Risk and reward of different N budgeting approaches – insights from farming system and RiskWi$e research

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Take home message

- Getting your nitrogen (N) fertiliser strategy right is critical to maximising yield potential while avoiding risks of N losses, soil fertility decline and managing costs
- Targeting a decile 5 yield rarely results in N deficits in crops, only in the best years or after multiple good years does this approach lead to sub-optimal crop yield and gross margin (GM)
- N budgets that target higher seasonal yield predictions, don't require extra N year after year, as excess N is cycled into subsequent years and is not wasted.
- Rather than applying a crop-by-crop approach to N supply, take a multi-year perspective to maintain the soil N status to avoid continued soil fertility mining
- Setting an annual target N supply rather than tailoring this to each season can perform well in northern farming systems
- Setting an N target for a decile 5 yield in your environment and soil appears to balance upside and downside risks.

Introduction

Nitrogen (N) is typically the largest variable cost in most grain production systems and optimising its application is often critical to maintaining long-term productivity and profitability of a grain production system. However, application of N to crops is fraught with uncertainty – how the season will play out and hence the crops likely demand and response to any additional N?; will the crop utilise the N applied and how much may be left for subsequent years?; and ultimately did the addition of N result in a positive yield or economic outcome?. 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.

Nitrogen supply strategies has been one of the key levers looked at in the northern farming systems project which has evaluated an approach that targets the median (or decile 5) yield compared to a more aggressive approach to N supply targeting decile 9 yields (which should ensure crop demand is satisfied and crops are 'N unlimited' in the best growing seasons). The degree that these crops have left residual N and/or increased cycling in subsequent years has been measured. Additionally, the national RiskWi$e project is looking at alternative approaches to budgeting N and aims to quantify the risks and returns for different approaches.

Farming systems nutrition strategies

Comparison of crop N inputs and crop demands

Over the life of the farming systems experiments nearly 90 comparisons of non-legume crops (i.e. wheat, barley, canola and sorghum) have been implemented, each with N budgets targeting a decile 9 and decile 5 yield predictions. Using site-specific APSIM simulations, the N budget was calculated for each season using that crop's sowing date and starting soil water. In general, the yield target and N budget for a decile 9 was around double that for a decile 5. Fertiliser was added to reach this budget after available soil mineral N prior to sowing was considered.

Despite the difference in the N budget between the two approaches, only 50% of the time did the higher yield target require additional fertiliser N to be applied, and only 30% of the time was this a significantly higher (i.e. >25 kg N/ha more) (Figure 1A). Because fertiliser was only applied to supplement the mineral soil N, this shows that in most cases this was more than the budgeted requirement of the lower yield target and in several cases sufficient to satisfy both N budget targets. Hence, once the background soil N status had been built the fertiliser N applied did not need to make up the full difference each time. Furthermore, in several circumstances (about 20% of the time), the crops fertilised to the higher yield target required less N to be applied than their counterparts with the decile 5 yield target (i.e. the cases with a negative value in Fig 1A), because there was much greater residual N following the previous crops. Both outcomes occurred because a large amount of the extra unused N applied in previous crops was recycled and was available for subsequent years.

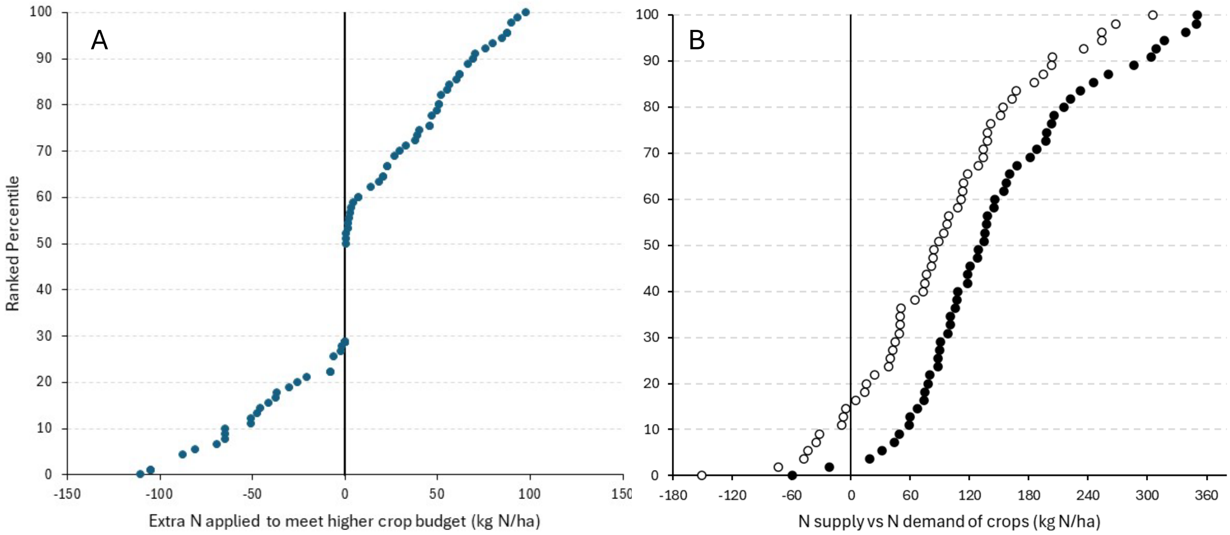

Figure 1. A) Comparison of extra N applied to crops to reach N budget for the decile 9 yield target compared to the decile 5. B) The surplus or deficit of N supply (i.e. soil mineral N and applied N) compared to seasonal demand (computed from measured yields) for each of these crops where N was budgeted targeting a decile 5 (open circles) compared to a decile 9 (closed circles) crop yield prediction across all experimental comparisons in farming systems sites.

Across all the cropping seasons and sites, the N supply from both fertiliser and soil mineral N was almost always sufficient to satisfy the seasonal crop demands (Figure 1B). In only 2 of the 90 crop comparisons was crop supply less than demand under the decile 9 yield target – in other words almost all these crops N was generally oversupplied. Similarly, even for the crops targeting a decile 5 yield, only 10–15% of the time was crop supply less than crop demand and the remainder of the time crops had sufficient or surplus N to meet seasonal demands. Over our dataset there were few growing seasons where crop potential and hence N demand exceeded N supply, and hence in only about 10% of cases we would expect there to be a growth or yield response to higher N supply.

Individual crop growth and economic responses

Because few seasons had an estimated N deficit in the decile 5 yield targets, there were limited cases of significantly positive yield responses to the higher N target (Figure 2). Most seasonal comparisons were within boundaries of ±500 kg/ha of grain yield and ±1000 kg/ha of biomass. Only in those 10 % of years was a grain yield increase >500 kg/ha observed or a crop biomass increase >1000 kg/ha from the higher N target, likely to induce a positive economic gain. Across the crop comparisons in the dataset the partial gross margin from the higher N target (i.e. income difference minus the cost difference) was increased 50% of the time and reduced 50% of the time. About half of the comparisons were within $50/ha difference either way (higher or lower), indicating very little change in those crop returns for these crops. The extremes in this comparison were induced where there was a positive yield response increasing crop GM by over $300/ha and counter to that we observed a couple of cases where crop yields and GM were significantly reduced due to haying off under the higher N budget.

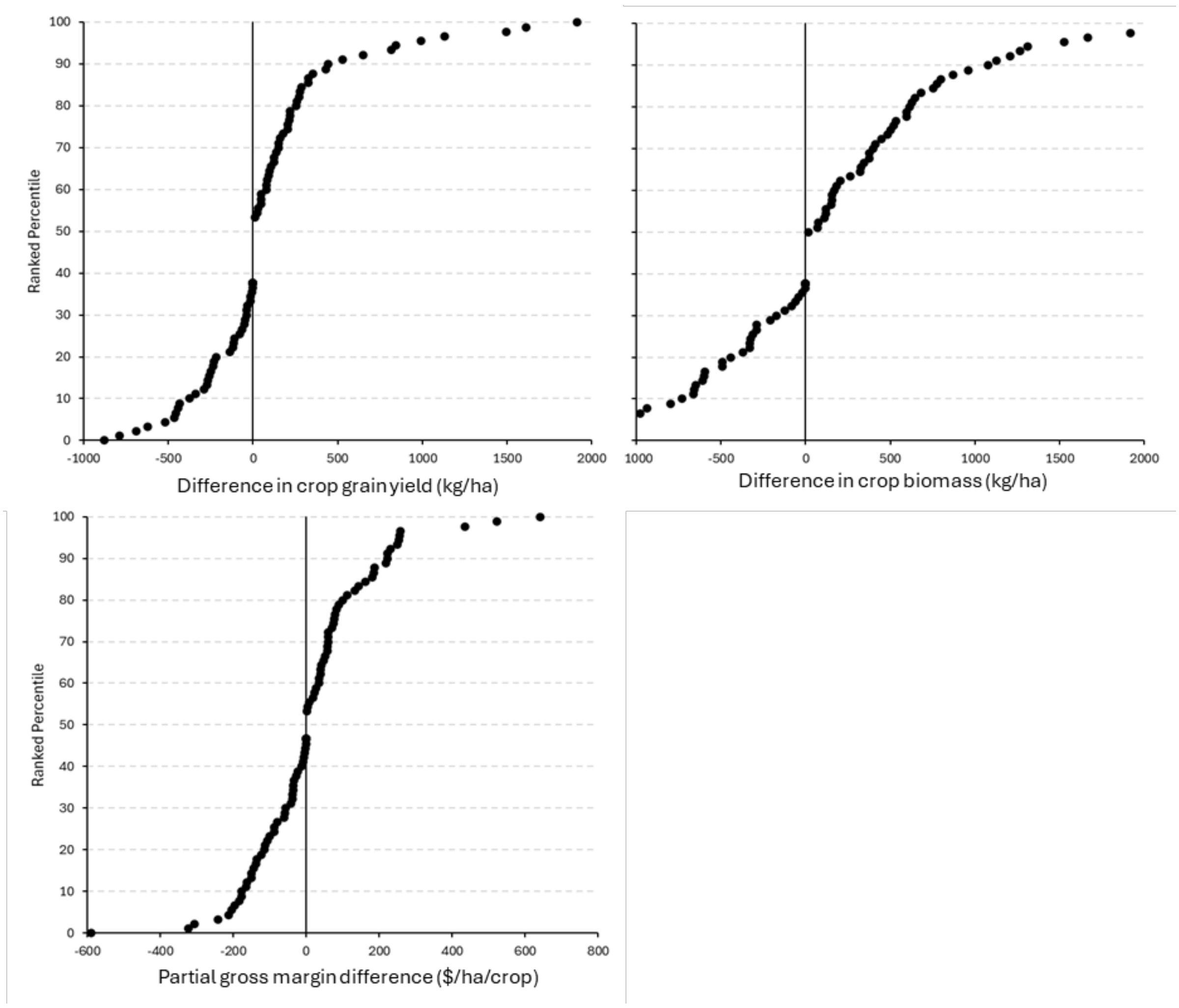

Figure 2. Response of crop grain yield (top left), crop biomass produced (top right) and partial gross margin (i.e. extra yield minus cost of extra N; bottom) for 90 individual crop comparisons that had different N budget targets, calculated for a decile 9 yield prediction compared to a decile 5 yield prediction across farming systems experimental sites.

System level N balance and economic outcomes

Over the long-term (8 years) across all farming systems sites, the higher nutrient supply strategy of fertilising to a decile 9 compared to a decile 5 seasonal yield target has only resulted in a higher overall income or yield at the Trangie red soil site and at Emerald (Table 1). At all other sites a similar yield and income has been achieved, except at Trangie on the grey soil where the higher fertiliser input reduced yield in one of the seasons. While there is some variation across sites, owing to the background nutrition and starting mineral N, the higher N targets required an additional input of about 20 kg N/ha/yr to meet the higher crop yield target. This extra input largely offset the net N removal which still occurred at almost all sites. The only exceptions were the Emerald and Billa Billa sites which required little fertiliser N input to meet the N budget targets across both strategies, due to high background fertility and high mineralisation rates at both sites.

Table 1. Comparison of 10-year average annual N inputs and N balance and overall crop income generated between Baseline farming systems supplied with N fertiliser to meet decile 5 or decile 9 seasonal forecast yields across farming systems experimental sites spanning the grain growing regions of Australia's subtropical summer-dominant rainfall.

Experimental site	System N applied (kg N/ha/yr)		Partial N balance (kg N/ha/yr)		Gross income ($/ha/yr)	
	Decile 5	Decile 9	Decile 5	Decile 9	Decile 5	Decile 9
Trangie – Red	37	75	-10	+19	860	925
Trangie – Grey	60	83	+2	+28	882	807
Narrabri	32	70	-24	+15	989	975
Spring Ridge	46	70	-26	-4	1279	1283
Billa Billa	3	10	-56	-53	967	965
Mungindi	23	43	-9	+6	527	531
Emerald	12	17	-50	-48	1085	1135
Pampas – mixed	44	75	-28	0	1183	1192
Pampas – summer	39	53	-21	-6	1004	994
Pampas – winter	28	49	-37	-17	1045	1042

Long-term predictions of N budget targets

Knowing that N response is highly seasonal, long-term simulation modelling has been used to extrapolate beyond the experimental period over a 30-year period. This involved developing simulations that captured the crop decisions over a sequence of years and developing a system that allowed N budgets to be targeted to yield predictions for each of these crops depending on sowing soil water conditions and sowing dates. This also allowed us to explore the implications of other N targets across our farming systems research sites. Here we compare systems with a seasonal N budget developed to target yield predictions in either decile 3, 5, 7 and 9 of predicted yields. As with the experimental protocols, the N budget was calculated from crop specific factors (e.g. 35 kg/t for wheat, 80 kg/t for canola, 25 kg/t for sorghum) and the predicted yield for each target for that seasonal circumstance. Fertiliser N applied at sowing was determined by the difference between this target and the mineral soil N at sowing. Results for a *Baseline* system only, have been presented, i.e. involving the main crop options at each location (i.e. mainly wheat, barley, sorghum, chickpea).

Table 2. Predictions of N fertiliser applied, N balance, system gross margin (GM), costs and return on fertiliser inputs, and individual crop GM where N budgets were applied that targeted decile 3, 5, 7 and 9 yields for the particular seasonal conditions over a 30-year simulation period for a Baseline farming system at Trangie, NSW (i.e. wheat 43%, barley 5%, canola 21%, chickpea 23%, field pea 8%).

System outcomes	**Seasonal N budget targeting different decile yields**			
	Decile 3	**Decile 5**	**Decile 7**	**Decile 9**
N balance				
N inputs per year (kg N/ha/yr	34	55	70	83
Fixed legume N inputs (kg N/ha/yr)	23	22	20	18
N removal (kg N/ha/yr)	102	118	127	134
N balance (kg N/ha/yr)	-45	-41	-37	-33
System profitability				
Annual GM	453	509	526	532
Annual costs	311	342	365	384
Return per kg N applied	13.1	9.3	7.44	6.4
Return on investment	1.24	1.26	1.22	1.18
Mean individual crop GM ($/ha)				
Wheat	421	520	567	609
Barley	359	394	389	349
Canola	851	994	1010	977
Chickpea	769	771	768	767

Long-term simulations for the example location of Trangie show that as the target yield increases the N inputs increase, but this is not a proportionate increase – more inputs are required to increase from decile 3 to 5 (21 kg N/ha/yr) than 7 to 9 (13 kg N/ha/yr). Legume N fixation also decreased with higher N targets. Both these results show that there is more residual N carried over to subsequent years at the higher decile targets. This increase in N applied was also higher than the increase in N removal meaning that the higher budget target did improve the N balance of the system.

From an economic perspective, the optimal outcome was to target decile 7 crop yields, though this was not greatly different from decile 9. Targeting decile 5 yields produced the highest return on investment (income over variable costs) of the N budgeting strategies. Different crops respond differently to this N target (at least in this environment). As expected, the gross margin of chickpeas was unaffected by N supply, but the optimal target for barley was predicted to be decile 5 or 7, for canola decile 7 and for wheat the higher target was predicted to be best. Part of the reason for these crop differences are that canola and barley were likely to be benefiting from residual N following the previous chickpea or wheat crops.

Strategic N bank target vs tactical season N budgets

The national RiskWi$e program is quantifying the rewards and risks amongst a range of N decision making approaches across different environments. One of these that potentially reduces the need for information and simplifies N decision making is a strategic N banking approach, which differs from the seasonal N budgeting method we have applied in our farming systems research. 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. 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. 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. The challenge with this system is working out the N bank target relevant to your production environment, soil and farming system.

To do this, long-term simulations using APSIM predicted the optimal N bank target for wheat and canola in a particular environment, by simulating a range of N bank levels (30 to 400 kg N per ha) over 30 years (1991 to 2022) at a range of locations across the country. 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). A urea price of $500 per tonne (or $1.08/kg N) was assumed and wheat grain price was assumed to be $221/t after freight, levies and insurance.

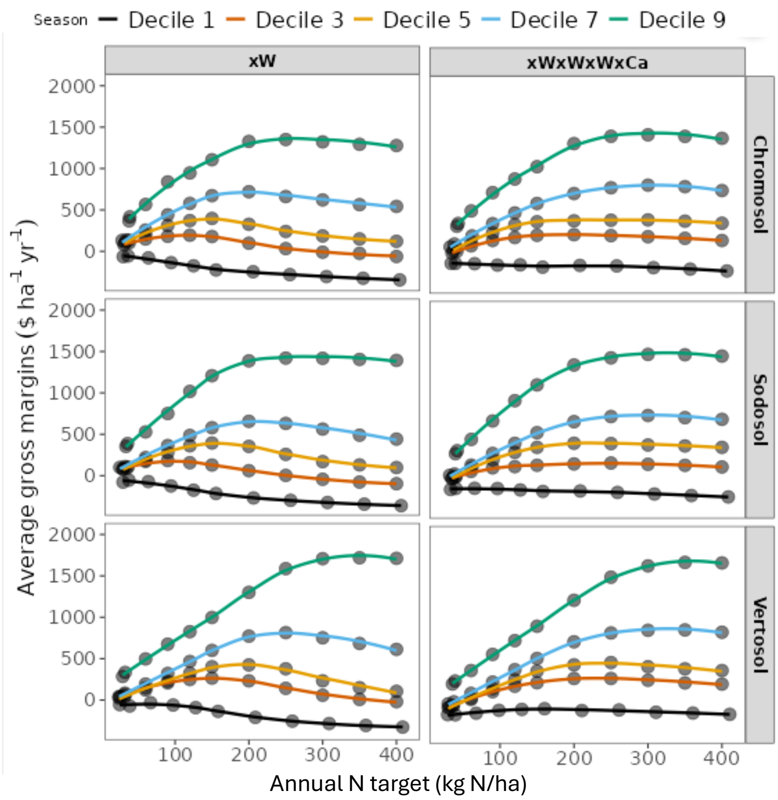

Figure 3. Predicted economic response to increasing annual N bank target in decile 1, 3, 5, 7 and 9 seasons for two rotations (left: continuous wheat; right: wheat/wheat/wheat/canola) at Dubbo, NSW

Figure 3 shows how the gross margin responds to increasing annual N bank target across seasonal conditions. This shows that the optimal N clearly differs across seasons – in decile 1 years GM are typically negative, and the additional N costs reduce this further, while on the other hand in decile 9 seasons there is a strong response to additional N targeting a higher N bank. The profit-maximising N bank target varies across these different season types. In other words, the N rate is almost always wrong, the question is what N rate gets it right most often. So, if a set N bank target is being implemented then it is about balancing the upside in the better seasons against the potential downside in the poorer seasons.

One way to look at this is to calculate the shadow cost for each season, that is the gap or difference between the best option for that season and the outcome for that N supply rate. This tells you how far below the optimum you might have been and how much this might have cost you. Figure 4 shows the box-plot distribution of these shadow costs for each N bank target, with the N bank generating the most values close to zero indicating the system with the lowest frequency and size of this shadow cost. These values generally correspond with the optimal N rate calculated for the decile 5 season shown in Figure 3.

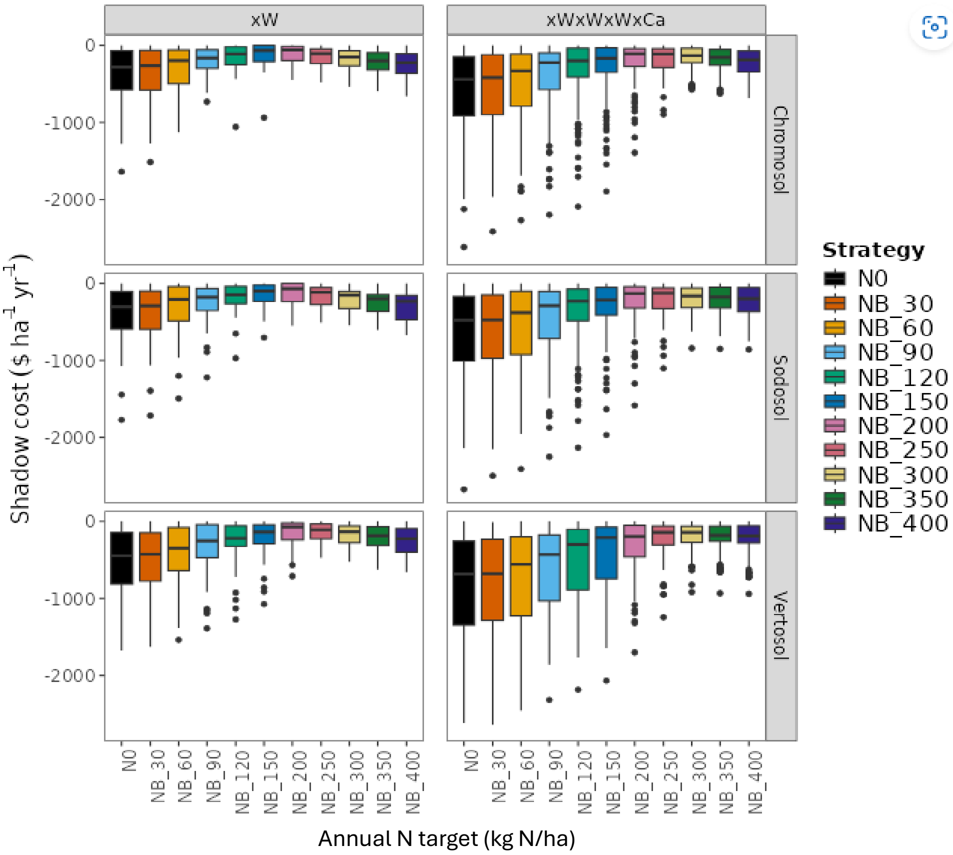

Figure 4. Shadow costs (i.e. difference between the best choice each year) response to increasing N bank target in decile 1, 3, 5, 7 and 9 seasons for two rotations (left: continuous wheat; right: wheat/wheat/wheat/canola) at Dubbo, NSW.

The simulation outputs in Figure 3 and 4 also show that the optimal N bank target is somewhat influenced by: the crop sequence being used – higher frequencies of canola are predicted to require or respond to a higher N target, and the risk or shadow costs of sub-optimal N is also higher; and different soil types – i.e. the optimal economic N target is lower (about 170 kg N/ha) on the soils with lower plant available water capacity (PAWC; Chromosol and Sodosol) than soil with a higher PAWC (Vertosol) (200–220 kg N/ha). Hence, why a general approach that allows site-specific estimation of the N target is needed.

Conclusions

Fertiliser N inputs are an important driver of your system's short- and long-term profitability, so developing an approach that ensures the soil can provide the bulk of your crop's 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. The results from the farming systems experiments and long-term modelling confirm that targeting decile 9 or maximum yield potential is unlikely to be the most economically optimal and likely to involve higher risks of N losses. Across both farming systems experiments and long-term modelling, setting the seasonal N target corresponding to decile 5 yield predictions provides a good balance of risk and return over the long term. More robust targeting decile 7 is likely to allow upside benefits in better years, and much of the N can be recycled for subsequent years. Rather than taking a more complex season-by-season budgeting approach which requires yield predictions, a more consistent year-on-year target (aka N banking), is likely to realise similar outcomes without higher risks and allowing for simpler decision making on appropriate N fertiliser inputs to maximise yield potential.

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