Using novel nitrogen management systems to solve a complex problem

James Hunt[1], James Murray[2], Kate Maddern[2], Juan Wang[1], Caixian Tang[1]

[1] Department of Animal, Plant and Soil Sciences, La Trobe University, Bundoora, VIC 3086, Email: j.hunt@latrobe.edu.au
[2] Birchip Cropping Group, 73 Cumming Ave, Birchip, VIC 3483

Abstract
Nitrogen (N) deficiency is a major cause of the yield gap that exists in Australian wheat production. Chronic N deficiency also results in many fields having negative N balances (N export in grain or hay exceeding N inputs from legumes, fertiliser and manures), leading to mining of soil organic N and a decline in soil organic matter (SOM). These problems arise from difficulties in managing N fertiliser to seasonal yield potential and fear of over-application. We propose that crop yield gaps and SOM decline due to N deficiency could be solved if a longer-term approach to N management was taken. A multi-year field experiment was established at Curyo, Victoria in 2018 to evaluate the ability of different fertiliser N management systems to profitably alleviate N deficiency. Systems evaluated included Yield Prophet® at different probabilities, 'N banks', replacement, national average (45 kg N/ha per year) and a nil control. After three years (2018-2020), Yield Prophet® at 50% probability and the 125 kg/ha N bank have applied more fertilizer (mean 81 and 63 kg N/ha/year, respectively) than the national average, have higher gross margins ($458/ha and $462/ha vs $368/ha) and have maintained positive N balances (45 and 4 vs -20 kg N/ha). With environmentally appropriate settings and when other yield limiting factors have been overcome, both Yield Prophet® and N banks are highly effective at alleviating N deficiency, closing yield gaps and likely slowing SOM decline in the long term.

Keywords
Nitrogen, fertiliser, yield, soil organic matter

Introduction

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 (Hochman and Horan 2018; Armstrong *et al.* 2019). This is also likely to be true for other non-legume crops (barley, canola and oats). 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 current intensity. 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 over-applied fertiliser that is not used by crops may be substantially lost to the environment through 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 extreme seasonal rainfall variability and the lack of accurate seasonal forecasts.

The difficulty in matching N supply to crop demand and a tendency for growers to be conservative with N fertiliser is responsible for a large proportion of the yield gap that can be explained by N deficiency. Chronic under-fertilisation has resulted in mining of soil organic N (Angus and Grace 2017), which causes soil organic matter to decline due to the stoichiometric demand of microbial biomass for carbon (C) and N (Kirkby *et al.* 2014). We propose that the yield gaps due to N deficiency and associated problems 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 Australia, environmental losses (volatilisation, denitrification, leaching, and run-off/lateral flow) of N are low and episodic (Smith *et al.* 2019). The majority of fertiliser N applied in one season and not taken up by the crop is stored in the soil either in mineral or organic form and can be carried over for use by subsequent crops. This means N fertiliser applied that is surplus to crop requirements in a given year is not a lost cost but will be recouped in subsequent seasons and can play a vital role replenishing soil organic N (Ladha *et al.* 2011).

We commenced a multi-year field experiment in 2018 to evaluate the potential for different N management systems to profitably close the yield gap and slow organic matter decline and results from the first three years of the experiment are reported here. These field results complement an associated simulation study (Meier *et al.*, these proceedings).

Methods

A multi-year experiment using a randomized complete block design with four replicates was established in a commercial wheat paddock near Curyo in north west Victoria in 2018. The site has an alkaline sandy loam topsoil (organic C = 0.65%, total N = 0.062%) with clay content and calcium carbonate increasing with depth. The preceding crop was lentils. Each replicate consisted of four adjacent 2.3 × 12 m plots, with all measurements taken on the two central plots only to avoid neighbour effects. Each plot consisted of 6 crop rows spaced 0.3 m apart.

There were four different N management systems tested; 1) matching N fertilizer to seasonal yield potential (Yield Prophet®, Hochman *et al.* 2009); 2) maintaining a base level of fertility using N fertilizer (N banks, Meier *et al.* 2021); 3) replacing the amount of N removed in grain each year with fertilizer in the next season; 4) applying national average N fertilizer rate (45 kg/ha) each season (national average, Angus and Grace 2017). All systems were compared to a nil control to which only starter fertilizer was applied. Within the Yield Prophet® and N bank systems there were different treatments targeting different yield potentials (Table 1). In the Yield Prophet® treatment, water-limited potential yield was determined at different levels of probability in mid-July of each year and the amount of N required to achieve these yields was top-dressed in late winter assuming a requirement of 40 kg N/ha per t/ha wheat yield and 80 kg N/ha per t/ha canola yield. For the N bank treatments, there were different target levels of N fertility (N bank target). N fertilizer rates in these treatments were calculated as the N bank target value minus soil mineral N (ammonium + nitrate, kg/ha) measured from soil cores taken prior to sowing to 1.0 m and segmented 0-0.1, 0.1-0.3, 0.3-0.7, 0.7-1.0 m depths and analyzed individually. All N fertilizer was top-dressed as urea in late July-August as per best practice when crops were in early stem elongation.

Table 1. Nitrogen management systems and treatments used in the experiments.

System	Treatment	Abbreviation	Description
Nil	-	Nil	No N applied other than in starter fertilizer
Replacement	-	R	Amount of N removed in grain applied as fertilizer N in the following season
National average	-	NA45	National average N fertilizer (45 kg/ha N) applied each season
Nitrogen	100	NB100	Soil mineral N + fertilizer = 100 kg/ha N
bank targets	125	NB125	Soil mineral N + fertilizer = 125 kg/ha N
(kg/ha N)	150	NB150	Soil mineral N + fertilizer = 150 kg/ha N
Yield	100%	YP100	Yield with lowest yielding season finish on record
Prophet®	75%	YP75	Yield with lower yielding quartile season finish (decile 2.5)
probabilities	50%	YP50	Yield with median season finish (decile 5)
	25%	YP25	Yield with higher yielding quartile season finish (decile 7.5)

Crops grown were wheat (cv. Scepter) in 2018 and 2020 and canola (Hyola 350 TT) in 2019. All treatments received the same starter fertilizer being 35 kg/ha urea (16 kg/ha N) applied by the host farmer in 2018, and 60 kg/ha Granulock® Z (N:P:S:Z = 11:22:4:1) in 2019 and 2020. The experiment was kept free of weeds, disease and deficiencies of nutrients other than N as per current best practice management.

Grain yield was measured by mechanically harvesting entire plots in 2018 and 2020 and in 2019 by hand harvesting above-ground dry matter in 0.6 m² (0.5 m x 1.2 m) quadrats from the central four rows of each plot before drying at 70°C for 48 hours, threshing, winnowing and weighing grain. Protein and/or oil content (%) of grain was estimated using a calibrated near infrared spectrometer and N content (%) estimated by dividing protein content by a conversion factor of 5.75. Grain N export was calculated as the product of grain N content and grain yield, and partial N balance was calculated as fertilizer N minus grain N export. All data were analysed in GentStat 19th Edition using mixed linear models (REML) with treatment as fixed effect and row and column as random effects. Linear and quadratic functions were fitted using least squares regression in Microsoft Excel. All gross margins were calculated using values from the 2019 SAGIT Gross Margin Guide (SAGIT 2019) with premiums paid for higher protein grades of wheat as per Smith *et al.* (2019).

Results

There was a quadratic relationship between 3-year mean fertiliser N application and grain yield, with yield being highest in the YP25 treatment (Figure 1a). There was also a quadratic relationship between partial N balance and gross margin, with YP25, YP50, YP75, NB100 and NB125 having equivalent and high gross margins (Figure 1b). The YP50 and NB125 treatments were the most profitable treatments to have either a neutral or small positive partial N balance (45 and 4 kg N/ha, respectively), indicating that they are unlikely to mine soil organic N to the same extent as the NA45 (-20 kg N/ha) or nil control (-77 kg N/ha). The YP50 and NB125 treatments applied more fertilizer (mean 81 and 63 kg N/ha per year, respectively) than the national average and have higher gross margins ($458/ha and $462/ha vs $368/ha).

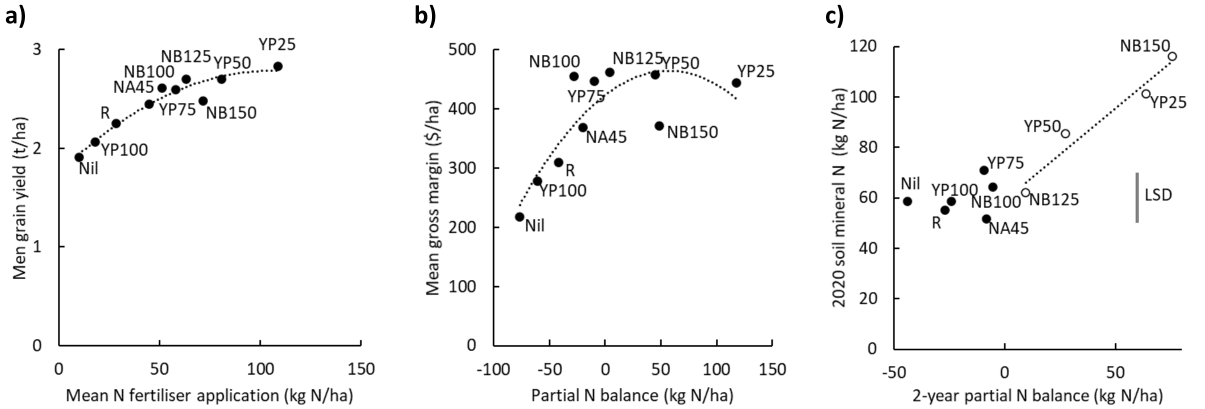

Figure 1. a) the relationship between mean (2018-2020) fertiliser N application and grain yield for the different treatments in the experiment. The fitted quadratic function is of the form $y = -0.00009x^2 + 0.019x + 1.752$, $R^2=0.93$. b) the relationship between partial N balance and mean annual (2018-2020) gross margin for the different treatments in the experiment. The fitted quadratic function is of the form $y = -0.0127x^2 + 1.4448x + 423$, $R^2 = 0.70$. c) the relationship between 2-year (2018-2019) partial N balance and soil mineral N measured prior to sowing in 2020. The linear function is fitted to the positive values (○) only and is of the form $y = 0.73x + 59$, $R^2 = 0.95$.

There was a split linear relationship between 2-year partial N balance and mineral N measured prior to sowing in 2020 (Figure 1c). In treatments with a positive N balance, 0.73 kg/ha of mineral N was recovered for every kg/ha of fertiliser N applied in excess of grain N export. This supports the notion that in this environment the majority of fertiliser N not taken up by crops in the year of application will carry over for use by subsequent crops. Of the remaining N, some would have been immobilised and some have been lost, but without using isotopically labelled fertiliser it is impossible to determine the relative proportions. The YP50 and NB125 treatments did not have substantially greater levels of remaining mineral N after 2 years compared to the Nil or NA45 controls (Figure 1c), implying that environmental losses or risk of haying off in these systems are unlikely to be any greater.

Conclusion

Both N bank and Yield Prophet® systems can profitably close yield gaps and solve the complex problem of crop N deficiency and mining of soil organic N without increasing levels of soil nitrate and thus risk of losses. Yield Prophet® is time and data intensive for growers to use with confidence but matches N inputs to seasonal yield potential which minimises the potential for losses. N banks are simpler to implement on-farm but rely on the premise that fertiliser N not taken up by crops in year of application will carry over for use by subsequent crops and is exposed to loss. More research is required to confirm the utility of the N bank system in a wider range of environments and in circumstances where other agronomic issues impact N response. Environmental losses and immobilisation from each of the systems also need to be quantified.

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