Strategies for long term management of N across farming systems

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Key words

nitrogen, yield gap, Yield Prophet®, N bank, nitrogen deficiency

Take home message

- Maintain a neutral to slightly positive long-term N balance (as much N inputs from legumes and fertiliser as is removed in grain) to maximise profit and slow soil organic matter decline
- 'N bank' targets, Yield Prophet® and WUE tools and are all valid ways to manage N fertiliser and achieve potential yield without total soil N run-down
- Don't fear occasional overapplication of N - on most soils in southern NSW unused N carries over and is available to subsequent crops and to help maintain soil organic matter.

Background

Modelled data suggests Australian wheat yields are only half what they could be for the rainfall received (Hochman et al., 2017). Nitrogen (N) deficiency is the single biggest factor contributing to this yield gap (Collis, 2018; Hochman and Horan, 2018). This is also likely to be true for other non-legume crops (barley, canola and oats) which reduces farm profitability and global food security. Alleviating N deficiency economically could increase national wheat yields by 40 per cent (Hochman and Horan, 2018), and substantially improve farm profit.

On farms with no legume pastures, and with low levels of soil organic matter (SOM), most of the crop N supply must come from fertiliser. Grain legumes do not provide enough N to support yield of subsequent crops at the intensity (and targeted yield levels) at which they are currently grown. N fertiliser is a costly input and use of it increases cost of production and value-at-risk for growers. Growers fear that over-fertilisation will result in 'haying off', which reduces both yield and quality. There is also the concern that overapplied fertiliser that is not used by crops is lost to the environment by leaching, volatilisation and denitrification. Consequently, efforts continue to be made to match N fertiliser inputs to predicted seasonal yield potential. This is difficult in southern Australia due to the lack of accurate seasonal forecasts for rainfall.

The difficulty in matching N supply to crop demand and a tendency for growers to be conservative in their N inputs is responsible for a large proportion of the yield gap that can be explained by N deficiency. Chronic N deficiency has also caused soil organic matter to decline (Angus and Grace, 2017) and has driven a rise in the proportion of low protein grain produced in Australia (GrainCorp, 2016), which has eroded our standing as a producer of quality wheat in export markets.

What can we do about it?

We propose that the yield gaps due to N deficiency could be reduced if a longer-term approach to N management within farming systems is taken. This means recognising that on most soil types in southern NSW, environmental losses (volatilisation, denitrification, leaching, run-off/lateral flow) of N are low and episodic (Smith et al., 2019). The majority of fertiliser N that is applied in one season and not taken up by the crop is stored in the soil either in mineral or organic form and carries over for use by subsequent crops. This means N fertiliser applied that is surplus to crop requirements is not a lost cost but will be recouped in subsequent seasons and in fact can play a vital role replenishing soil organic N (Alvarez, 2005; Ladha et al., 2011).

How do we implement this?

The first step is using a valid method to ensure that enough fertiliser N is being applied to meet seasonal crop demand. The two key types of tools to do this are:

1. Those that try and match N inputs to seasonal demand such as WUE tools (e.g. Yield Prophet® Lite), Yield Prophet® and;
2. 'N bank' targets which maintain a base level of fertility.

Both are valid ways to calculate N supply to meet crop demand.

Yield Prophet® is still a highly effective tool to match N supply to seasonal demand. The downside of Yield Prophet® is that it is 'data-hungry' and requires experience to get it right. Yield Prophet Lite® and this simple spreadsheet tool (available here; https://www.bcg.org.au/understanding-crop-potential-and-calculating-nitrogen-to-improve-crop-biomass-workshop-recording/) requires less data but doesn't give probabilistic output or include seasonal forecasts.

'N banks' (Meier et al., 2021) are a strategy to manage N in crop production areas with low environmental losses (leaching, denitrification, volatilisation). Most of southern NSW has soils which are free-draining and hold a reasonable amount of water, receive low to medium rainfall and are generally acidic in the surface. Therefore, environmental losses of N are low, and N banks are likely to be an effective strategy to manage N in most of the region. Exceptions are areas prone to waterlogging or that have very sandy soils where leaching may occur. The advantages of N banks are that they are simple to calculate, crops are rarely N deficient, and if set at an appropriate level for the environment, the soil organic N is not mined but maintained. They also shift the cost of N fertiliser into years following a season of high production (when income is high), rather than within the current season of **possible** high production. Possible disadvantages include higher chance of N losses if the N is not used or immobilised, and haying-off (low yield, high protein) in low rainfall seasons. The risk of these are being experimentally evaluated at a BCG-La Trobe long term field experiment in the southern Mallee.

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 early in the growing season, and if less than the target N bank, is topped up to the target value with fertiliser N. A more detailed description of N banks and a long-term experiment investigating their effectiveness can be found here: http://www.ausgrain.com.au/Back%20Issues/301mjgrn20/Grower%20group%20focus.pdf

The problem with Yield Prophet® and WUE tools is they require a forecast of the future (i.e. how much rain is going to fall between now and the end of the season). The N bank management strategy that is currently being developed does not even attempt to match crop N supply to seasonal demand, it simply makes sure that the crop has enough N supply (soil mineral N measured early in the season + fertiliser) to achieve water limited potential yield in most seasons. We do this by selecting an N bank yield target appropriate for the environment and apply N accordingly. A target of 125kg/ha N is proving most profitable in the southern Mallee (average wheat yield ~3.0 t/ha), but it is likely to be more like ~200 kg/ha N (average wheat yield >5 t/ha) at higher rainfall locations in south eastern NSW (Smith et al., 2019). We then use soil mineral N measurements from soil cores to work out how much mineral N the crop has available and top up the balance with fertiliser. For example:

Soil mineral N measured in soil cores (0-1 m) = 75kg/ha N

N bank target = 200kg/ha N

Fertiliser required to meet N bank target = 200 – 75 = 125kg/ha N (271kg/ha urea)

This system relies on having well drained loams or clay soils with low risks of leaching or denitrification losses associated with waterlogging, so that most surplus N applied carries over to the next season. Less N is needed following a low yielding year when a lot of mineral N is not used by the crop and carried over, and more N is required to be applied following a high yielding year when lots of N has been taken up by the crop and removed in grain.

How do the two different approaches stack up?

Three years of results from a BCG-La Trobe University long term experiment at Curyo indicate that an environmentally appropriate N bank strategy and Yield Prophet® (matching N to seasonal yield potential) use similar amounts of N and are equally profitable (Figure 1), and this is confirmed by simulation studies over many seasons (Meier et al., 2021). Modelling also suggests the strategy works in southern NSW across a rainfall gradient from Griffith to Young in free draining soils with at least 147 mm plant available water capacity (Smith et al., 2019).

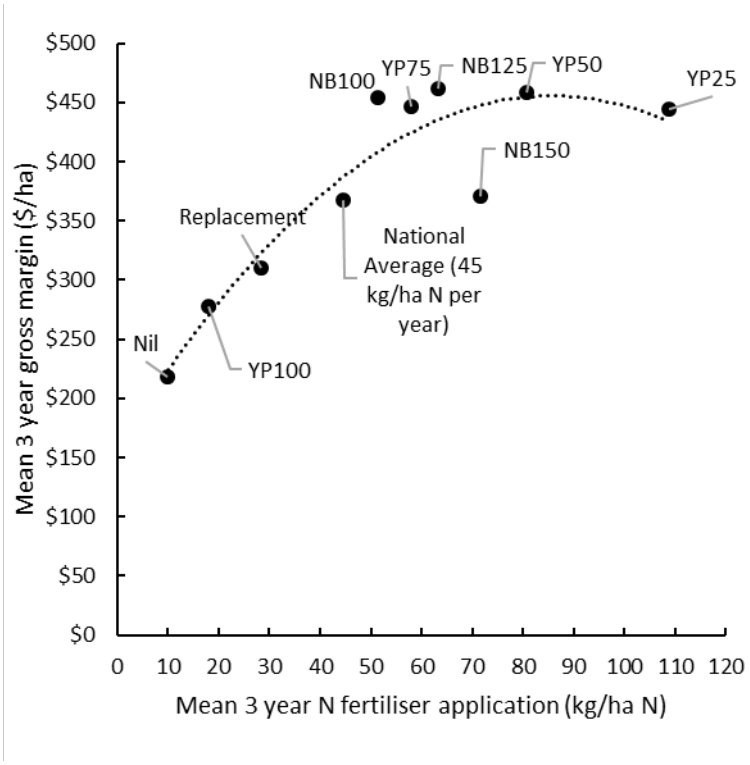

Figure 1. Mean fertiliser application and mean gross margin (2018-2020) for the BCG-La Trobe University long-term N management experiment at Curyo. For details of the experiment see http://www.ausgrain.com.au/Back%20Issues/301mjgrn20/Grower%20group%20focus.pdf. The number following 'N bank' treatments, is the N bank target in kg/ha. YP=Yield Prophet treatments at different levels of probability (YP100% targets yield assuming the worst season finish on record, YP50% targets yield assuming a median finish etc.).

Soil testing is essential

WUE tools, Yield Prophet® and the 'N bank' management system all rely on growers knowing how much mineral N (nitrate and ammonium) they have available to a crop early in the growing season. In all these tools it is best not to include in-season mineralisation in the calculations, because mineralisation is cancelled out by immobilisation in systems where soil organic matter is being maintained (i.e. stubble retained systems with neutral to positive N balance). Consequently, for any rational decision to be made on N management, it is critical that paddocks are soil tested to measure mineral N at the start of the season. Assessment of the soil N bank is achieved by testing for nitrate and ammonium. This can be done any time from March through to June, but if done following

sowing it is essential that samples are taken from the inter-row to avoid sampling any fertiliser N applied at sowing. Soil cores should be taken to at least 0.6m (ideally >1.0m) and segmented into different depths (e.g., 0-0.1 m, 0.1-0.3 m, 0.3-0.6 m). At least six cores need to be taken per paddock or production zone within a paddock, and bulked samples carefully mixed. Samples should be kept cool and sent to the laboratory as soon as possible after sampling. A good soil sampling contractor will do all these things for you!

Managing spatial variability

Soil mineral N varies a lot spatially, and this makes soil sampling difficult and prone to error. It can be beneficial to soil sample high and low yielding zones of paddocks independently to get a better picture of what is happening across the paddock. Some growers are making variable rate N applications based on protein maps from previous crops and are reporting a high level of success at achieving higher yield and protein in high performing areas of paddocks and avoiding chronic over-fertilisation in low yielding areas. Whilst protein maps are an effective way of informing how N is best allocated across a paddock, they can't help with estimating the base rate, with soil testing and the management systems described above necessary to achieve this.

Reviewing performance

N management performance should be reviewed over the longer term (>3 years), and there are two effective ways to do this and make sure growers are achieving your production goals. The first is by reviewing wheat grain protein. If growers are producing wheat with less than 10.5% protein (ASW), then yields are highly likely to be N limited, and profits will almost certainly be increased by increasing N application rates. If protein is between 10.5% and 11.5% (APW), yields are likely to be N limited and profits improved by increasing N application. If protein is between 11.5% and 13% (H2) yield is likely maximised and there will be no benefit from further N application. If protein is over 13% (APH) it is extremely unlikely that yields are N limited, and growers may be over applying N at the expense of some yield and perhaps profit, depending on whether they are attracting price premiums for high protein grain.

The second way to review N management is to calculate a long-term N balance for individual paddocks. N balance is the sum of N inputs from fertiliser and legumes minus the amount of N that has been exported in grain (a simple spreadsheet to calculate N balances is available here; https://www.bcg.org.au/understanding-crop-potential-and-calculating-nitrogen-to-improve-crop-biomass-workshop-recording/. N balance is a good indicator of levels of soil organic N mining. Paddocks with a neutral to positive N balance are unlikely to be mining soil organic N, and soil organic matter under cropping should be maintained. Paddocks with a negative N balance are mining soil organic N and soil organic matter will be declining. A very positive N balance indicates chronic over application, and whilst this might be building soil organic matter in stubble retained systems (soil organic matter contains C and N as well as P and S in constant ratios), profits might be increased by reducing N applications.

The BCG-La Trobe field experiment (Figure 2) and simulation studies (Meier et al., 2021; Smith et al., 2019) both indicate that profit is maximised at neutral to slightly positive N balances.

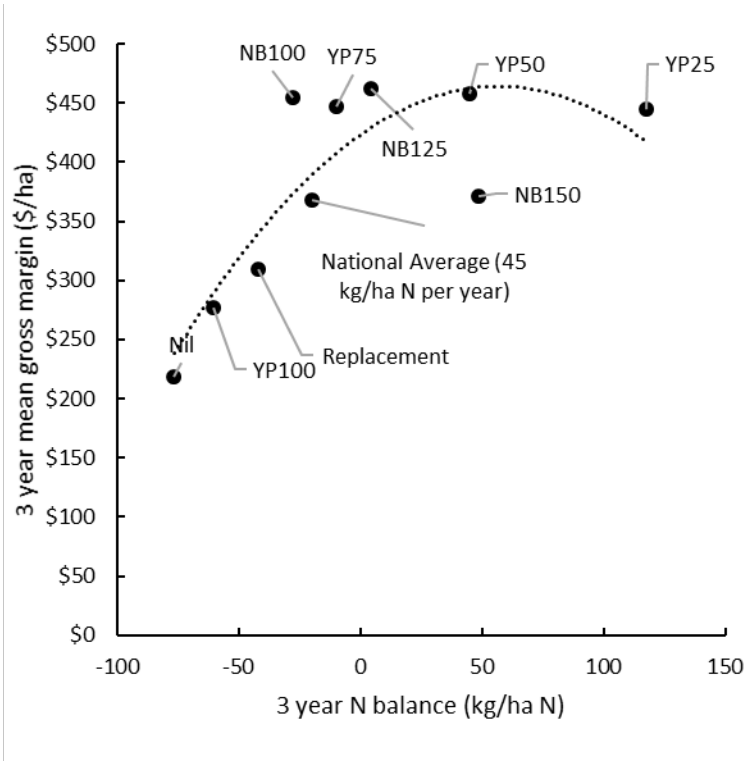

Figure 2. The BCG-La Trobe University long-term N management experiment at Curyo is showing that N management strategies that over-apply (i.e., have a neutral to positive N balance) are more profitable. These strategies will also reduce likelihood of mining soil mineral N and thus running down soil organic matter. For details of the experiment see: http://www.ausgrain.com.au/Back%20Issues/301mjgrn20/Grower%20group%20focus.pdf The number following 'N bank' treatments is the N bank target in kg/ha. YP=Yield Prophet treatments at different levels of probability (YP100% targets yield assuming the worst seasonal finish on record, YP50% targets yield assuming a median finish, etc.).

Recent farming systems experiments in southern NSW demonstrate the concept

GRDC funded farming systems experiments in southern NSW over the last 3 years have used different crop sequences and N strategies that exemplify the concept of taking a longer view with N management. The experiments included two N targets for topdressing decisions – one targeting Decile 2 conditions (conservative) and one targeting Decile 7 conditions (more akin to N-bank). The results during the two consecutive Decile 1 years of 2018 and 2019 tended to demonstrate that Decile 7 approach was less profitable in those years, however the record season of 2020 revealed significant responses to carry-over N that had been applied in previous years. At the time of writing the data for the full 3 years N balance was being reviewed and will be presented at the Update.

Conclusion

Nitrogen deficiency is the single biggest cause of the Australian wheat yield gap. Growers can easily reduce this yield gap, increase profit, and stop mining soil organic matter by taking a longer-term view of N management. Soil testing is essential to do this. N banks, Yield Prophet® or WUE tools are all equally effective at reducing N limitation and increasing profit. N management performance can be reviewed using wheat grain protein and calculating N balances for individual paddocks to make sure yields and profit are maximised and organic N is not being mined.

Acknowledgements

This project is funded by La Trobe University through the Securing Food, Water and the Environment Research Focus Area and the Mallee Catchment Management Authority, through funding from the Australian Government's National Landcare Program.

Useful resources

http://www.ausgrain.com.au/Back%20Issues/301mjgrn20/Grower%20group%20focus.pdf

https://www.bcg.org.au/managing-n-fertiliser-to-profitably-close-yield-gaps/

https://grdc.com.au/resources-and-publications/all-publications/publications/2020/a-nitrogen-reference-manual-for-the-southern-cropping-region

References

Alvarez R. (2005) A review of nitrogen fertilizer and conservation tillage effects on soil organic carbon storage. Soil Use and Management 21, 38-52.

Angus JF and Grace PR. (2017) Nitrogen balance in Australia and nitrogen use efficiency on Australian farms. Soil Research 55, 435-450.

Collis C. (2018) Growers hold the aces for WUE and yield. GroundCover, Vol. 135. Barton, ACT: GRDC, 33.

GrainCorp. (2016) GrainCorp Australian Crop Report 2015/16. Sydney: GrainCorp, 40.

Hochman Z, Gobbett DL and Horan H. (2017) Climate trends account for stalled wheat yields in Australia since 1990. Global Change Biology 23, 2071–2081.

Hochman Z. and Horan H. (2018) Causes of wheat yield gaps and opportunities to advance the water-limited yield frontier in Australia. Field Crops Research 228, 20-30.

Ladha JK, Reddy CK, Padre AT and van Kessel C. (2011) Role of Nitrogen Fertilization in Sustaining Organic Matter in Cultivated Soils. Journal of Environmental Quality 40, 1756-1766.

Meier EA, Hunt JR and Hochman Z. (2021) Evaluation of nitrogen bank, a soil nitrogen management strategy for sustainably closing wheat yield gaps. Field Crops Research 261, 108017.

Smith CJ, Hunt JR, Wang E, Macdonald BCT, Xing H, Denmead OT, Zeglin S and Zhao Z. (2019) Using fertiliser to maintain soil inorganic nitrogen can increase dryland wheat yield with little environmental cost. Agriculture, Ecosystems & Environment 286, 106644

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