Exploring the potential for refining sugarcane nitrogen fertiliser management by accounting for climate impacts in the Tully region.

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Abstract

Increasing the precision of nitrogen (N) fertiliser management is integral to increasing the environmental and economic sustainability of cropping systems. In a simulation study, we found natural variability in year-to-year climate has a major effect on optimum N fertiliser rates for sugarcane ratoon crops in the Tully region of north-eastern Australia. The Tully sugarcane region is characterised by very high rainfall (*c* 4,000 mm per year) and annual N discharges that pose a high risk to nearby Great Barrier Reef ecosystems. We found interactions between seasonal climate, soil type and ratooning date that made optimum N rates field-specific, meaning generalisations could not be drawn about the effect of seasonal climate alone on field-scale optimum N rates. However, at the regional scale, the average optimum N fertiliser rate over the 65 years simulated was substantially lower than current industry guidelines. These lower optimum N rates led to reduced N losses to the environment in the simulations which, if reflected in N discharges from rivers in the region, would almost meet current government targets for water quality improvement. While there were many assumptions made in this study, the potential environmental benefits justify field validation and further development of the concepts identified leading to a dynamic N management system.

Keywords

Sugarcane, Nitrogen, Simulation, Great Barrier Reef, Water quality.

Introduction

The cornerstone of increasing nitrogen (N) use efficiency is generally accepted as applying fertiliser to crops at the "right rate, right time, right place, using the right type" (Snyder 2017). In sugarcane, and other crops, it is accepted that the "right rate" of N fertiliser will vary from soil-to-soil and from region-to-region (e.g. Schroeder et al. 2014; Morris et al. 2018). The climatic conditions experienced during the crop growing season are also important, because climate affects crop growth, and therefore crop N demand and potential N losses to the environment. The growing season also influences soil water and nutrient cycling which contribute to the supply of N to the crop (Thorburn et al. 2017). Thus, incorporating forecasts of the coming seasonal climate has potential to improve N fertiliser guidelines. Yet systems for developing N fertiliser applications to crops usually lack an explicit consideration of climate.

Increasing N use efficiency is an important goal in the Australian sugarcane industry (Bell 2015) because over-application of N fertiliser leads to discharges of dissolved inorganic N (DIN) to the Great Barrier Reef (Thorburn et al. 2013; State of Queensland 2018). The Queensland Wet Tropics region experiences both high annual rainfall and high interannual variability of rainfall (Nicholls et al. 1997). Farmers face the dilemma of how to optimally manage N and improve N use efficiency in the face of this extreme climate variability. The Wet Tropics rainfall is well correlated with the El Nino-Southern Oscillation (ENSO) phenomenon, raising the prospect that climate forecasting could be incorporated into farmers' N fertiliser management decisions (Thorburn et al. 2011; Skocaj et al. 2013).

The objectives of this study are to determine whether simulated optimum N rates and cane yields in ratoon crops vary depending on the seasonal climate for different soils and growing seasons encountered in the Tully region of the Wet Tropics, and the extent to which these optimum N rates and yields differ from those simulated for the industry's baseline SIX EASY STEPS® N guidelines (Schroeder et al. 2014). If optimum N rates are found to be dependent on seasonal climate, there is an opportunity to develop a seasonal climate forecast-based N fertiliser advice system.

Methods

The Agricultural Production Systems sIMulator (APSIM) model was used to simulate cane yield response to N fertiliser application rate using 65 years of historical climate records from two climate zones (North -

wetter and South - drier) in the Tully sugarcane growing region (Sexton et al., 2017). In each simulated year, the seasonal climate was characterised, and optimum N rate determined. Soil parameters required by the APSIM model were derived from published soil profile information which have classified 51 different soil types in the Tully region (Murtha 1986; Cannon et al. 1992). These soil types were classified into five groups according to agronomic performance (Skocaj et al. 2019). The dominant soil in each of the five groups was parameterised for modelling and supplemented with three extra soils (eight soils in total) for which previous knowledge of yield response to N was available. Crop management was specified in the model based on local experience. Crops in the region suffer lodging and waterlogging and these processes were specified in the model based on the observations of local agronomists. To provide confidence that the resultant yield responses to N fertiliser were consistent with local knowledge, we sought advice and feedback from local agronomists, farmers and sugar mill staff who formed an advisory panel for the research.

Cane yield responses were simulated for the eight soils in each of the two sub-regional climate zones (North and South) for two different growing seasons. The growing seasons consisted of ratoon crops starting (following harvest of the preceding crop) on the 15-Jul (early season crops) and 15-Nov (late season crops). The simulation output was analysed to determine an optimum N application rate, defined as 98 % of maximum yield (approximating the long-term economic N application rate). To summarise how optimum N is impacted by rainfall, each simulated N response curve was grouped by terciles according to rainfall received in the first six months of the simulated crop growing season. This was done to broadly compare crop performance in wet tercile years and dry tercile years. Simulated optimum N, cane yield at optimum N, and total N lost at optimum N were compared in wet and dry tercile years.

The simulated cane yield and total N lost from the soil to the environment (i.e. sum of N lost via deep drainage, denitrification, and runoff) at the simulated optimum N rate and at N fertiliser rates resulting from Step 4 of the SIX EASY STEPS N guidelines (for the Wet Tropics region) for these soils were compared.

Results

Optimum N

The effect of rainfall (i.e. wet and dry terciles) on optimum N differed across the crop growing seasons and, to a lesser extent, soil type (Figure 1). The median simulated optimum N for crops that started to grow in July (early season) was greater in wet years than dry years, particularly in the slightly drier, southern climate zone. For the late growing season (crops that started to grow in November), the trends were generally opposite. The median simulated optimum N was less in wet years compared to dry years, except for four soils (Silty Clay A, Silty Clay B, Sandy Loam A and Clay Loam) in the southern climate zone.

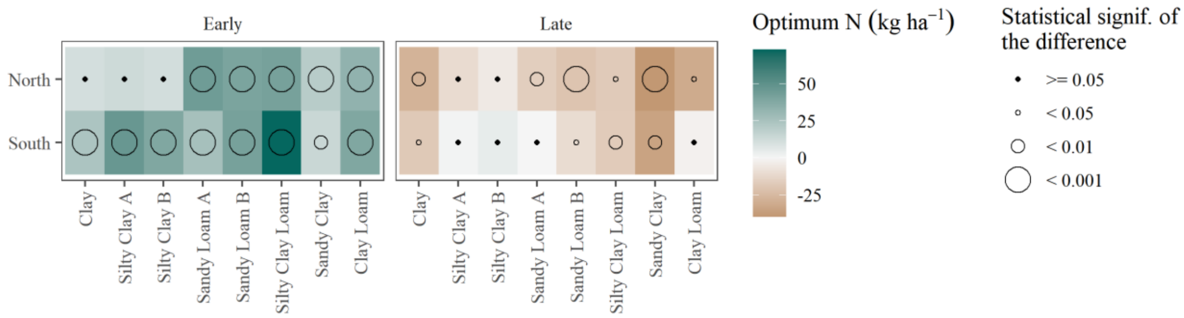

Figure 1: Heatmap displaying the difference in median simulated optimum N between the wet and dry rainfall terciles. Green hues (positive values) signify the median simulated optimum N is greater in wetter years when compared to drier years. Brown hues (negative values) signify the median simulated optimum N is less in wetter years when compared to drier years. Whilst multiple significance tests should be interpreted with care, p-values less than 0.001 as marked by the larger circle, indicate significance with the Bonferroni correction factor applied whilst maintaining a family-wise type I error rate of 0.05.

Optimum N relative to current guidelines

From the soil organic C concentration used to parameterise the eight soils, the baseline N application rate was determined from the SIX EASY STEPS guidelines for the Wet Tropics region (Step 4). These N rates are held constant through time in this study (Figure 2a) because soil organic C remained relatively constant in our simulations (although this may not happen in practice). In comparison, the optimum N rate varied from year to year (Figure 2a). The simulated median optimum N rate was consistently lower than the simulated SIX EASY STEPS N rate for all soils (median decrease of 61 kg N ha^{-1} or 47 %). However, in many soils optimum N in individual years could exceed the SIX EASY STEPS rate (represented by the whiskers extending above the SIX EASY STEPS rate in Figure 2a).

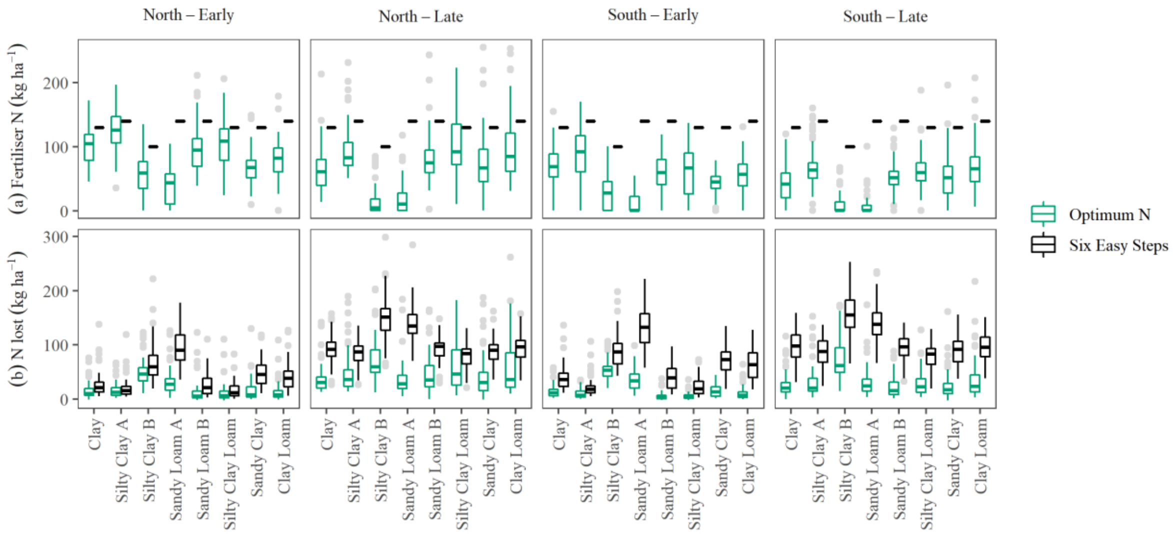

Figure 2: Comparison of (a) fertiliser N, and (b) N loss variability for Optimum N (green) and the current guidelines (SIX EASY STEPS = black) across eight different soils (x-axis), two climates (North & South) and different growing seasons (Early and Late). The boxplot shows the year-to-year variability in outcomes.

Median total N lost to the environment (the aggregate of N leaching, runoff and denitrification) in the simulations was 32 kg N ha^{-1} or 59 % lower at the optimum N rate than the SIX EASY STEPS rate across all soil-growing season-climate zone combinations (Figure 2b). In many cases the between-year variability in total N losses was lower with optimum N than the SIX EASY STEPS rate, although there were still some years where optimum N resulted in greater losses in some soils-growing seasons-climate interactions.

There were small differences in the simulated median cane yield at the optimum and SIX EASY STEPS N rates across the different soils (data not shown). Median cane yield at optimum N was between 0.6 and 1.5 t ha^{-1} (or 0.8 % and 1.9 %) lower than at SIX EASY STEPS rates.

Discussion

These results show climate has a major effect on optimum N rates for sugarcane ratoon crops in the Tully region. The general trend was for optimum N rate to be higher in wet years for early growing season crops but lower in wet late growing season crops. However, optimum N rates differed depending on the soil type and growing season of crops, and between climatic sub-regions. Thus, there may be potential benefits from a climate forecast-based dynamic N fertiliser management system. We also showed there may be substantial environmental benefits from optimum N rates compared with current N guidelines (median reduction in N loss of 59 %), and these benefits come at relatively small yield reductions (range of reduction of 0.6 to 1.5 t ha^{-1}). If the systems simulated in this study could be applied across the whole Tully cane growing region and the proportional reductions in N lost to the environment were reflected in DIN discharged from rivers in the region, it would nearly satisfy the government goal of a 50 % DIN discharge reduction (State of Queensland 2018). While our results show that the cane yield reductions associated with applying optimum N rates are relatively small, this loss of production would still be of much concern to growers and owners of the sugar mill in the region. It may be worth exploring if these concerns could potentially be offset by green finance mechanisms given the potential environmental benefits.

Given there are substantial potential advantages for increasing the precision of fertiliser N inputs to sugarcane crops in the region, it is worth considering additional work needed to progress this study. This was an exploratory simulation study, and thus would require empirical field testing. These simulations were conducted with substantial simplifications; only eight soils represented, reasonably constant soil organic C and uniformity across many crop management practices. Hence it would be beneficial to expand these simulations to identify if results apply to more bespoke soil types, growing season and crop management practices.

To capture the benefits identified in this study, farmers would need forecasts of seasonal climate to apply N at the optimal rates identified. Because this study was retrospective, the seasonal climate was known for each year simulated (i.e. equivalent to "perfect knowledge"). However, seasonal climate forecasts are not "perfect". Inaccuracies in seasonal climate forecasts have previously limited farmers' interest in incorporating that information into their management decisions (Thorburn et al. 2011). However, since then global circulation model outputs have become more accessible offering additional insights into seasonal climate forecasting, and these may make it worthwhile to revisit a climate-based approach to N fertiliser management.

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References

Bell MJ, (2015), A review of nitrogen use efficiency in sugarcane. SRA and DoE commissioned research report. Sugar Research Australia Limited

Cannon MG et al, (1992), Soils of the Cardwell-Tully area, North Queensland. CSIRO, Melbourne

Morris T et al, (2018), Strengths and limitations of nitrogen rate recommendations for corn and opportunities for improvement. Agronomy Journal 110:1–37.

Murtha GG, (1986), Soils of the Tully-Innisfail area, North Queensland. CSIRO Australia, Division of Soils

Nicholls N et al, (1997), Australian rainfall variability and change. Weather 52:66–72.

Schroeder BL et al, (2015), Evolving nature of nitrogen management in the Australian sugar industry. In: Bell MJ (ed) A review of nitrogen use efficiency in sugarcane. Sugar Research Australia Limited, pp 15–88

Sexton, J., Everingham, Y., Skocaj, D.M., Biggs, J., Thorburn, P.J., Schroeder, B., 2017. Identification of climatological sub-regions within the Tully region. Proc. Aust. Soc. Sugar Cane Technol. 39, 342–350.

Skocaj DM et al, (2013), Nitrogen management guidelines for sugarcane production in Australia: Can these be modified for wet tropical conditions using seasonal climate forecasting? Springer Science Reviews 1:51–71.

Skocaj DM et al, (2019), Spatial distribution of potential soil constraints affecting nitrogen management in the Wet Tropics. Proceedings of the Australian Society of Sugar Cane Technologists 41:371–379

Snyder CS, (2017), Enhanced nitrogen fertiliser technologies support the '4R' concept to optimise crop production and minimise environmental losses. Soil Research 55:463–472.

State of Queensland, (2018), Reef 2050 Water Quality Improvement Plan 2017-2022. State of Queensland

Thorburn PJ et al, (2017), Prioritizing crop management to increase nitrogen use efficiency in Australian sugarcane crops. Frontiers in Plant Science 8:1504.

Thorburn PJ et al, (2013), Water quality in agricultural lands draining to the Great Barrier Reef: A review of causes, management and priorities. Agriculture, Ecosystems and Environment 180:4–20.

Thorburn PJ et al, (2011), Agricultural decision support systems facilitating co-learning: a case study on environmental impacts of sugarcane production. International Journal of Agricultural Sustainability 9:322–333.