed P in south-west and central Queensland
UOA2312-008RTX - Improving the understanding and the effectiveness of N fixation in pulses in Australia

Take home messages

The nitrogen (N) fertiliser demand for cereal cropping systems can increase due to two factors:

1. A reduction in the amount of soil organic N mineralised due to the continued decline of natural capital (soil organic carbon and total nitrogen) that occurs under cropping; and
2. An increased crop N demand due to higher yield potentials resulting from optimising other components of the cropping system.

The amount of biological N fixation by pulse crops (chickpea/mungbean) is related to the crop yield and biomass and the availability of soil mineral N from mineralisation or carry-over of residual fertiliser. Where deep phosphorus (P) and potassium (K) application increases chickpea biomass (and grain yield), there is generally more N fixed. While some of this is re-exported in grain, the greater residue return means more N is carried forward to the next crop.

Growers have a selection of fertiliser N management practices that have differing strengths and weaknesses – it is not a one-size-fits-all model for CQ (or northern region) farming systems. The 4R framework allows choice of rate, source, time and place for any nutrient applied to be implemented suiting each growers' preferences, with on-going research addressing several themes in regional Qld.

Introduction

Cropping soils of the northern region are declining in natural fertility as the time since conversion to cropping from previous land uses increases. At the same time, improved agronomic practices continue to increase grain yield of both cereal and pulse cropping systems. Collectively therefore, the nutrient cycle is changing with increasing plant demands and potentially diminishing soil reserves. These transfers of nutrients within soil profiles, and off farm as product export, requires evolution of soil fertility management, including nitrogen.

The N cycle

There are many authors that have described the fundamentals of the N cycle in cropping systems for Australian (Barton et al. 2022), northern region (Herridge 2011, Cox and Strong 2017) and central Queensland (CQ) specific scales (Cox and Strong 2017). They all outline the potential flows of N between different soil pools and to plants and the atmosphere.

DAF is investing with GRDC and other partners in a new national project (UQ2204-010RTX) to develop a better understanding of fertiliser N cycling and loss in grain production systems, with that understanding used to improve decision support tools and systems models, like APSIM. This research uses a stable isotope of N (^{15}N) to track movement, recovery, recycling and loss of fertiliser N for up to three consecutive crop seasons. The movement of fertiliser N down the soil profile during the recharge of soil water during a summer fallow, and the implications for N availability to a following winter cereal crop, is being investigated simultaneously through a project funded by federal Department of Agriculture, Water and Environment. Both projects are led by Prof. Mike Bell at the University of Queensland, with the Qld research occurring at Gatton, Kingsthorpe, Pampas and Mungindi. The objective of both studies is to better understand fertiliser N dynamics once applied to soil, and how recovery and use of that fertiliser can be optimised.

The ^{15}N isotope can also be used to measure how much N is being fixed from the atmosphere by pulse crops through a method called 'natural abundance' (Unkovich et al. 2008). By having an unfertilised non-fixing reference plant in the same paddock during growth of the pulse crop, we can use the differences in abundance of ^{15}N in the tissues of the reference crop (soil N only) from that of the legume crop (soil N and atmospheric N) to determine how much N was fixed from the atmosphere by the legume. By doing similar calculations on the grain removed from the field, the amount of soil N removed from the field can be compared to the amount of fixed N returned in residues, and a N balance calculated for the crop. Of course, all the N in legume residues is potentially available to following crops, so the total amounts of residue and their rates of breakdown have to be estimated if we are to finesse the fertiliser N estimate for the following crop. This is where well calibrated system models can really help refine our N management.

N in CQ farming systems research

Since 2014 the CQ smart cropping centre (formerly the Emerald Agricultural College) has been part of a DAF-led and GRDC-supported project evaluating different cropping parameters around fertility management, crop choice for pathogen/weed management, and cropping intensity across the northern region. Another update on the results in CQ and the broader project are presented in this update (Bell and Aisthorpe 2023).

A component of the monitoring of N dynamics between different cropping sequences involves measuring the soil mineral N (nitrate and ammonium) within the soil profile pre-sowing and post-harvest for all crops. This gives an insight into the behaviour of the immediately available plant N pool in the soil. It is only a partial story because the bigger picture includes N that is exported in grain, N remaining in stover and roots after harvest, N which has been incorporated into the soil organic matter pool, or lost off-farm via gaseous (denitrification, volatilisation) or aquatic (leaching, runoff) pathways.

This paper looks at apparent N balances on four of the management systems in the experiment:

1. Mixed baseline (M01)
2. High nutrient (M02)
3. High fertility (M02b)
4. High legume (M03)

Let's start with the baseline system (M01), a wheat-chickpea-sorghum opportunity cropping system with fertiliser N inputs designed to meet the demands of crops achieving a median target yield. There have been 9 crops harvested (Table 1), including 7 cereal and 2 chickpea. The soil mineral N content at sowing has typically been higher than crop N demand, so fertiliser N applications have been minimal, totalling 110 kg N/ha since 2015.

In 'Managing Legume and Fertiliser N for Northern Grains Cropping' by David Herridge (2011), there are a series of equations that allow the estimation of how much N a pulse crop might have fixed. It works backwards using a harvested grain yield, and some starting mineral N levels to give a modelled estimate. Using that framework, the N fixed at the Emerald experiment has been calculated, and those values used as part of evaluation of system N balances.

It is suggesting that ~260 kg N/ha was fixed by two chickpea crops in the baseline treatment. The higher mineral N (215 kg N/ha) in winter 2016 (Win16) (prior to sowing the 2016 chickpea crop) would have contributed to the relatively low proportion of N derived from atmospheric fixation (Ndfa% of only 40%) compared to that achieved in the chickpea crop in 2022 (Win22), when the starting soil mineral N (110 kg N/ha) was half that of the 2016 season. Cumulative N exported has been 571 kg N/ha in 26,148 kg of grain, which means this system has run up a deficit of 201 kg N/ha, i.e., there's been 200 kg/ha more N exported than added into the system through fertiliser and fixed N. This N has to have been supplied by a rundown of the soil organic matter and N.

Table 1. CQSSC farming system mixed baseline running N balances

Code	Chron Year	Crop	Min N to 0.9m (kg/ha)	Crop N budget (kg/ha)	Fert N app (kg/ha)	Sim Tot N fixed /Ndfa%*	Grain N exp (kg/ha)	Dry Matter (kg/ha)	Grain yield (kg/ha)	(Fert N + TNF) – grain N (kg/ha)	Cum (Fert N + TFN) - grain N (kg/ha)
M01	Win15	wheat	132	102	16		38	6276	1671	-22	-22
M01	Win16	chickpea	215		3	112/40%	95	7908	3059	20	-2
M01	Win17	wheat	175	98	26		37	5278	1759	-11	-13
M01	Sum17	sorghum	218	119	4		53	11573	3096	-49	-62
M01	Win19	wheat	210	98	2		59	8512	2961	-57	-119
M01	Win20	wheat	151	76	1		48	4638	2239	-46	-166
M01	Sum21	sorghum	153	220	48		66	10071	4393	-18	-184
M01	Win22	chickpea	110		2	149/56%	84	7131	2847	66	-118
M01	Win23	wheat	89	95	7		91	7848	4124	-83	-201
M01 Total					**110**	**261**	**571**	**69234**	**26148**	-201	
* simulated modelled values using (Herridge 2011)											

In the high nutrient M02 system, the starting mineral N levels have been consistently high pre-sowing (data not shown), reducing the amount of fertiliser needed to meet a 90% yield target such that only an additional 55 kg N/ha more than the *baseline* has been applied over the entire sequence (Table 2). Grain yields for the *baseline* and *high nutrient* systems are equivalent (69,200 vs 70,000 kg/ha, respectively), but that higher fertiliser N input has resulted in slightly lower total N fixed. Collectively then, it is not surprising that the slightly higher fertiliser N input is balanced by higher grain N export, with the cumulative N balance (Table 2) being similar to that of the baseline system (i.e., -198 kg N/ha).

Table 2. CQSSC farming system high nutrient tunning N balances

Code	Fert N app (kg/ha)	Sim Tot N Fixed* (kg/ha)	Grain N exported (kg/ha)	DM (kg/ha)	Grain yield (kg/ha)	(Fert N + Tot N Fixed) - Grain N (kg/ha)
M02 Total	165	235	597	70030	27648	-198

*simulated modelled values using Herridge (2011)

When the experiment was commenced a treatment (M02b) attempting to re-establish a high natural fertility status through addition of a large amount of organic matter was established. This was achieved through applying 50 t/ha of (dry equivalent) feedlot manure in two applications. These manure additions have resulted in large increases in the soil mineral N and annual fertiliser N applications have not been applied, with the exception of the N in the starter fertiliser (i.e., 2–6 kg N/ha as MAP, Table 3). Grain production has increased by a cumulative ~5 t/ha more than the M01 and M02 treatments, while an additional ~80–100 kg N/ha being removed in grain (672 kg N/ha, Table 3). The amount of Ndfa% is slightly lower, consistent with the higher soil mineral N supply.

Using the manure application rates and chemical analysis, an estimate of the addition of carbon (C), N, phosphorus (P) and potassium(K) was done correcting to 0% moisture. Total inputs are 10,480 kg C/ha (equivalent to 1% C), 1,110 kg N/ha, 416 kg P/ha and 1,000 kg K/ha. If we include the N addition from the two manure applications with the N fertiliser applied, an apparent surplus of 730 kg N/ha exists.

Table 3. CQSSC farming system high fertility (M02b) running N balances

Code	Chron Year	Crop	Min N to 0.9m (kg/ha)	Crop N budget (kg/ha)	Fert + Manure N app (kg/ha)	Tot N Fixed /Ndfa%*	Grain N exp (kg/ha)	Dry Matter (kg/ha)	Grain yield (kg/ha)	(Fert N + Tot N Fixed) - grain N (kg/ha)	Cum (fert N + TFN) - grain N (kg/ha)
M02b	Win15	wheat	157	140	281		45	6278	1926	237	237
M02b	Win16	chickpea	238		3	103/37%	96	8500	3023	10	247
M02b	Win17	wheat	266	132	890		51	7155	2367	839	1086
M02b	Sum17	sorghum	389	170	6		69	12307	4245	-63	1023
M02b	Win19	wheat	369	132	3		70	10419	3402	-68	955
M02b	Win20	wheat	410	113	3		65	6194	3056	-62	894
M02b	Sum21	sorghum	327	242	2		82	11553	5556	-80	813
M02b	Win22	chickpea	261		6	102/36%	92	7854	3016	16	829
M02b	Win23	wheat	141	113	5		102	9252	4644	-97	732
M02b Total					1199	205	672	79511	31233	732	

*simulated modelled values using Herridge (2011)

All three of these systems (M01, M02 and M02b) have been cereal dominated. The *high legume* treatment (M03) attempts to have a 50:50 cereal:pulse ratio over time, and in the system so far, 5 of 9 crops have been pulses. This doubling of the number of pulse crops has altered several results. Cumulative grain yields are 5 t/ha less than the mixed baseline system, reflecting the typically lower yields of grain legumes compared to cereals in the same seasonal conditions. Dry matter production and crop residue return to the soil is also less in this system, but grain N export is not that much lower than the baseline system (531 vs 571 kg N/ha) due to the typically higher N concentrations in the legume grain.

Having a higher legume intensity is altering the N input dynamics of that system. Fertiliser N input is negligible (22 kg N/ha) essentially coming starter fertiliser applications. Simulated total N fixed by the system is ≈360 kg N/ha. These are modelled numbers so do have a larger uncertainty, but suggest the potential for pulse crops to make reasonable system N inputs. Cumulatively the system is still in net deficit of ≈150 kg N/ha.

Table 4. CQSSC farming system high legume (M03) running N balances

Code	Chron Year	Crop	Min N to 0.9m (kg/ha)	Crop N budget (kg/ha)	Fert N app (kg/ha)	Sim Tot N fixed /Ndfa%*	Grain N exp (kg/ha)	DM (kg/ha)	Grain yield (kg/ha)	(Fert N + TNF) - grain N (kg/ha)	Cum (fert N + TFN) - grain N (kg/ha)
M03	Win15	chickpea	96		2	77/44%	55	4031	1842	23	23
M03	Win16	wheat	176	79	3		77	9611	3761	-74	-50
M03	Win17	chickpea	144		3	65/35%	62	3642	1931	6	-44
M03	Sum17	sorghum	132	119	4		51	11874	2982	-47	-91
M03	Win19	chickpea	105		2	52/36%	54	5729	1509	1	-91
M03	Win20	wheat	120	76	1		37	3893	1767	-35	-126
M03	Sum21	mungbean	117		2	6/10%	23	4091	627	-15	-141
M03	Win22	chickpea	88		2	163/62%	87	6972	2831	101	-40
M03	Win23	wheat	103	95	2		87	7951	3967	-85	-147
M03 Total					22	362	531	57795	21215	-147	

Other factors that will affect fixed N inputs in cropping systems

While the percentage of crop N derived from fixation is influenced by the soil mineral N, as shown in the rotation sequences, the amount of N fixed by pulse crops is ultimately determined by the amount of biomass grown in that season. The more biomass that is grown, even at the same %Ndfa, the more N that is likely to be added to that system through fixation. In sites that have been strongly responsive to deep P applications (e.g. Sands et al. 2022), substantial yield (and profit) responses to subsurface P applications have been recorded, with those responses accompanied by substantial increases in crop biomass production. By applying the assumptions and model of Herridge (2011) to the Dysart deep P trial site, an estimate of total N fixed across a range of deep P treatment scenarios can be determined (Table 5). The experiment had two deep P applications during the research phase. Initial treatments had untreated control or 'Farmer Reference' treatment, then increasing subsurface P rates (0, 10, 20 or 40 kg P/ha) applied as MAP in 2014. In 2019, those original plots (apart from the FR) where split with a reapplication of 30 kg P/ha (as MAP). In Table 5 a treatment of 20P was the original P rate without reapplication, while the 20+30P represents an initial application of 20P and a reapplication of 30P.

These modelled estimates suggest that improving plant P access could increase total N fixation from 50 to 230 kg N/ha, and Ndfa% from 45 to 76%, comparing the farmer reference to two deep P applications. Even with increasing grain N removal, the estimated residual N carried forward was increased nearly 3-fold, from 66 to 190 kg N/ha. Of course, the release rate of N from the residues would be seasonally dependant, and recovery by future crops would be related to residue decomposition and movement of mineralised nitrate-N into the soil profile.

Table 5. Estimated %Ndfa and simulated total N fixation with deep P treatments at Dysart in 2019

Treatment	Farmer Reference	20P	20+30P	40P	40+30P
Grain Yield (12%)	1.16	1.92	3.34	2.44	3.36
Grain N (kg N/ha)	36	59.6	103.7	75.7	104.3
%Ndfa	45.3	59.9	76	66.9	76.2
Total N fixed (kg N/ha)	50	107.1	230.2	150.6	232.9
Residue N (kg N/ha)	66	110	190	139	192

Chickpea N fixation in Queensland in 2023

This last winter season (2023) DAF has been measuring on-farm N fixation by chickpea across 25 sites in Central and Southern Queensland, using the previously described ^{15}N natural abundance method. After the analytical processes are completed, we'll be able to give another update early in the new year. The project is monitoring fallow water and mineral N changes between harvest and sowing of the next crop. DAF is also part of a new national consortium (led by University of Adelaide) investigating the understanding and effectiveness of N fixation in pulses. We will be following up with more information about N fixation in the new year.

Conclusions

Growers and advisers have a range of tools and techniques to fine-tune N management on their properties.

There are many factors that come together into a successful cropping N management strategy. Using a crop model such as ArmOnline to generate a range of yield potentials allows an estimation of different crop N demands and the likely amount of N which will be exported from the field. Soil sampling for mineral N can provide a good starting point as to how much plant available N is present before sowing. Higher soil mineral N backgrounds can reduce the reliance on recovery of fertiliser N in that year. Having an indication of the soil mineral N status also allows some estimating of likely soil N recovery by a pulse crop.

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Contact details

David Lester
Queensland Department of Agriculture and Fisheries
Leslie Research Facility, Toowoomba Qld 4350
P: 0428 100 538
E: david.lester@daf.qld.gov.au

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