Optimisation of nitrogen supply from sugarcane residues in the wet tropics

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Abstract

Retention of sugarcane leaves and tops on the soil surface after harvesting has almost completely replaced burning of crop residues in the Australian sugar industry. Long term retention of residue is believed to improve soil fertility to the extent that nitrogen (N) fertilizer applications might be reduced by up to 40 kg N/ha/y. However, the fate of N in the extreme environment of the wet tropics is not known with certainty. Indices of potential N mineralisation and nitrification were developed and indicate that potential N fertility is greater in the wet tropics compared to more southern cane growing areas, and is enhanced under residue retention. Field results from the wet tropics support this prediction, but indicate high soil ammonium-N concentrations relative to nitrate-N.

Keywords

Organic matter, mineralisation, fertilizer, trash blanket, green cane harvesting

Introduction

The Australian sugar industry occupies over 554 000 ha along the Queensland and northern NSW coast as well as a small area in the Ord region of WA. Of this, 32 000 ha is restricted to a narrow coastal strip sandwiched between environmentally sensitive World Heritage rainforest and reef areas in north Queensland. The area corresponds to the wet tropics region of Queensland, which according to the K?ppen system of climate classification has a hot climate together with either a short dry season or uniform rainfall distribution throughout the year (1).

By reason of its sensitive location and reliance on large chemical fertilizer inputs, the sugar industry in the wet tropics is facing increasing environmental scrutiny. Recommended N fertilizer rates stand at 120-150 kg N/ha/y for fallow plant crops and 160-200 kg N/ha/y for ratoon crops (2), but crop recoveries of annual fertilizer N applications are consistently low at 20-40% (3). The remaining 60-80% of N fertilizer applied is immobilised in the soil organic matter or is susceptible to different loss pathways. Nitrate concentrations in groundwater are generally low in the tropical region, possibly due to dilution by high rainfall (4), but large amounts of nitrate accumulated at depth in tropical ferrosols suggest that the buffering capacity of these soils may be significantly occupied such that groundwater quality will require ongoing monitoring (5). Gaseous losses of N fertilizer by denitrification in wet soil (6) or volatilisation (7) can be very high depending on fertilizer type and method of application.

Retaining sugarcane crop residues on the ground after harvesting, in place of pre- and post-harvest residue burning, represents a shift in N cycling that is still not fully understood (8). In the wet tropics, residue retention has been practiced for up to 20 years, and now occurs on 90-100% of cane grown in this area. Residues are estimated to return 30-60 kg N/ha to the soil compared to net losses of N from burning (9). Furthermore, it has been estimated that N fertiliser applications may be reduced by up to 40 kg N/ha in situations where long-term residue retention has been practised (9). However, the timing and amount of release of mineral N from residues are mediated by the microbial biomass, whose activity is governed by the soil environment and organic matter quality. As sugarcane is a C4 plant, sugarcane residue has a high C:N ratio of up to 120:1 (9) and consequently crop recovery of N from a single year's harvest residues are less than 10% (10). Residues have been implicated in fertilizer N losses (6, 7), but the extent to which residues protect fertilizer N by immobilisation has received little attention. Early field results suggest that some protection of N fertilizer may occur in low N soils (E. Meier, unpublished data), which may offer opportunities for synchronisation of N supply to the crop N demand during residue decomposition. The timing of within-season release of N from residues is also topical, possibly promoting suckering and prolonging vegetative growth (11,12).

The aim of this paper is to (a) indicate the potential for enhanced N mineralisation from soil organic matter mineralisation in wet tropical cane growing areas compared with drier areas by developing and examining mineralisation and nitrification indices based on N cycle modelling, and (b) compare enhanced N mineralisation predicted by the indices with field experimental results.

Methods

Mineralisation and nitrification indices

Potential N mineralisation and nitrification indices were developed using the capacity of the Agricultural Production systems SIMulator (APSIM) to model organic matter decomposition as a function of soil water and temperature (13) resulting from integrated climate, crop and residue influences. Gross mineralisation of organic matter in the model is a function of organic matter quantity and quality, organic matter C:N ratio, soil moisture and soil temperature. Temperature and moisture are considered as factors (on a scale between 0 and 1) representing the extent to which they limit potential mineralisation. The combination of these two factors into a single multiplicative index isolates the effect of climate on residue decomposition from crop-specific variables. The index is therefore properly named a 'potential N mineralisation index' because immobilisation processes are not included in the index and N mineralisation is assumed to be proportional to organic matter mineralisation. Potential nitrification is modelled by APSIM using Michaelis-Menton kinetics and ammonium concentration, reduced by the most limiting temperature, water or pH factor (again represented on a scale of 0-1). The potential nitrification index therefore consists of the lower of the temperature or water factors given non-limiting pH.

Monthly data points on the indices represent the average index of daily soil and temperature factors in the surface 200 mm of soil from 100 y of simulated continuous ratoons using the soil and crop model parameters from the Mackay site of Thorburn et al. (8). Sugarcane cropping systems in the simulations were ratooned on 1 September and fertilized 30 d later at the ratoon fertilizer rate of 160 kg N/ha/y, and subjected to different residue management regimes (residue retention on the soil surface, 50% incorporated to a depth of 200 mm, or removal by burning). In order to highlight the effect of climate on N cycling in the wet tropics, the crop systems were subjected to the strongly contrasting climates of Babinda in the wet tropics (4202 mm/y at 17.347 ?S, 145.923 ?E) and the drier cane growing location of Bundaberg (1141 mm/y at 24.867 ?S, 152.346 ?E). Irrigation was applied at Bundaberg (as is common practice there) to avoid crop death when available soil water reached 1% in the top 500 mm of soil, up to an allocation limit of 400 mm/crop cycle.

Field nitrogen measurements

Mineral N was measured in field experiments initiated to investigate the effect of different residue management regimes at four farms near Babinda from 1999 to 2001 (14). Residue was left on the ground, incorporated or burnt after harvest each year. Soil samples were randomly taken across treatment replicates within farms to a depth of 30 cm at intervals of 4-8 months during the experiment. Soil was bulked across depth increments within the replicate and stored in an esky or in air conditioning before packaging for transport to the laboratory by refrigerated vehicle. In the laboratory, soil was thoroughly mixed and subsampled, and ammonium and nitrate were extracted with 2M KCl followed by analysis with an autoanalyser.

Results and Discussion

Indices

At both Bundaberg and Babinda, higher index values during summer (Figure 1) under all residue management practices reflect higher temperature and rainfall. The sharp drop in the index in Bundaberg during winter reflects the combined effects of low rainfall, lack of irrigation and a mature crop on soil moisture. There is a trend for more favourable conditions for N mineralisation to exist at Babinda than at Bundaberg from February to August. Although climate is the primary effect upon the index, N mineralising conditions are also affected by complete (surface) retention of residue during September to January. Nitrification indices (not presented) follow the same shape as mineralisation indices and produce the same ranking of locations and treatments.

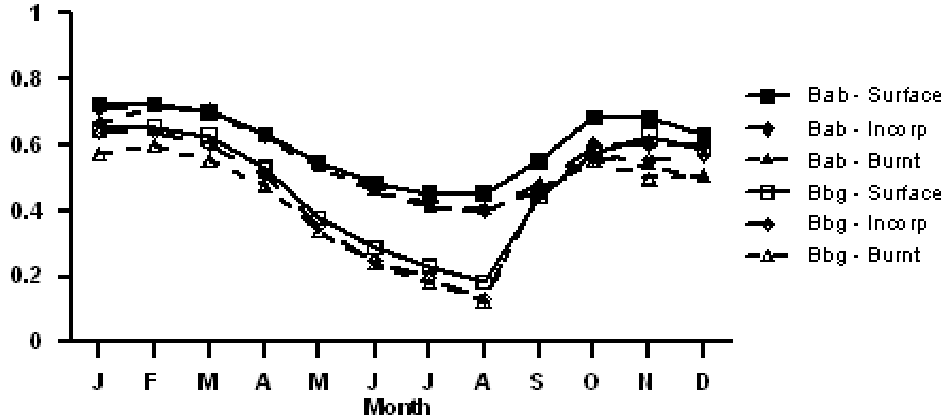

Figure 1. Indices of potential nitrogen mineralisation in response to residue retained on the soil surface, incorporated or burnt at Babinda (Bab) and Bundaberg (Bbg). Standard errors (not shown) are <0.01 for all points.

Field experiment

Mineral N concentrations in the field experiment averaged 30-40 kg mineral N/ha in the surface 200 mm of soil in surface-applied and incorporated residue treatments, and concentrations measured in these treatments were similar across farms (combined farm averages shown in Fig. 2). As predicted by the mineralisation index, Babinda soils were well supplied with mineral N compared with concentrations obtained in Bundaberg soils under ratoon crops with comparable residue and N fertilizer management. Annual sampling over 5 years in Bundaberg (15) consistently found less than 20 kg N/ha in the surface 200 mm soil in August-September. Mineral N concentrations in the Babinda soils were similar at all times, consistent with the generally similar values in the Babinda indices throughout the year. Slightly higher mineral N levels tended to occur in surface and incorporated residue treatments, which was again consistent with the index.

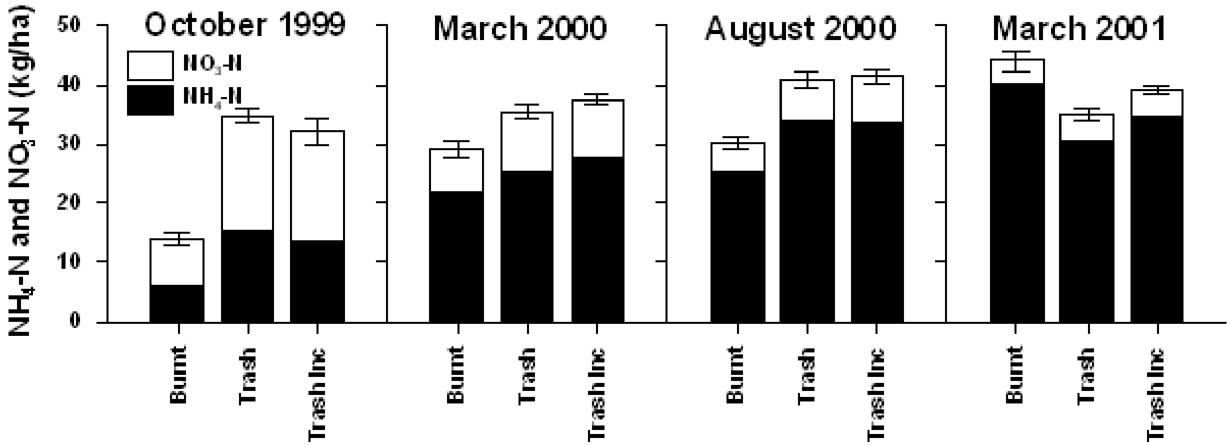

Figure 2. Average mineral N (NH4+-N and NO3—N) in surface 200 mm soil layer at all farms in Babinda field experiment. Vertical bars represent standard errors for total mineral N.

Although field results were consistent with the mineralisation index in terms of gross mineral N, 50-90% of mineral N occurred in the ammonium form at Babinda. A relatively high nitrification index for Babinda predicted that nitrification proceeded at 60-70% of potential rates, and so the majority of mineral N should be nitrate, in contrast to the field results. The large proportion of ammonium found in the Babinda soils may have resulted from loss of nitrate from the system by leaching and/or denitrification. However this would suggest that initial mineral N levels in the soil prior to these losses were originally considerably higher than those measured. Inhibition of nitrification rather than loss of nitrate is an alternative possibility that may have contributed on ammonium dominance at Babinda. Inhibition due to pH or pesticides is unlikely to be the main cause of ammonium dominance since nitrification is slowed rather than completely prevented under these conditions. Another possibility is that the population of nitrifiers is small and limited nitrification occurs, as identified by Sierra and Marban (16) in a soil from Guadelope. Identifying the composition and seasonal activity of tropical microbial biomass will therefore be a key step in understanding the N cycle in the Australian wet tropics.

Conclusion

The indices provide a useful means of comparing climatic versus residue management effects on soil N mineralising potential. Indices for Babinda indicate that seasons in the wet tropics tend not to have a strong limiting effect on the rate of N supply from residues, although the N mineralised will also depend upon the residue quantity and quality. Small differences between indices for different residue management practices at either location, and little difference between soil N in retained residue treatments at Babinda, suggests that costs incurred in managing trash by incorporation may not be warranted. Residue retention and burning should not be equally regarded management practices however, as residues provide a source of N apart from generating a marginal improvement to soil N mineralising conditions. Although indices were useful for indicating the relative field N concentrations in response to climate, the model was not successful in predicting the form of mineral N in soils and requires refinement of this process for tropical soils. Improved understanding of the fate of soil N in these soils has implications for N fertilizer management (which has the implicit assumption that mineral N availability is low because nitrate is leached from soils).

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References

(1) Gentilli, J. 1972. Australian Climate Patterns. Thomas Nelson (Australian) Limited.

(2) Calcino, D. 1994. Australian Sugarcane Nutrition Manual. BSES/SRDC, Brisbane, Australia.

(3) Vallis, I, Catchpoole, V.R., Hughes, R.M., Myers, R.J.K., Ridge, D.R. and Weier, K.L. 1996. Aust. J. Agric. Res., 47: 355-370.

(4) Thorburn, P.J., Biggs, J.S., Weier, K.L. and Keating, B.A. 2002. Agric. Ecosys. Environ. (in press).

(5) Rasiah, V. and Armour, J.D. 2001. Aust. J. Soil Res., 39: 329-341.

(6) Weier, K.L., McEwan, C.W., Vallis, I., Catchpoole, V.R. and Myers, R.J. 1996. Aust. J. Agric. Res., 47: 67-79.

(7) Freney, J.R., Denmead, O.T., Saffigna, P.G., Wood, A.W., Chapman, L.S. and Hurney, A.P. 1991. Proc. Aust. Soc. Sugar Cane Technol., 13: 38-43.

(8) Thorburn, P.J., Van Antwerpen, R., Meyer, J.H., Keating, B.A. and Robertson, F.A. 2001. Proc. Int. Soc. Sugar Cane Technol., 24: 33-39.

(9) Robertson, F.A. and Thorburn, P.J. 2000. Proc. Aust. Soc. Sugar Cane Technol., 22: 225-229.

(10) Ng Kee Kwong, K.F., Deville, J., Cavalot, P.C. and Riviere, V. 1987. Plant Soil, 102: 79-83.

(11) Salter, B. and Bonnett, G.D. 2000. Proc. Aust. Soc. Sugar Cane Technol., 22: 322-327.

(12) Klok, J.A. and Kingston, G. 2002. Proc. Aust. Soc. Sugar Cane Technol., 24: 70.

(13) Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C. and Strong, W.M. 1998. Agric. Syst., 56: 1-28.

(14) Thorburn, P.J., Goodson, M., Meier, E. and Biggs, J.S. 2002. Proc. Aust. Soc. Sugar Cane Technol., 24: 80.

(15) Thorburn, P.J., Dart, I.K., Biggs, I.M., Baillie, C.P., Smith, M.A. and Keating, B.A. 2002. Irrig. Sci., (in press).

(16) Sierra, J. and Marban, L. 2000. Soil Sci. Soc. Am. J., 64: 2002-2010.