RiskWi$e N management systems – exploring N banking in the northern region

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Take home message

- Developing a robust nitrogen (N) fertiliser strategy is critical to maximising seasonal yield potential while avoiding long-term carbon decline and mitigating risks of N losses
- Tactical N budgeting in the face of uncertain seasonal outcomes is tricky and has high data demands to make helpful predictions of seasonal yield potential
- Longer-term strategic approaches can be simpler and have advantages of incurring costs following higher profit years, but have higher risks of N losses
- Take a multi-year perspective on nitrogen use efficiency and return on investment rather than just the year of application
- Strategic approaches like N banking can perform well in northern farming systems allowing yield potential to be maximised while avoiding environmental losses
- Setting the appropriate N target to balance the upside and downside risks is likely to be influenced by your risk attitude.

Introduction

Nitrogen (N) is typically the largest single variable cost in most grain production systems and many farmers underapply N fertiliser which can limit their long-term productivity and profitability, and mine their soil organic matter (SOM) over the long term. Applying fertiliser is considered a ‘risky’ decision because of uncertainties associated with a lack of return on investment in the year of application, negative yield responses to applied N or losses of N. This often leads growers to take a conservative approach to their N inputs. The largest difficulty with N fertiliser management is the capacity to match N supply to crop demand and being able to do this when variable climate conditions significantly change the yield potential, and hence likely response to additional N inputs.

The national RiskWi$e initiative aims to quantify the risks and rewards for deploying a range of N management strategies or decision-making processes across a range of production environments and systems nationally. While field experiments are underway, here we explore how crop modelling would predict the performance of a more strategic approach to N decision making, like N banking over the longer term (30 years).

N decision making approaches

Tactical approaches to seasonal N supply

In the past, efforts have often focussed on trying to match seasonal N fertiliser inputs to seasonal yield potential using crop N budgeting approaches. To confidently set the yield target for each year relies on accurate information on soil water status of the crop (at sowing or during the season), seasonal forecasts (which often have limited skill when decisions are being made), detailed soil information (e.g. soil plant-available water-holding capacity), as well as agronomic information such as crop cultivars, sowing dates and starting soil mineral N status. To inform these decisions a range of tools have been produced and used, such as YieldProphet, Whopper Cropper, CropARM, but these are often data hungry and take time to use effectively. Even then, decision makers are often faced with a range of potential outcomes depending on how the season will unfold.

Strategic longer-term approaches to system N management

An alternative to taking a highly responsive approach to the seasonal outlook is to apply a longer-term approach to N management. This could reduce some of the complexity with the decision making and if applied appropriately could reduce situations where grain yield is limited by inadequate N inputs or when N is not located in the soil profile where crops can access it. This approach also often has the advantage of shifting the cost of fertiliser into the year following a high production season when income is likely to be high. However, these more strategic approaches will work best in situations when most of any surplus N is retained in the soil system and there is low risk of N losses (e.g. leaching, denitrification and volatilisation). Some strategic approaches include:

A replacement strategy – where the crop N removed in grain is applied in the following growing season to maintain the system balance. This level of replacement may then be geared upwards to account for losses or downwards if other inputs of N (e.g. legumes) are included in the system. This has the advantage, that once you know your yield and protein you can calculate and budget for the N to be applied to each field or management zone, and potentially spread your risk of application over various times the following year.

A financial strategy – using a similar approach to the replacement strategy, however, the amount of N to be applied is determined based on a percentage of your net return from the previous year. For example, if you aimed to allocate 10% of the previous year's income to N fertiliser, following a year where your crop income was $900/ha, you would apply $90 worth of urea per hectare in the following season. This approach takes out the influence of fertiliser price, so that in seasons when the cost is high you would apply less and when the cost is low you would apply more. Such an approach could also be applied spatially to target extra inputs into the higher producing parts of the farm.

N banking - N banks require growers to set a locally relevant target for crop N supply (soil mineral N plus fertiliser N) that is enough to maximise yield in most seasons. Soil mineral N is then measured prior to, or early in the growing season, and if less than the target N bank, is topped up to the target value with fertiliser N. This approach does not attempt to match seasonal demand each year, but simply requires fertiliser to be applied to meet the N bank target to supply the crop sufficient N to meet its water-limited yield potential in most years. The challenge with this system is working out the N bank target relevant to your production environment, soil and farming system – this is explored below.

Predictions of N bank targets

An 'N bank target' is the set amount of N supply available to the crop from both soil mineral N at sowing and fertiliser inputs. This is likely to oversupply N in some lower-yielding years, with unused N being carried forward depending on the environment and seasonal conditions.

Long-term simulations using APSIM can be used to predict the optimal N bank target for a particular environment. We simulated ten N bank levels from 30 to 400 kg N per ha for the period 1991 to 2022 at a range of experimental locations across the country. These were conducted using a generic characterisation for soils commonly found in that region, and all simulations looked at a wheat crop sown on a short fallow. To investigate the effect of SOM on these predictions, we also set the soil to five different levels of labile organic carbon (C). To estimate the economically optimal N bank (i.e. the level that generates the highest average gross margin) we assumed common variable input costs across all sites and scenarios for inputs other than N fertiliser (i.e. $163/ha). We assumed a urea price of $500 per tonne (or $1.08/kg N) and wheat grain price was assumed to be $221/t after freight, levies and insurance.

To demonstrate how the N bank targets can be estimated, Figure 1 shows the relationship between grain yield and crop gross margin in response to increasing N bank targets (i.e. soil mineral N and balanced by fertiliser inputs) for the Liverpool Plains region of NSW. This shows that the N bank that maximises yield is often higher than that which optimises gross margin; the latter accounts for the cost of the N inputs. What is also evident is that soil type, as it influences crop yield potential, has a significant influence on the optimal N target; soils with lower PAWC and lower yield potential have lower N targets.

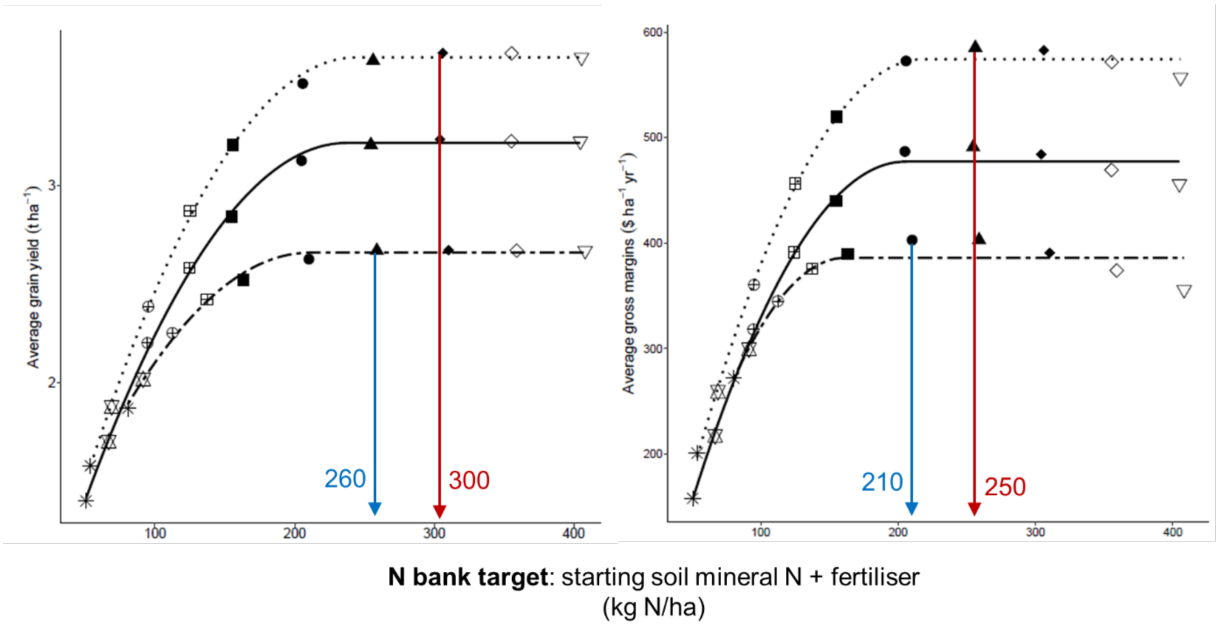

Figure 1. Estimated N bank targets to maximise grain yield potential (left) or gross margin (right) on different soils on the Liverpool Plains, NSW; dotted line – Vertosol with 200 mm PAWC, solid line – Dermosol with 160 mm PAWC and dot-dash line – Sodosol with 130 mm PAWC. Symbols indicate different N bank targets.

However, these model predictions assume perfect crop agronomy and management which may not be achievable in the real world. Hence, an alternative approach is to consider the N supply that would reduce the yield gap caused by lack of N supply. Figure 2 shows the distribution of crop yields as a proportion of the water-limited yield that were achieved over the full range of simulated years under the different N bank scenarios. Achieving higher than 80% of water-limited yield is regarded as an appropriate target, so we estimated the N bank required to achieve this in most years (i.e. >75% of the time when the lower part of the box is higher than the 80% threshold). This approach generates a significantly lower N bank target (see Table 1).

What is also noticeable in Figure 2 is that soil organic C status significantly influences the potential yield at lower N supply levels, but it doesn't have a large impact on the predicted optimal N bank target. This is because soils with higher organic C that may provide more N, may reduce the proportion of N coming from fertiliser but the total supply required for that environment remains fairly stable.

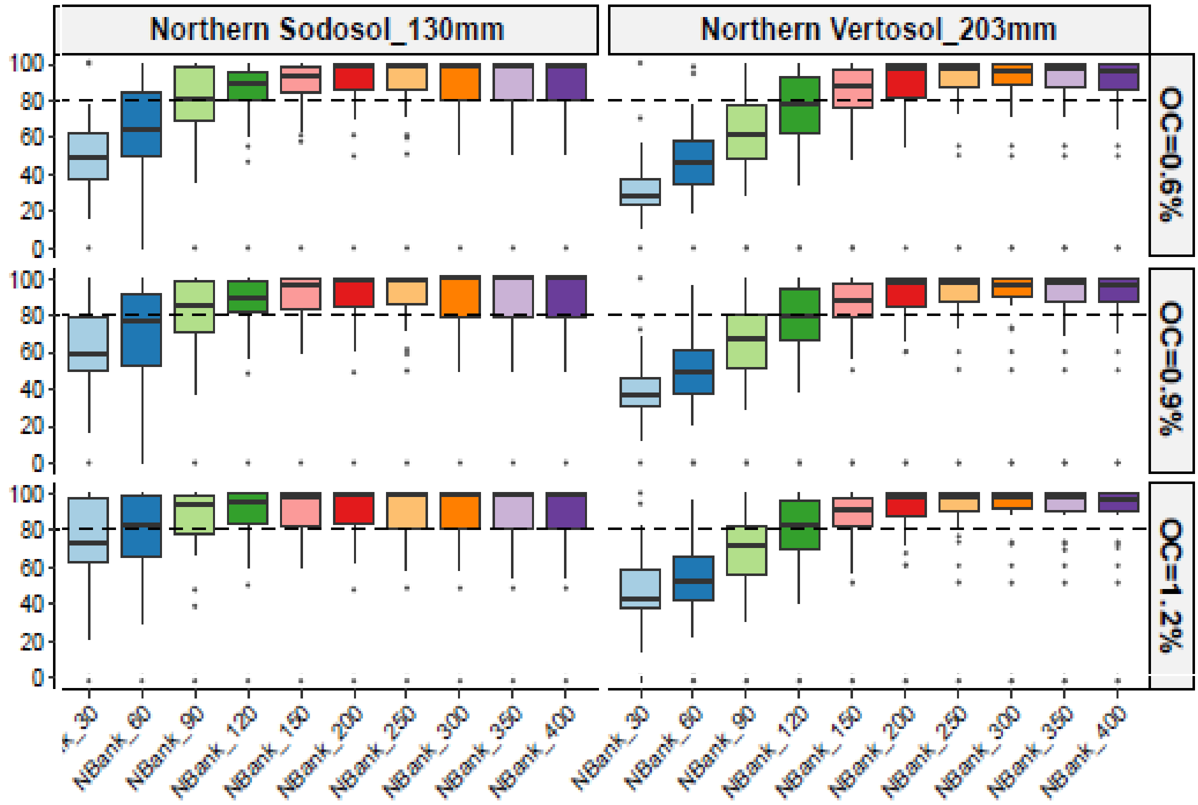

Figure 2. Relative yield (%) compared to the water limited yield in any particular year attained under different N bank levels (kg N/ha) on different soil types and soil organic carbon levels. Boxplots show the median (solid line), the 25th and 75th percentile (within the box) and the 5th and 95th percentile (whiskers) of the predicted outcomes.

While we are still conducting a larger nation-wide analysis to predict N bank targets across all grain growing regions, below are some examples of the estimated N bank targets (discussed above) for different production environments in northern NSW. These show that as the production potential of an environment declines, so too does the N bank target.

Table 1. Estimates of N bank targets for wheat that maximise long-term average yield, optimise gross margin or achieve water-limited yield potential in most years in simulated locations and soil types in subtropical Australia.

Location	Soil type (PAWC mm)	N bank target (kg N/ha)		
		Yield maximising	Gross margin optimising	Achieving > 80% of water-limited potential in most years
Premer	Vertosol (200 mm)	300	250	160
	Sodosol (130 mm)	260	210	120
Gurley	Vertosol (200 mm)	240	200	150
	Dermosol (160 mm)	200	180	120
Walgett	Vertosol (200 mm)	180	150	120

Production, nutrient use-efficiency and environmental implications

In addition to the production outcomes, a critical question with the more strategic approaches like N banking is how this influences the overall N inputs required, recovery and cycling of N over seasons, and overall system N balance. Table 2 below shows some of these metrics for different N bank levels for a winter cereal-dominated system in northern NSW.

Firstly, this shows that whilst the N bank target increases, the amount of N applied does not increase at the same rate. As the N bank target increases by around 30 kg N/ha supplied, only about 15 kg of extra fertiliser N/ha per year is required to achieve this – so about half of the extra supply is coming from fertiliser inputs and half is coming from higher levels of soil mineral N at sowing of the crop. This additional soil N at sowing has come from residual N at harvest of the prior crop and from higher rates of fallow mineralisation, though at higher N supply levels this balance shifts more towards residual N left over at harvest. So, to achieve the predicted economically optimal N bank target for this site and scenario (i.e. 200 kg N/ha) would only require inputs of about 82 kg of fertiliser N/ha per year on average.

Table 2. Simulated long-term (1991–2022) production, N inputs, losses, balance and use efficiencies and overall impact on soil greenhouse gas (GHG) emissions under different N bank targets at Gurley in northern NSW, on a Vertosol soil with a starting labile C of 0.9%.

N bank target (kg N/ha)	30	60	90	120	150	200	250	300	350
Grain produced (t/ha/yr)	1.41	1.68	2.12	2.49	2.79	3.00	3.07	3.05	3.05
Biomass grown (t/ha/yr)	4.14	4.88	5.91	6.76	7.46	7.94	8.05	8.01	7.98
Metrics of N inputs, dynamics and balance									
Fertiliser applied (kg N/ha/yr)	2	14	34	50	65	82	93	102	111
Average soil mineral N in top 1 m at wheat sowing (kg N/ha)	50	53	62	77	93	128	168	210	252
Residual N at harvest (kg N/ha)	21	22	25	31	38	55	84	120	160
Fallow mineralisation (kg N/ha/yr)	61	67	74	80	85	89	90	89	89
N balance (kg N/ha/yr)*	-27	-22	-15	-9	-4	4	11	19	27
NUE (yield per kg N supplied)	29	26	23	20	18	15	12	10	9
Environmental metrics									
Soil C balance (kg C/ha/yr)	-251	-221	-195	-176	-164	-156	-156	-156	-156
N_2O loss (kg N/ha/yr)	0.3	0.4	0.6	0.8	1.0	1.4	1.8	2.1	2.3
Leaching (kg N/ha/yr)	0	0	0	0	0	0	0	0	0
Net soil emissions (kg CO_2-eq/ha/yr)	1052	960	915	907	927	1020	1130	1228	1303

*N balance is calculated as the total N removed in grain minus the fertiliser N applied per year.

Secondly, at lower N bank targets the predicted N export of grain exceeds the fertliser N inputs, meaning that these systems are continuing to mine SOM (as shown by faster rates of decline in soil C balance). The economically-optimal N bank target was predicted to reach long-term N balance when inputs and outputs were approximately equal and soil C decline would be stabilised.

Finally, a question about these longer-term strategies is their capacity to increase N losses via leaching or denitrification. At least in this scenario, these values are low and a high proportion of the added N is retained. Nonetheless, the nitrous oxide (N_2O) emissions are significant contributors as a potent greenhouse gas. As N supply increases the lower soil C reduction is sufficient to offset the higher N_2O emissions, until yield starts to plateau. Nonetheless, the optimal N bank of 200 kg N/ha here produced lower net soil emissions (1020 kg CO_2-eq/ha/yr) than running a nutrient depleted system at 30 kg N/ha supply (1052 kg CO_2-eq/ha/yr) . Only once this optimal N bank was exceeded did overall emissions increase further.

Risk and reward implications

One of the goals of RiskWi$e is to look at the balance of risk and rewards for different N decision making strategies. While we don't have a full complement of them all to compare at this stage, Figure 3 below demonstrates the trade-off between risk (i.e. returns in the worst 20% of years) and reward (i.e. the long-term average) across N bank targets or N supply. This shows that the optimal economic N bank target (i.e. the one generating the highest long-term average), also has lower returns in the worst years. This is because there would have been higher fertiliser costs than were necessary and in some seasons grain yield can be reduced from excess N supply. What this demonstrates is that for a risk averse farmer, trying to mitigate N losses in the worst cases, slightly lower N bank targets may be a safer choice, but are likely to sacrifice some income over the long term.

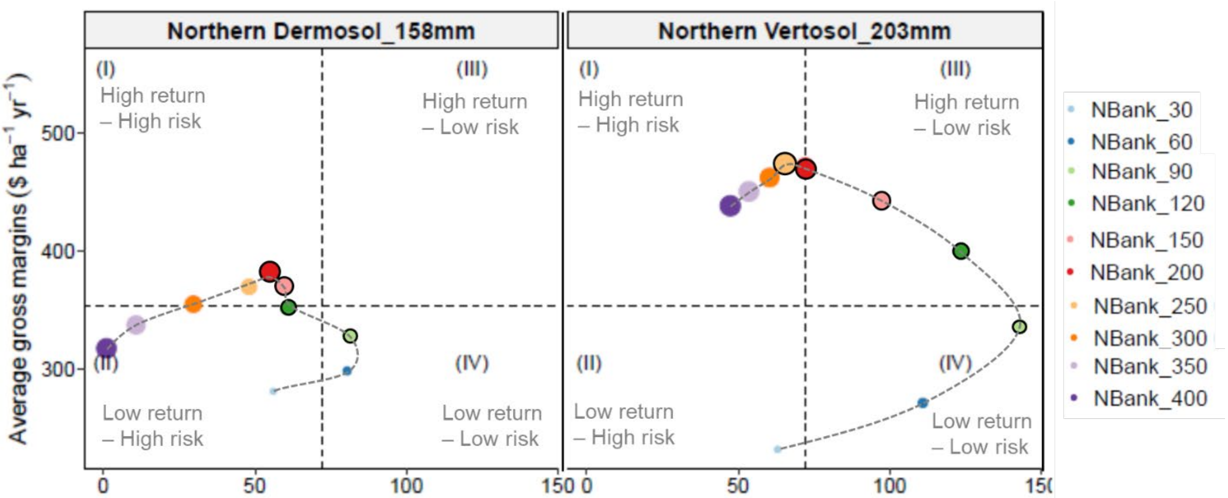

Figure 3. Relationship between long-term average gross margin and the average gross margin in the worst 20% of years for various N bank targets on 2 different soils at Gurley in northern NSW.

Conclusions

Fertiliser N inputs are an important driver of your systems short-term profitability and the long-term fertility of your soils. Developing an approach that ensures the soil can provide the bulk of your crops N demands rather than trying to 'catch-up' by relying on in-season applications will reduce the likelihood of N deficient crops and reduced yield potential. Traditional approaches have worked well while our soils have still had sufficient fertility to support continued negative N balances, but as our soil fertility continues to decline and we increasingly rely on synthetic N inputs there is a need to reconsider our long-term N strategies. Here we show that an N banking approach could be highly effective in the northern grain-growing region allowing for simpler decision making on appropriate N fertiliser inputs to maximise yield potential. Further studies will examine how this approach compares to other decision-making strategies over the long term and across different production environments.

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