Identifying on-farm management practises aimed at reducing greenhouse gas emissions from sugarcane primary production

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Abstract

A scoping study was undertaken by CSIRO and CANEGROWERS to assess the potential for sugarcane growers to implement practical and effective abatement strategies to reduce greenhouse gas emissions from sugarcane cropping. A range of management practices was explored for the Herbert River Region and the impact of the different agronomic regimes on annual net emissions and farm productivity were estimated using the Agricultural Production Systems Simulator (APSIM) and a spreadsheet based greenhouse gas calculator (GreenCalc). The results suggest that green cane trash blanketing can provide greater crop yields and a reduction in greenhouse gas emissions, compared with burnt systems. Further reductions in emissions may be obtained by incorporating a fallow period into the cropping cycle. Growing legumes during this period should reduce N fertiliser applications.

Key words

Abatement, nutrient cycling, APSIM, GreenCalc

Introduction

As a signatory to the Kyoto Protocol, Australia has pledged to reduce anthropogenic contributions to the enhanced greenhouse effect. Approximately 15% of the net greenhouse gas emissions from Queensland for 1995 were derived from agriculture (1). One of the largest and most important rural industries in Queensland is sugarcane production, with the Queensland coastal plains yielding up to 85% of Australia's sugar production. The main greenhouse gas exchanges occurring during sugarcane primary production involve carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The flux of C and N sources and sinks is influenced by many agronomic practices, independently and in interaction. This paper summarises some of the main effects of agronomic practices used in the production of sugarcane, on C and N cycling that result in the emission of greenhouse gases.

Crop growth: C and N are harvested from the system annually in the form of crop yield, with the amount of C removed directly related to crop yield. Nitrogen removed during harvest is compensated by application of N fertiliser, of which only 30-40% is recovered by the crop, the remainder either stored in soil organic matter or lost through denitrification (2), leaching and volatilisation. Rates of denitrification may be reduced by the use of nitrification inhibitor-coated fertilisers, avoiding anaerobic soil conditions and the application of more frequent but smaller rates of N fertiliser.

Irrigation and drainage: Excessive soil water results in loss of soil C stores indirectly through increased decomposition with the net evolution of CO_2 and CH_4. Irrigation and drainage can be used to manage N lost *via* denitrification. Soils have the capacity to act as both a source and a temporary sink for N_2O. Anaerobic conditions may stimulate denitrification and the evolution of N_2O. The capacity of a soil to act as a temporary sink for N_2O is due to microbial activity (although some N_2O may be further reduced to N_2 and lost to the atmosphere), and is negatively affected by increasing nitrate concentrations.

Cultivation: As a result of the disaggregation of soils, fracturing of soil micropores and increased biological activity, cultivation stimulates a net loss of C from the soil. This inhibits microbial activity and biomass, which can reduce CH_4 uptake. Carbon is also liberated through fossil fuel use in the farm machinery. Effects of cultivation on fluxes of N_2O from soil are not yet fully understood.

Residue inputs: A green cane trash blanket (GCTB) can increase total soil C by ≈0.2% in the top 10cm within 5 years (3). The increased levels of C resulting from GCTB, increase microbial biomass and activity, and thus the rate of decomposition. Decomposition is also influenced by post-harvest management, climatic conditions and initial residue mass. Soils beneath GCTB may act as a net sink for CH_4, consuming up to 105 kt CH_4-C yr^{-1} nationally (4). Despite the possible promotion of volatilisation, immobilisation, leaching and denitrification, GCTB can return up to 65% of the total plant uptake of N and increase levels of soil N in the upper 2-5 cm of soil after only 3 ratoons (5). Immediately following trash application, net immobilisation of N may occur as a result of increased microbial activity and a higher rate of denitrification due to the addition of soluble carbon as an energy substrate, and emission of N_2O under certain circumstances.

Burning trash: This can result in up to 95% of the dry matter content being lost from the system, with 5% remaining as charcoal. Pyrolysis during smouldering produces CH_4 emissions. Burning may result in almost 100% loss of crop residue N, depending on the method of burning. N_2O is also released during burning.

Fallow periods: During a fallow period the ground may be sown with a legume break crop. Legume residues contain up to three times more N than sugarcane residues and can contribute substantially to soil C and N. Legumes also undertake biological N fixation. Soils left bare during a fallow period are prone to high rates of decomposition, the subsequent low levels of microbial activity enabling a slow build-up of mineral N.

It is evident from the above and other studies (4, 6), that agronomic practices may offer a useful tool for managing greenhouse gas emissions from the primary production of sugarcane. Given the large number of effects resulting from different agronomic practices, a modelling approach has been used to simulate crop/soil/residue related C and N dynamics for a number of production scenarios using the systems model, APSIM (Agricultural Production Systems Simulator, (7)) and GreenCalc, (8), a spreadsheet based calculator used to estimate net emissions of key greenhouse gases at the paddock scale.

Materials and methods

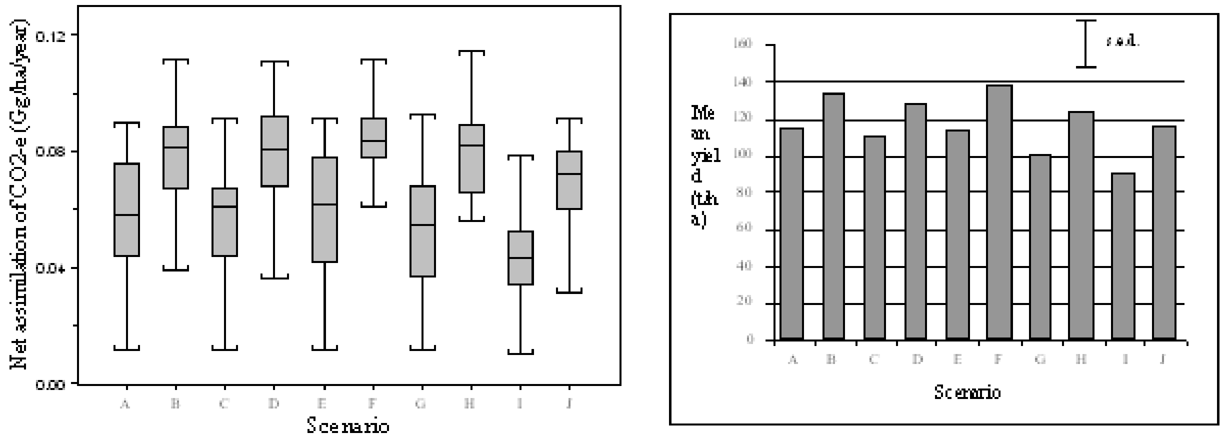
Ten alternative scenarios (Table 1) were developed to represent a range of agronomic practices used in the growth of sugarcane in the Herbert Region. The main treatments were sugarcane trash management (burnt, GCTB), rotations (legume or bare fallow, plough-out/replant (PO/RP)) and fertiliser application (plant and ratoon, ratoon only). All scenarios assumed the use of sugarcane variety Q124, a plant density of 10 plants m^2, a cropping cycle consisting of a plant and four ratoon crops and, if applied, an annual urea application rate of 45 and 90 kg/ha 1 and 90 days after sowing, respectively. Scenarios containing soybeans assumed variety 'Davis' was planted on 15 October at a density of 25 plants m^2 and the whole crop was incorporated into the soil on 20 March of each fallow period. APSIM was configured to represent the management and growing conditions of each scenario. The configuration included the soil water module SOILWAT2, the soil nitrogen module SOILN2, the surface residue module RESIDUE2 (9) and two crop modules, SUGARCANE (10) and LEGUME (11). APSIM was parameterised with soil data for the region (12) and run using historical climate data for the period 1957 to 2001. Model output from each APSIM simulation relating to crop/soil/residue C and N dynamics, crop yield and residue biomass was subsequently fed into GreenCalc. Estimates of CO_2, CH_4 and N_2O emissions for the alternative scenarios were expressed as CO_2-e (Gg/ha) and compared to provide a qualitative assessment of the sensitivity of individual management practices to reduce emissions.

Table 1. Scenarios of agronomic practices used to grow sugarcane in the Herbert River Region.

	Scenario									
	A	B	C	D	E	F	G	H	I	J
Fallow	Legume	Legume	Legume	Legume	Bare	Bare	Bare	Bare	PO/RP	PO/RP
Sowing	1 Mar	1 Mar	1 Mar	1 Mar	1 Mar	1 Mar	1 Mar	1 Mar	30 Oct	30 Oct
Plt. lgth (days)	458	458	458	458	458	458	458	458	357	357
Rat. lgth (days)	397	397	397	397	397	397	397	397	357	357
Trash Urea	Burnt Plt. and rat.	GCTB Plt. and rat.	Burnt Rat. only	GCTB Rat. only	Burnt Plt. and rat.	GCTB Plt. and rat.	Burnt Rat. only	GCTB Rat. only	Burnt Plt. and rat.	GCTB Plt. and rat.

Results and discussion

Across all scenarios, simulated sugarcane yields obtained under GCTB systems were 21% larger (*P* <0.01) than those produced under burnt systems (Fig. 1*a*), reflecting observed field data (13). In general, cropping systems containing a fallow yielded 17% better (*P* <0.01) than those under PO/RP for either burnt or GCTB practices. Whilst there appears to be no effect of a reduced application of N fertiliser in cropping systems containing a legume fallow in the simulations, there is a notable, although not significant, reduction in yield when N-fertiliser is applied to only ratoon crops in bare fallow systems (i.e. scenarios G and H). This would suggest that the N requirement for the plant crop may be satisfied by growing a legume during the fallow period. Estimates of net CO_2-e balance from the simulations (Fig. 1*b*) showed generally constant variability and relatively little overall skewness for all scenarios. Across all treatments, GCTB resulted in a greater sink of CO_2-e than burning. In general, management scenarios containing a fallow period produced higher median estimates of net CO_2-e balance, compared with PO/RP systems. This suggests that over a period of time, greenhouse gas emissions may be lower from cane production if a fallow period is incorporated into the cropping cycle.



(a)

(b)

Figure 1. (a) Estimates of mean yield of sugarcane (t/ha); (b) estimates of net CO_2-e balance (Gg/ha) (boxes contain 50% of estimates, horizontal line indicates median, whiskers identify max/min).

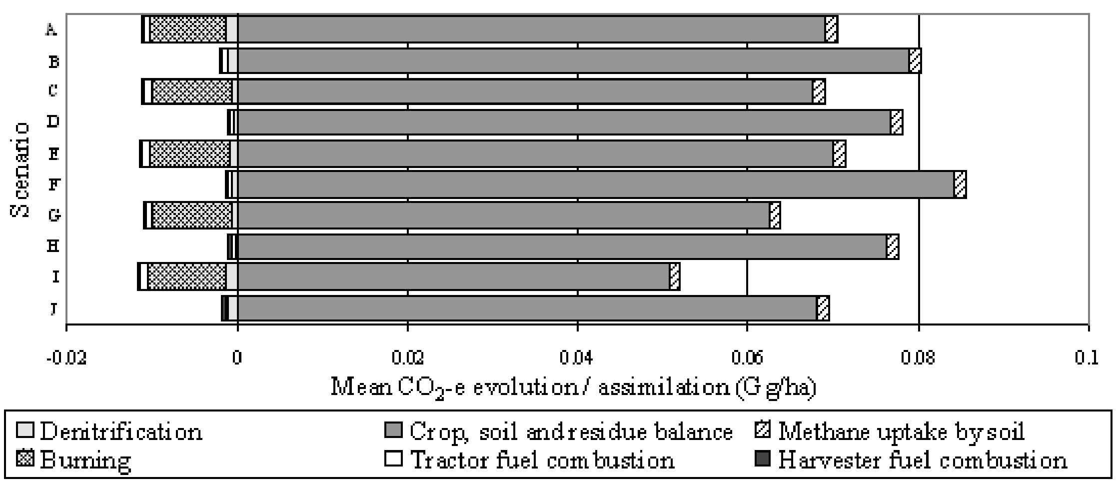


Figure 2. Mean evolution / assimilation of CO_2-e (Gg/ha/year) from a range of sources.

The uptake and assimilation of both CO_2 by the cane crop and, to a lesser extent, CH_4 by the soil, provides a sink for potential greenhouse gases, whilst fuel combustion, denitrification and in scenarios A, C, E, G and I, burning, are sources of emissions (Fig. 2). Similar to other systems (6), the CO_2-e balance is dominated by the assimilation of large amounts of CO_2 into crop biomass. APSIM does not capture the processes associated with soil CH_4 uptake; a single estimate of CH_4 assimilation was defined in GreenCalc for use in all scenarios. When crop and soil CO_2 and CH_4 processes are excluded from the analysis (Fig. 3), the largest determinant of greenhouse gas emissions is the management of harvest residues. The reduced tillage operations under GCTB are reflected in emissions from tractor fuel being approximately halved, compared with conventional cultivation techniques associated with burning. Denitrification varies greatly across the scenarios, but is generally higher where N fertiliser is applied to both the plant and ratoon crops. Denitrification is particularly high in scenarios containing a legume fallow, possibly due to incorporation of N rich legume residues. Fertiliser N applications might be reduced by incorporating legumes into the cropping cycle.

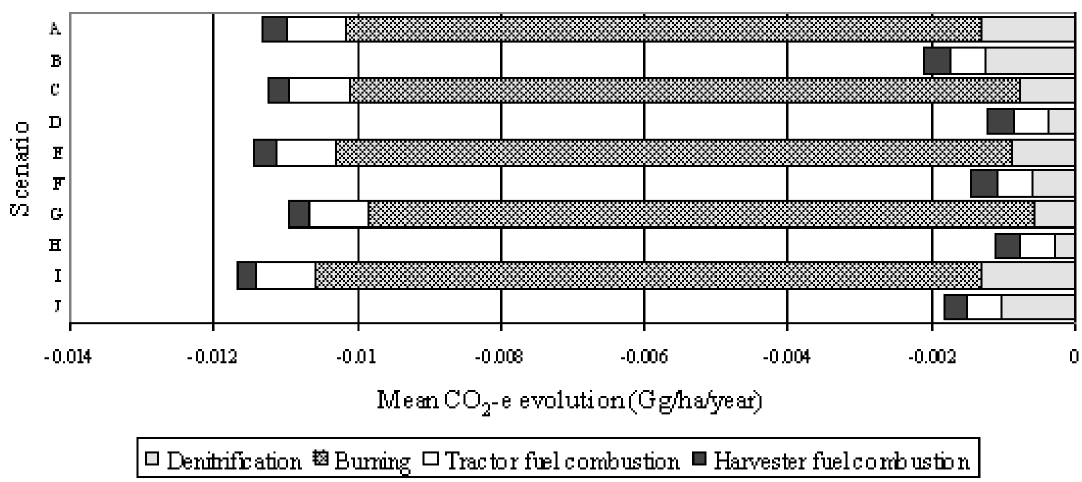


Figure 3. Mean evolution of CO_2-e (Gg/ha/year) from a range of sources.

Conclusion

This analysis suggests that by adopting GCTB the sugarcane primary production system can provide a greater sink for C and N compared to systems in which harvest residues are burnt, during the period that the cropping systems are maintained. The simulations suggest that GCTB may reduce greenhouse gas emissions by up to 10% compared with burning. Whilst GCTB produces reduced rates of greenhouse gas emissions, it is also predicted to result in greater yields of sugarcane under the conditions simulated. Further reductions in emissions and an improved soil condition are provided by the inclusion of a soybean fallow into the cropping cycle (14). Environmental benefits may be gained from the reduced N fertiliser requirements of a plant crop following a legume fallow. Whilst GCTB, legume fallows and reduced N fertiliser applications may offer an effective means of reducing greenhouse gas emissions from the primary production of sugarcane in the Herbert Region, this study suggests a full cost/benefit analysis would need to be undertaken to assess whether these practices are financially viable for growers to implement, especially given the sugarcane revenues that must be foregone in order to introduce a fallow period into the cropping cycle.

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