Profitable, low-emission nitrogen application strategies in Western Australian dryland cropping

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Abstract

Purpose/Research Question(s)
Our goal is to find highly profitable, lower-emission nitrogen application approaches for dryland farming in Western Australia.

Method(s)
Simulation modelling is used to analyse gross margins and greenhouse gas emissions for nitrogen strategies in various land use sequences across a range of locations in Western Australia's grainbelt.

Findings
The study's main finding is that there are preferred nitrogen (N) application strategies that consistently achieve high gross margins in crop production yet ensure emissions are relatively low or moderate. A useful strategy for a farmer is to evaluate the ratio of the price of nitrogen and grain and have a goal for N application that maximises the gross margin.

While the gains in gross margins and emission reductions from altering N application strategies may appear small at a paddock level, those changes when replicated over the 9 million hectares of crops in the study region, annually deliver significant improvement. Further, when summed over many years of crop production, these seemingly minor improvements can lead to substantial additional profits and emission savings for the agricultural region. The study also concludes that very high or very low N application rates are inferior strategies. The better options are to apply 50 or 75 kg N/crop ha, depending on the farm location, for economic and environmental reasons.

Implications
Choosing nitrogen application strategies that are both highly profitable and which result in lower emissions throughout the study area can lead to significant economic and environmental advantages.

Introduction

Until the mid-1990s, N used by Australian dryland crops mostly came from the soil organic matter and N-fixing, legume-based pastures grown in rotation with crops (Angus and Grace, 2016). However, after the mid-1990s, N fertiliser use increased significantly, averaging around 45 kg N/ha per crop. Despite this increase, only about half of the applied N was absorbed by crops; the rest remained in the soil post-harvest or was lost through denitrification, ammonia volatilisation, and leaching (Angus and Grace, 2016). These environmental losses became a growing concern from the 2010s onwards, as Australia sought to reduce greenhouse gas emissions to achieve carbon neutrality. While overuse of N fertiliser in Australia is uncommon due to the lack of subsidies in crop production, the release of nitrous oxide (N_2O)—a potent greenhouse gas—during fertiliser application remains a significant environmental issue. Notably, spikes in N_2O emissions in Australian cropping systems are often linked to summer rains post-harvest rather than during the growing season (Barton et al. 2022).

Historically, farmers' decisions regarding N fertiliser use have not accounted for associated emissions. The traditional farm-management decision framework, established by Anderson et al. (1988) and Dillon and Anderson (1990), focuses on crop yield response functions and their related costs and returns. The optimisation process considers crop yield (Y) and crop price (P_c) to generate revenue, the costs of N applied (N), price (P_n) and other variable costs (VC_{other}) not dependent on N. This leads to the gross margin (GM) calculation:

$$GM = Y \times P_c - N \times P_n - VC_{other}.$$

To maximise this margin, the derivative of the GM with respect to N must equal the price ratio of N and the crop. This approach aims to maximise profit rather than yield, highlighting the flatness of the economic response near the optimum and the influence of price and yield volatility. Thus, precise recommendations for N rates may not be significantly beneficial to farmers unless they are significantly off the optimal plateau.

The traditional framework assumes farmers are motivated solely by profit, ignoring their risk attitudes, which affect N application rates. Colaço and Bramley (2018) describe the decision-making process as a complex, multivariate risk-optimisation problem that considers various weather and soil conditions. Additionally, the traditional decision framework fails to incorporate the environmental costs of N use, which is increasingly relevant today. Without considering emissions, most Australian farmers use a few strategies for N application, including single-rate applications and split applications. Split applications involve applying N at sowing or mid-late tillering, followed by a "top-up" application based on seasonal conditions and outlook. This approach aligns with state-contingent farm management, where decisions are based on the likelihood of different states of nature.

In the future, farmers may rely on sensor-based machine learning and artificial intelligence to determine N applications based on real-time weather data. The increased use of N fertiliser has made N a significant component of farmers' input expenditures, now comprising up to a quarter of their costs. The shift toward more crop-dominant farming systems in Australia, especially in Western Australia, has made applied N increasingly crucial for crop yields.

The current study aims to identify the environmental impacts and profitability of different N application strategies in various cropping systems and environments in Western Australia. It considers all sources of emissions (scopes 1, 2, and 3) rather than just on-farm emissions from applied N. By evaluating different locations, cropping systems, and environments, the study seeks to determine the robustness of each strategy and identify those that generate high profits without significantly increasing greenhouse gas emissions. This comprehensive approach aims to establish which changes in N application strategies could have the most significant positive impacts on emissions and land-use sequence gross margins.

Methodology

Multiple locations across the WA grainbelt were carefully selected to represent the region's diverse geographical, soil, and climatic conditions. Comprehensive data on production inputs, crop diversity, yields, stocking rates, input costs, revenue streams, and emission profiles for each location are extensively documented in d’Abbadie et al. (2022) and Kharel et al. (2022). The Economic Valuation of Alternative Land Use Sequence (EVALUS) model (Kharel 2023) was utilised to conduct an economic evaluation of different nitrogen and liming strategies, along with their associated emissions. Fifteen years of randomised weather and price data, sourced from actual records, were used to create a 15-year data sequence from which gross margins were calculated. Thirty iterations were performed to model data variability. The estimation of greenhouse gas (GHG) emissions for various scenarios followed methodologies described in the Primary Industries Climate Change Centre's (PICCC) Cropping GHG Accounting Framework (C GAF). For more detail on these methodologies, see Ekonomou and Eckard (2022).

Nitrogen strategies

Three nitrogen application strategies—an Agronomic Target (AT), Economic Target (ET), and Constant Rate (CR)—were evaluated. The assessment considered variables including: rainfall patterns, sources of nitrogen, nitrogen costs, and the final price of the grain harvest. The study explored adjusted (Adj) and unadjusted (Unadj) in-season nitrogen options for the AT and ET strategies where N rate was adjusted as the season progressed for the Adj option while N rates were decided at the start of the season and were unchanged during in-season application in the Unadj option.

Agronomic Target (AT): The goal here was to apply enough N to maximise crop yield, considering water availability and soil characteristics.

Economic Target (ET): The objective for N application was to maximise the gross margin of crop production.

Constant Rate (CR): This approach involves applying fixed amounts of N at sowing, irrespective of the crop's potential yield. Six different fixed rates of N applied were considered, ranging from low to very high N application rates.

Table 1: Modelled nitrogen strategies

	N application strategy		
Within season adjustment	Agronomic target (AT)	Economic target (ET)	Constant rate (CR)
Unadjusted	AT Unadj	ET Unadj	25, 50 or 75 (kg N/ha)
Adjusted	AT Adj	ET Adj	

Results and discussion

The modelling exercise looked at various locations, but in this paper only results from Northampton and Merredin sites are presented. Results of other locations can be found in d'Abbadie et al. (2024). Northampton is a higher rainfall location with 414 mm of April to October Growing Season Rainfall (GSR) in the north of the study region while Merredin is a low-rainfall (214 mm GSR) eastern grainbelt location. Data points between the first and third quartiles of emissions and gross margins are illustrated by the shaded boxes in Figures 1 and 2. With its higher rainfall, Northampton has higher crop yields, N application rates, and consequently higher emissions and GM per hectare. On the other hand, Merredin has lower rainfall, hence lower yield, N application, GM and emissions.

Adjusting nitrogen application throughout the season was more profitable and resulted in lower emissions compared to a fixed N application strategy, regardless of location. Seasonal N adjustment impacted both profit and emissions, particularly in the northern, higher rainfall location of Northampton. This effect may be due to the greater variability in rainfall and lower soil organic carbon because of Sandy soil and low clay content at Northampton. Additionally, higher N applications at Northampton enabled the benefits of adjusting N applications to be more pronounced. By contrast, there was a smaller impact on gross margin and emissions of adjusting N applications at the low-rainfall location, Merredin. However, farms in the Merredin area are larger in size, so small improvements applied across a larger area may generate larger impacts on whole farm profit and emissions.

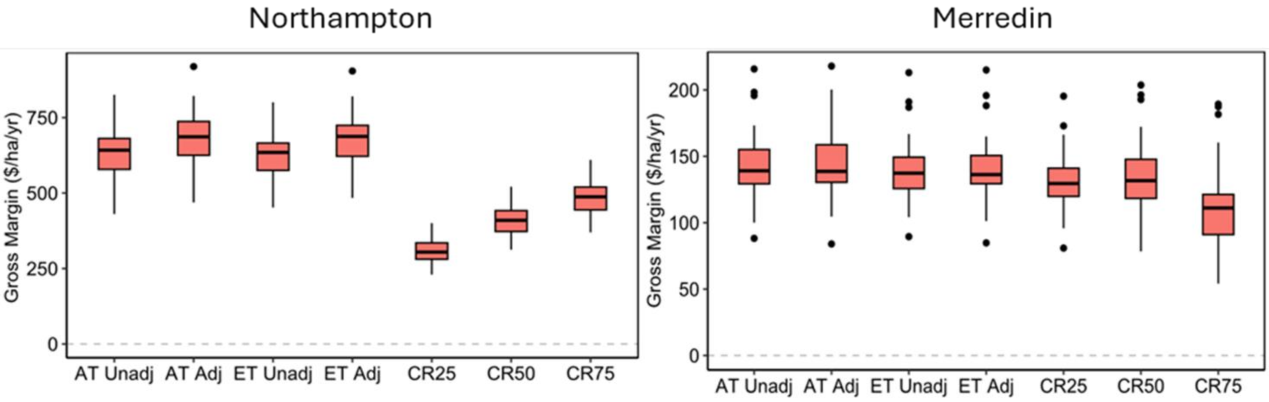

Figure 1: Nitrogen strategy gross margins for 30 randomised selections of weather-year and price sequence at Northampton and Merredin, AT: Agronomic Target, ET: Economic target, CR: Constant Rate Unadj: Seasonally unadjusted, Adj: Seasonally adjusted.

The difference in profitability between the yield maximisation (AT) and gross margin maximisation (ET) strategies was minimal across most locations. This minimal difference is attributed to the high ratio of wheat price to N price in the data used for analysis, which causes the AT and ET strategies to yield similar results. However, if the wheat-to-N price ratio were to decrease, the gross margin ET strategy would outperform the AT strategy (Abadi and Farre, 2015). The ET strategy uses lower N, leading to reduced emissions as N use was consistently lower in the ET strategy.

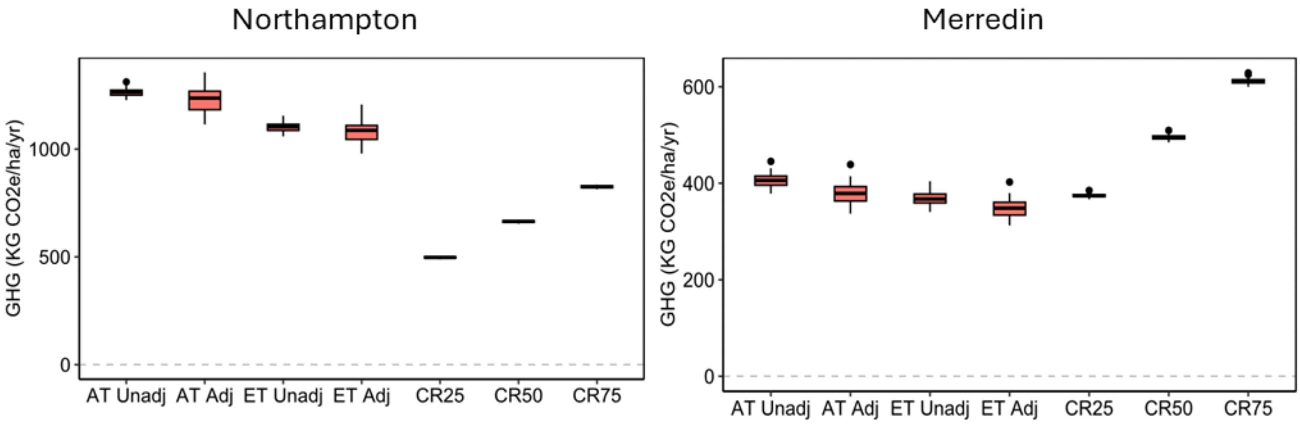

Figure 2 Nitrogen strategy GHG emissions for 30 randomised selections of weather-year and price sequence at Northampton and Merredin, AT: Agronomic Target, ET: Economic target, CR: Constant Rate Unadj: Seasonally unadjusted, Adj: Seasonally adjusted.

Caveats

This study acknowledges several limitations. It did not explore all N strategies, such as using seasonal forecasts for N applications, which previous studies found economically insignificant. However, some research suggests that seasonal forecasts might be useful for initial N applications at seeding times. The study's modelling approach does not account for infrequent, episodic events that cause spikes in N_2O emissions, potentially underestimating the true emission range. Additionally, emission factors may change as more data on N processes and in situ emissions are collected, indicating that current global N_2O flux estimates might be inaccurate due to insufficient field sampling.

Conclusion

This study evaluates various nitrogen (N) application strategies in different locations in southwest Australia, considering weather-year and price variations. The analysis reveals a subset of preferred N strategies that consistently achieve high gross margins with relatively low or moderate emissions. These strategies, while yielding slightly higher gross margins, also generate fewer emissions. Effective strategies include adjusting N application as the season progresses and targeting N application to maximise the gross margin. Despite small gains at a paddock level, these strategies can significantly enhance industry profits and reduce industry emissions when summed across the region's vast agricultural area and when summed across years.

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