

# Reducing nitrous oxide emissions from sugarcane soil with legume intercropping

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## Abstract

Australian sugarcane cropping has low nitrogen (N) use efficiencies, largely due to a mismatch of early-season N fertiliser application and later season peak crop N demand, in combination with poor soils and wet climate. To address the problem of N losses via run-off, leaching and N<sub>2</sub>O emissions, the sugarcane industry is evaluating several avenues. One approach is to improve N use efficiency (NUE) by reducing the use of vulnerable-to-loss N fertiliser, supplementing crop needs with biologically fixed N via sugarcane-legume intercropping. In an optimised system, decomposing legumes would deliver N to sugarcane, synchronised with sugarcane's long N accumulation phase. We hypothesised that legume intercropping in combination with lower N fertiliser rates will reduce N losses (N<sub>2</sub>O emissions were quantified here) but not sugar yields. Here we report on one of several field trials with sugarcane grown as monoculture or intercropped with legumes at full N fertiliser or lowered rates (67 or 41% of full N). In the second year of implementation and compared to full N fertiliser, N<sub>2</sub>O emissions were reduced by 50 to 70% in the 67% N treatments irrespective of legume presence. Highest sugarcane biomass was achieved with full-N rate, 67% N, and 67% N + soybean intercropping. Sugarcane production was reduced in 67% N + mung bean intercropping, 41% N and zero N treatments. Sugar yield was variable but statistically similar across all treatments. These early results indicate that evaluation across different growing regions, fertiliser rates and planting times are needed to optimise sugarcane-legume intercropping systems.

## Keywords

greenhouse gas, sugarcane, sugarcane-legume intercropping, agriculture, nitrous oxide

## Introduction

Sugarcane cropping in tropical Australia is based on high N applications which exceed early crop uptake capacity, and a substantial proportion of applied N is generally lost to the environment during major rainfall or irrigation events (Robinson et al. 2011, Webster et al. 2012, Brackin et al. 2015). Emissions of N<sub>2</sub>O from sugarcane soils can be substantial, and depend on climate, soil type, and management practices. Australian sugarcane soils often generate larger N<sub>2</sub>O emissions than the IPCC emission factor (1% of fertiliser-N), with emission factors of up to 21% (Allen et al. 2010, Denmead et al. 2010). The key driver of N<sub>2</sub>O emissions is the presence of high concentrations of available N (especially ammonium and nitrate) in combination with oxygen limitation, common in high rainfall regions or flood-irrigated crops. The strong relationship between N fertiliser application methodology (amounts, timing, one or several doses) and N<sub>2</sub>O emissions provides a basis for reducing emissions through improved N management (Allen et al. 2010, Denmead et al. 2010, Huth et al. 2010). The critical issue of poor synchrony in timing N fertiliser application and crop N demand (Robinson et al. 2011, Brackin et al. 2015) is, *inter alia*, investigated by using 'enhanced efficiency' fertilisers with the aim to improve crop N capture by shifting N release from the early to the later crop season (Verbure et al. 2015, Wang et al. 2016).

Another approach is supplementing N fertilisers with biologically fixed N (Jensen et al. 2012, Brooker et al. 2015). While crop rotation or so-called 'break cropping' with legumes (the interruption of the sugarcane ratoon cycle with a year of legume crops) is now widely practiced in Australia (Park et al. 2010, Thorburn et al. 2010), legume intercropping is not. Legume intercropping for N fixation benefits and grain harvest is relatively common in developing nations, but is rare where mechanical harvesting is used (Brooker et al. 2015). Intercropped legumes have the potential to fix and release N for the sugarcane crop, but legumes can also be responsible for increased N<sub>2</sub>O emissions by enriching with N in the surrounding soil, and during senescence and decomposition (Jensen et al. 2012, Wang et al. 2012, Saggar et al. 2013)

A main driver of high N<sub>2</sub>O emissions from sugarcane soils is N fertiliser, generally supplied in a single

application at the start of the cropping season. By reducing initial fertiliser application, and replacing it with legume-derived N that is released over a longer period, we hypothesised that sugarcane-legume intercropping facilitates better N supply of sugarcane across the growing season and reduces accompanying N losses from soil. Here we investigated the relationship between N fertiliser rates, legumes and sugarcane on N<sub>2</sub>O emissions and sugarcane yield.

## Methods

A field trial was established at a sugarcane farm (18°27'56.35" S 145°50'55.28" E) in the Wet Tropics at Abergowrie, Queensland, Australia (Figure 1). The site is rainfed agriculture with an average annual rainfall of ~1500 mm on a Dermosol. Rainfall during the 2014-2015 crop season was 860mm, 44% below average. Treatments were established in 2013-2014, and repeated in the 2014-15 season (reported here). Treatments were Full N (148 kg/ha of N), 67% N (91 kg/ha of N), 67% N + soybean intercrop, 67% N + mungbean intercrop, 41% N (66 kg/ha of N) + soybean intercrop, and Zero N (0 kg/ha of N). Each plot consisted of 6 rows of sugarcane (row spacing of 1.65 m), with a length of approximately 212 m (total area of 0.21 ha). The field trial had three blocked replicates. Placement of treatments was randomised within each replicate. Legumes were planted into the sugarcane (on both shoulders of the row) on the 15/12/2014. Fertiliser was applied on 09/10/2014. N<sub>2</sub>O gas sampling commenced on 10/10/2014, and continued at regular intervals until sugarcane harvest. N<sub>2</sub>O emissions were quantified in full N, 67% N, 67% N + legumes and zero N treatments. Two manual greenhouse gas sampling chamber bases (0.5 x 0.5 m) were installed in each plot, one covering the sugarcane row (which was fertilised), and one covering the inter-row space. During regular gas sampling, air tight gas sampling chambers (0.5 x 0.5 x 0.5) were placed on the bases for 1 h, after which a 30mL gas sample was removed *via* a valve. N<sub>2</sub>O concentrations were quantified using gas chromatography as per Wang *et al.* (2016). Baseline environmental gas samples were also taken to determine initial N<sub>2</sub>O atmospheric concentrations. Fluxes of N<sub>2</sub>O were then calculated using formulae presented in Wang *et al.* (2016), using weighed averages to calculate per-hectare emissions. Statistical analysis for cumulative N<sub>2</sub>O and sugarcane yield was performed using a GLM-ANOVA and LSD post-hoc tests at P<0.05. Sugarcane was harvested with a commercial harvester on 04/09/2015, and yield data quantified by recording commercial harvest bin numbers linked with bin weights and sugar contents provided by the sugar mill to obtain stalk and sugar yields.

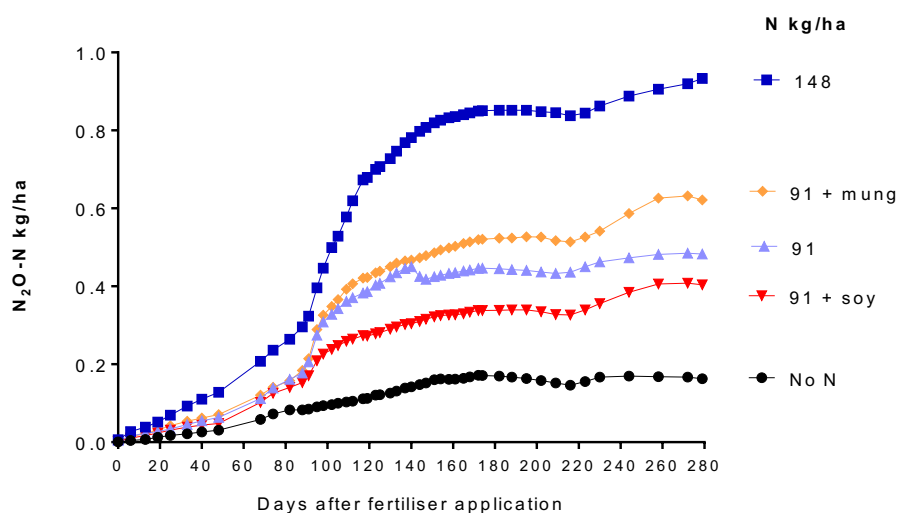


**Figure 1: (Left to right) Legume planting into ratooned sugarcane, N<sub>2</sub>O sampling, soybean intercrop.**

## Results & Discussion

Nitrogen fertiliser input was the main driver of N<sub>2</sub>O emissions with highest emissions in the full N fertiliser treatment (Figure 2). Total emissions from fertiliser application until harvest were 0.9 kg/ha of N<sub>2</sub>O-N, substantially lower than many previously published studies at similar N rates (9.6 - 45.9 kg/ha of N<sub>2</sub>O-N; Allen *et al.* 2010, Wang *et al.* 2016, Denmead *et al.* 2010), but similar to emissions recorded in Brazil (de Oliveira *et al.* 2013). The 67% N fertiliser treatments had significantly lower emissions. The presence of a soy or mungbean intercrop at 67% N had no statistically significant effects on N<sub>2</sub>O emission. As expected, lowest N<sub>2</sub>O emissions occurred in the zero N treatment. The low emissions reported here are likely to be largely due to exceptionally dry conditions during this cropping season, particularly in the critical 3-4 month period post fertiliser application.

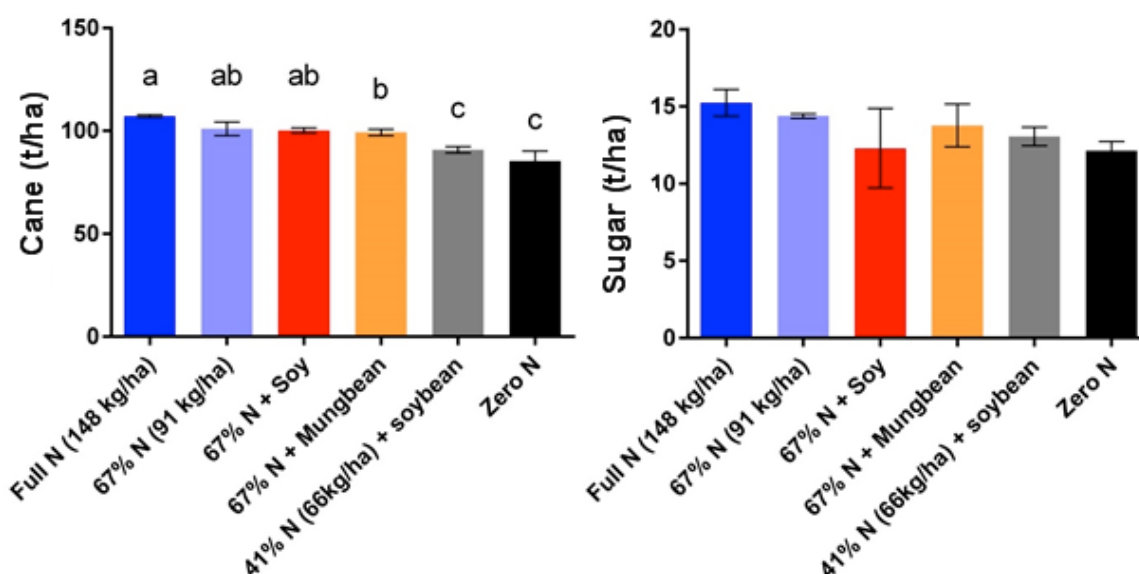
Sugarcane stalk yields were highest in the full fertiliser treatment, 67% N treatment and 67% N + soybean treatment (Figure 3). Stalk yield in the 67% N + mungbean treatment was significantly lower than the full N treatment, but statistically similar to the other 67% N treatments. 41% N + soybean and Zero N treatments produced significantly lower biomass yields than all other treatments.



**Figure 2.** Nitrous oxide ( $N_2O-N$ ) emissions per hectare at different N rates (148 or 91 kg/ha of N) in sugarcane as monocrop and sugarcane-soybean/mungbean as intercropping systems at Abergowrie, 2014-15 growing season. Data are means of three replicate plots.

Due to high variability, sugar yield did not significantly differ across treatments, although two of the three 67% N + soybean replicates had greatly reduced sugar content (data not shown). Reasons for this variation have not yet been identified, but may reflect competition between the crops, which is currently being investigated. Yield appeared to be limited by other factors alongside N (such as low rainfall), which may have contributed to the lack of stimulated sugarcane productivity *via* biologically fixed N. Alternatively, legume-N may have been released too late in the growing season for sugarcane biomass effects to be apparent. Further conclusions have to await the results from ongoing research to shed light on the interactions between sugarcane and legumes. Facilitation and competition are likely to determine the relationship between crops across different sugarcane growing regions and annual climate variations.

While intercropping can increase yield and profitability (Parsons 2003, Brooker et al. 2015), this was not apparent in the results presented here. Similar to previous studies that detected neutral or negative impacts, the success of intercropping is determined by factors including legume planting time, N fixing capacity, and water availability (Roodagi et al. 2001, Gana and Busari 2003). Additional factor of relevance for sugarcane cropping is the potential for intercrops to reduce soil biological constraints that demand crop rotations in the current systems.



**Figure 3:** Sugarcane stalk yield (left panel) and sugar yield (right panel) from final harvest. Data are means  $\pm$  standard error of the mean (n=3). Lower case letters indicate significant differences. Data was log transformed where required for statistical analysis. No statistically significant differences were found in sugar yields.

## Conclusion

Legume intercropping has potential to deliver sustainability and yield benefits; however, these were not apparent in this early trial. Successful legume-sugarcane intercropping requires a knowledge-based fine tuning of several parameters that range from timing and density of legume sowing, cultivars and other agronomic measures. Further evaluation will occur once we have fuller insight into the sugarcane-legume intercropping system with data from current multi-year field trials in three geographical locations.

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