Comparison of the 'Nitrogen Bank', Yield Prophet® and national average nitrogen fertiliser rates on yield and gross margins of wheat

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Abstract
Wheat yield gaps are ~50% of water limited yield potential. Nitrogen (N) deficiency frequently contributes to yield gaps but matching N supply to crop requirements is difficult because of high variability in seasonal rainfall and hence potential yield. In this study we compared production and economic outcomes for wheat crops grown in response to three N fertiliser strategies: the national average rate of N fertiliser in the grains industry (45 kg N/ha), a seasonally variable amount calculated with the Yield Prophet® decision support tool, and an alternative concept based on maintaining soil mineral N (SMN) concentrations (an 'N bank') at a level that can support water-limited potential yield in most years. We simulated these three N fertiliser strategies in four case studies in Victoria for a 20-year period. The most profitable N bank and Yield Prophet strategies resulted in greater N application, yield, and profitability than the national average rate at three of the case studies (Birchip, Longerenong and Lake Bolac). The fourth site (Mildura) had low rainfall and yield potential and the most profitable N bank strategy had similar yield and profitability to the national average rate of fertiliser. N losses under all N strategies from loam to clay soils at Birchip, Longerenong and Lake Bolac were modest, but there were large episodic losses of nitrate in leaching from the sandy soil at Mildura following crops with low yields. We conclude that the N bank strategy has potential to reduce yield gaps but must be matched to water limited yield potential on different soils and environments; this requires further testing in field studies.

Keywords
APSIM, nitrate leaching, denitrification.

Introduction
Australian wheat is grown on more than 10 M ha and provides export income for Australia of 2.5 bn USD (in 2019; FAOSTAT, 2021). However, the national wheat crop is estimated to attain only ~50% of water-limited potential yield (Hochman et al. 2016), suggesting an opportunity to increase farm and national incomes. The yield gap occurs for various agronomic reasons, but nitrogen (N) deficiency is predicted to be the single biggest cause (Hochman and Horan, 2018).

The amount of N required to meet the needs of wheat crops is determined by the potential for growth in each season. Most Australian wheat crops are not irrigated and interannual rainfall is highly variable, so it is not possible to predict the water limited potential yield of the forthcoming season and hence the N requirement to achieve that yield. Growers therefore apply conservative amounts of N fertiliser each year to avoid the risk that the cost of greater N fertiliser applications will not be recovered in grain income. One approach to calculate the N recommendation that would remove this uncertainty is the concept of maintaining a reserve of SMN (a N 'bank') that is sufficient to deliver water limited potential yield (Smith et al., 2019). These studies, conducted in the field (Temora, NSW) and in simulations (Griffith, Ardlethan, Temora and Young, NSW), suggest that the concept holds promise to deliver improved yield without excessive environmental losses.

The purpose of this study was to further develop the N bank concept by extending it to additional locations, including on soils prone to environmental losses of nitrate in leaching and denitrification, and to compare its performance against production and economic outcomes from other approaches to calculate N fertiliser requirements. This study has been reported in full (Meier et al., 2020) and complements new field studies (Hunt et al., these proceedings).

Methods

The yield and gross margins of wheat crops in case study farm locations were simulated in response to the N bank and alternative methods to determine N fertiliser recommendations.

Farm case studies

Paddock scale farm operations were set up for four case studies within Victoria with contrasting rainfall and soil properties (Table 1). Soil properties had been sampled during previous research activities (APSoil database; Dalgleish et al., 2012) and local weather information was obtained from the SILO database (Jeffrey et al., 2001). Locally appropriate wheat agronomy including times of sowing and choice of cultivar were used at each location.

Table 1. Selected details of the case study farms (PAW, plant available water)

Details	Mildura	Birchip	Longerenong	Lake Bolac
Rainfall zone	Low	Medium	Medium	High
Rainfall (mm/yr)	288	345	412	564
APSoil No.	1097	573	1008	914
Soil texture	Sand	Sandy clay loam	Clay	Loam over clay
PAW (mm) (profile depth)	69 (0.0-1.5 m)	255 (0.0-1.3 m)	249 (0.0-1.3 m)	163 (0.0-1.8 m)

Nitrogen fertiliser strategies

Wheat yields and gross margins were calculated in response to three strategies to determine the N fertiliser requirement: the N bank (‘termed NB’), the commercial decision support tool Yield Prophet® (termed ‘YP’; https://www.yieldprophet.com.au/yp/HowItWorks.aspx), and the national average (termed ‘NA45’) amount applied in the grains industry (Angus and Grace, 2017). The strategies differed in the method used to determine the amount of N to apply but otherwise used fertiliser of the same type (urea-N) applied at the same time (15 July).

Table 1. N fertiliser strategies applied to wheat crops at all locations

Strategy	Target rate	Amount applied
National average (NA45)	45 kg N/ha	Flat rate applied to each crop
N bank (NB50 to NB400)	50-400 kg N/ha, in increments of 25	Target rate reduced by SMN (0-1 m) at sowing; combined N from fertiliser and SMN is the N bank target (same every year)
Water-limited Yield Prophet (YP25 to YP100)	N required to attain water-limited yield at 25, 50, 75, 100% of historic climate probability outcomes	Target rate calculated with Yield Prophet® reduced by SMN (0-1 m) at sowing; combined N supplied from fertiliser and SMN is the Yield Prophet calculation (changes every year)

Simulations

The Agricultural Production Systems sIMulator (APSIM) v7.10 (Holzworth et al., 2014) was configured with modules for soil water and N, crop residue and wheat. Modules were parameterised with the weather, soils and management practices used at the four locations (Tables 1, 2). Wheat crops were first simulated for 20 yr ‘run in’ period (1979-1998) with fertiliser applied at the NA45 rate; these results were discarded. Crops were then simulated for an additional 20 years (1999-2018) in response to the N fertiliser strategies (Table 2). Yield constraints other than weather and N rate were not simulated. Gross margins were calculated using industry gross margin information (PIRSA, 2018) with simulated crop yields and amounts of N fertiliser applied with the different N fertiliser strategies.

Results

Average yield, economic and N loss outcomes in response to the most profitable NB and YP strategies are presented in Figure 1 and compared to those from the NA45 N rate. For these NB and YP strategies, the most profitable N rates delivered a high proportion of potential yield and indicated potential to close yield gaps. For all locations there were NB and YP fertiliser strategies that delivered similar average N rates and outcomes (depending on alignment of the fertiliser increments simulated). In general, the performance of the different N strategies was divided between those for Mildura, and those for the other locations.

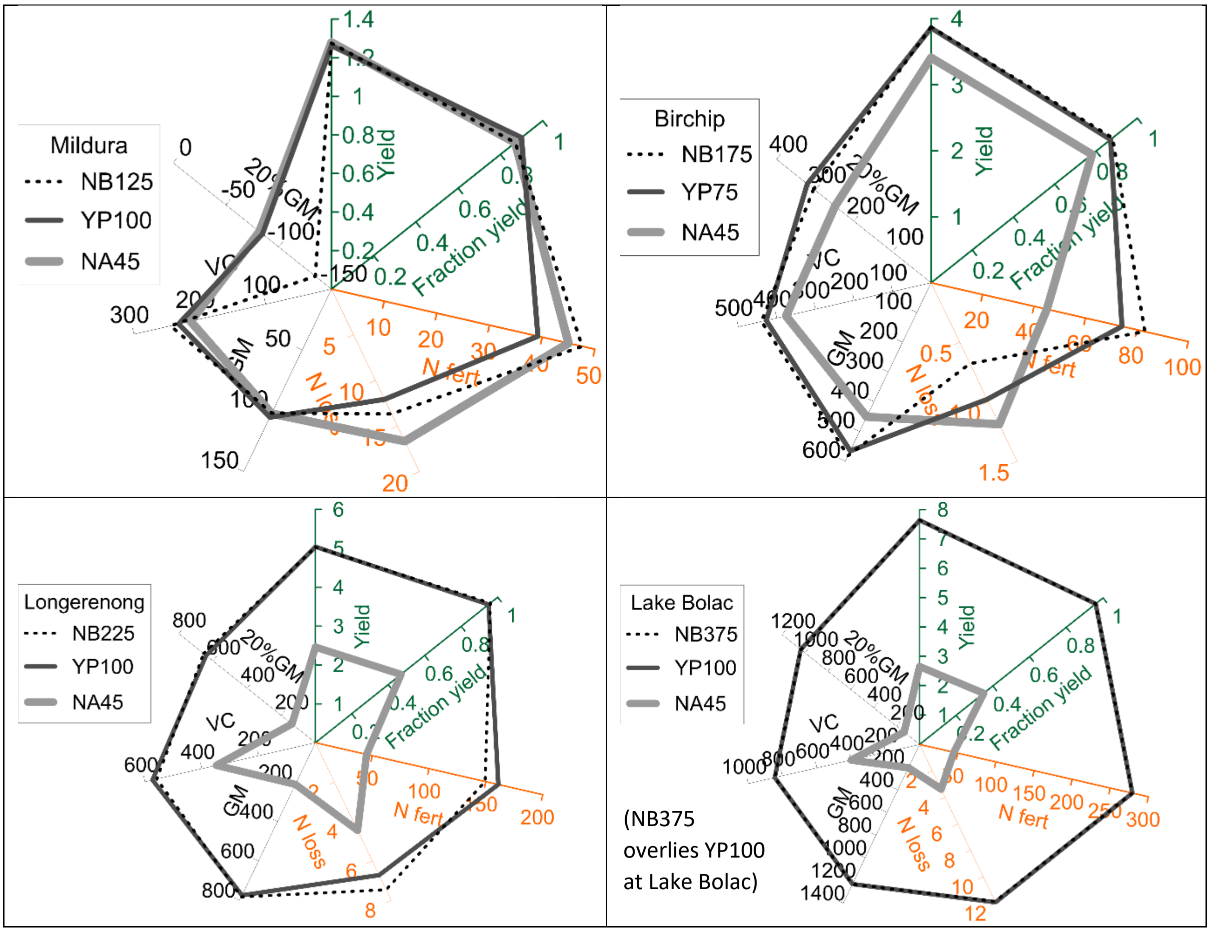

Figure 2. Average outcomes for the most profitable N bank (NB; dotted line) and Yield Prophet® (YP; solid black line) strategy at each case study farm compared to the national average (NA; solid grey line) N fertiliser rate. Economic outcomes of gross margins (GM; $/ha/crop), variable costs (VC; $/ha/crop) and 20th percentile gross margin (20%GM; $/ha/crop) are presented on black axes. Yield (t/ha) and the fraction of maximum yield obtained are presented on green axes. Amount of fertiliser applied (kg N/ha/crop) and the combined N loss from nitrate leaching or denitrification (kg N/ha/yr) are presented on orange axes. Locations are presented in order of increasing rainfall.

Birchip, Longerenong and Lake Bolac

The most profitable NB and YP strategies for Birchip, Longerenong and Lake Bolac provided progressively larger amounts of N fertiliser than the NA45 rate, consistent with increasing annual rainfall (Table 1) and hence of rainfed yield potential of these locations, respectively. For these locations, the greater variable costs of additional N fertiliser inputs were recovered in greater yield and in gross margins that were greater both on average and in years of lower gross margins (20%GM). Despite substantial increases in N fertiliser under the YP and NB strategies, N losses did not increase proportionately.

Mildura

The most profitable NB and YP strategies were similar to the NA45 rate at Mildura (Fig. 2), where N rates under all three strategies resulted in similar yields. However, despite relatively low rainfall at this location, average N losses (principally from episodic nitrate leaching) were the largest of any of the locations and a consequence of the sandy, rapidly draining soil at this site. While N fertiliser applications under the NB and YP strategies were greater than the NA45 rate, losses were lower because both strategies reduced N fertiliser applications for SMN present at sowing. However, maintenance of the N bank in low profit years increased the risk of economic losses (20%GM) compared to the other methods. These results highlight the importance of matching N fertiliser rate to rainfed yield potential on sandy soils to limit waste and negative environmental impact. Greater variability in gross margins from maintaining the N bank suggests that it may not be appropriate for low yield potential environments with high potential for environmental losses of N.

Conclusion

The most profitable NB strategy resulted in substantially greater yield and gross margins than NA45 at three of the four case study farms, suggesting potential under appropriate conditions to reduce Australian wheat yield gaps and improve farm profitability. The success of the NB approach relies upon the occurrence of minimal environmental losses of N from the soil to ensure that investment in additional N fertiliser is not wasted and is recovered in better yields and gross margins. Environmental losses of N increase exponentially in response to increasing rates of N fertiliser in many cropping systems, so the nature of the soils and climates under which the NB strategy would be effective requires further field testing. Outcomes from the most profitable NB and YP fertiliser strategies were similar, but the simplicity of the NB approach once a target is determined is that it could replace the need for annual N fertiliser estimation under the YP strategy.

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