# THE IMPACT OF TRASH MANAGEMENT ON SOIL CARBON AND NITROGEN: I MODELLING LONG-TERM EXPERIMENTAL RESULTS IN THE SOUTH AFRICAN SUGAR INDUSTRY

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**Abstract**

Trash blankets contain substantial amounts of nitrogen (N) and other nutrients. The availability of N in trash is complicated because most of the N cycles through the soil organic matter. To gain insights into the long-term fate of N contained in trash, N dynamics in the SASEX long-term trash management experiment (BT1) were simulated with the APSIM-Sugarcane cropping systems model. Initially, the model was verified against cane yields and soil organic carbon data from the experiment. Then, simulations were conducted over 60 yr (1940 to 2000) with N fertiliser application rates ranging from 20 to 260 kg/ha. Cane yields and soil organic carbon results from the BT1 experiment were well represented by the model. The N response simulations showed that cane production not only responds positively to trash retention at the BT1 site, but that the response is dependent on the amount of N fertiliser applied to the crops. To maximise the production benefits from trash retention, additional N (approximately 60 kg/ha) should be applied where trash is retained compared to that where trash is burnt. The additional N is required for the crops to reach their potential with the additional moisture available in the trash retained system. The simulations also show that it takes three to four decades for the response of cane yields to N fertiliser application rates to stabilise, although even after this time soil organic C is still simulated to be declining (as occurred in the BT1 experiment). This study illustrates the additional insights that can be gained into the complexities of agricultural systems with the aid of a comprehensive simulation tool. Analyses of the likely impacts of trash retention at other sites in the South African sugar industry will be reported in a companion paper.

*Keywords:* fertiliser response, green cane harvesting, nitrogen mineralisation, nutrition; soil organic matter; sugarcane

## Introduction

Trash blankets contain considerable quantities of dry matter and nutrients, particularly nitrogen (N) and potassium (Wood, 1991; Ball-Coelho *et al*., 1993; Mitchell *et al*., 2000). When sugarcane is burnt either pre- and/or post-harvest, 70–95 % of the dry matter and N are lost from the system, with lower losses of other nutrients (Mitchell *et al*., 2000). Thus harvesting cane green and retaining the trash blanket has a considerable effect on organic matter conservation, nutrient cycling and N fertility of the soil.

Field experiments have been conducted in the South African and Australian sugar industries comparing trash blanketed and burnt treatments for up to 60 years. In these experiments, increases in soil organic matter and total N in trash blanketed treatments are small, confined to the surface soil, and poorly related to the age of the experiments (Thorburn *et al*., 2000; van Antwerpen *et al*., 2001). However, microbial activity is clearly stimulated by trash blanketing (Sutton *et al*., 1996;

Graham *et al*., 1999), even after only short periods of trash retention (Robertson and Thorburn, 2001). Ng Kee Kwong *et al*. (1987) showed that a crop uptake of N from a trash blanket in the season following deposition of the trash was negligible and the N was mainly immobilised in the soil organic matter. Previous studies have often concentrated on measuring only one of the possible sinks of N in a trash blanketed system, i.e. 'storage' of N in soil organic matter. Apart from this, other potential fates of N include (1) increased environmental losses of N (e.g. by leaching and/or denitrification; Weier *et al*., 1998; Thorburn *et al*., 2001b), or (2) increased net removal of N from the site if trash blanketing increases yields and/or N concentrations in cane (which occurs if soils become 'N-rich'; Catchpoole and Keating, 1995). Thus it is difficult to predict the impact of trash blanketing on cane production and N fertiliser management.

In this paper, we examine N dynamics in the South African Sugar Association Experiment Station (SASEX) long-term trash management experiment (BT1; van Antwerpen and Meyer, 1998; Graham *et al*., 1999; van Antwerpen *et al*., 2001) using the APSIM-Sugarcane cropping systems model, to gain insights into the long-term fate of N contained in trash and the N fertiliser management implications of trash retention. Specifically we ask; is the model capable of reproducing the trends of the major N pools (cane yields and soil organic carbon) in the experiment; how does trash retention influence the amount of N fertiliser required for maximum yield; and, what are the time scales over which N cycling at the site will come into equilibrium?

## Materials and Methods

The model's performance was first assessed against measured yields, which control N removal from the site in cane and recycling of N in trash blanketed treatments, and total soil carbon (C), which is mechanistically linked to the soil N cycle. These measured data were reported by van Antwerpen *et al*. (2001). Other data that could be used to verify the model, such as the amount of trash produced had not yet been published and, the N concentrations of the crops, and losses of N to the environment, were not available. Following the verification, simulations were preformed of different rates of applied N to each of two trash management practices; trash burnt and trash retained at harvest. These simulations were conducted for the period 1940-2000. A description of the sites, the model and the parameterisation and simulations follow.

*Site*

Simulations were based on data from the BT1 experiment at Mount Edgecombe, South Africa (van Antwerpen and Meyer, 1998; Graham *et al*., 1999; van Antwerpen *et al*., 2001). The experiment was established in 1939 and the long-term average annual rainfall at the site is 950 mm. Soil at the site was a cracking, medium clay at with a surface soil pH of approximately 5.5. There were four replicates of the burnt (both before and after harvest) treatment and eight replicates of the trash retained (blanketed) treatment of BT1. During the experiment four varieties were planted, Co281 (1939), Co301 (1948), NCo376 (1957 and 1977) and N16 (1991).

*Model configuration*

The APSIM model configuration consisted of modules for soil N and C (APSIM-SoilN; Probert *et al*., 1998), soil water (APSIM-SoilWat; Probert *et al*., 1998) and sugarcane residue (APSIM-Residue; Thorburn *et al.* 2001a) dynamics, and sugarcane growth (APSIM-Sugarcane; Keating *et al*., 1999). The modules are one-dimensional, use a daily time-step and are driven by climatic data. The dynamics of water, N, C and roots are simulated in soil layers, with water (and associated nitrate) moving between layers where gradients exist. The soil was divided into seven soil layers, with a total depth of 1.5 m. N mineralisation, N immobilisation and nitrification are explicitly described in each layer, as are the N losses from denitrification and leaching. Soil moisture and temperature affect all soil N cycling processes. The soil water module is a 'cascading bucket' water balance model. The presence of plant residues on the soil surface affects runoff (and hence infiltration) and evaporation. The sugarcane module uses intercepted radiation to produce assimilates, which are partitioned into leaf, cabbage (defined as the immature top of the stalk plus green leaf sheaths), structural stalk, roots and sugar. These processes are responsive to radiation and temperature, as well as water and N supply. Farming operations (such as fertilisation, planting, incorporation of crop residues through cultivation, or burning of crop residues) were specified through the APSIM-Manager module.

*Parameterisation and simulations*

In all simulations, the model's soil parameters were based on the experimental data for the site obtained from SASEX records. Starting soil C contents in the APSIM-SoilN module were taken from total soil C measurements made prior to the experiment's commencement (JH Meyer, unpublished data). The C:N ratio of the soil was estimated from the average (across treatments and through time) of measurements made during the latter stages of the experiment. Soil water parameters were determined from soil moisture characteristic data from the site, measurements of runoff from a similar soil under a range of crop residue treatments in central Queensland, Australia (Thorburn 1992) and default values for cracking clays given by Probert *et al*. (1998). Parameter values for NCo376 (Keating *et al*., 1999) were used for simulating sugarcane in the experiment, as parameters for the other varieties were not available. Daily climate data were obtained from the SASEX records. Prior to 1960, daily measurements of solar radiation were not available. For these years, the mean daily radiation for the years 1960-1999 was used. Simulations were conducted for the period 1939-2000.

In simulations of the experimental results, management variables (planting and harvesting dates, type, amount and date of N fertiliser applications) were obtained from SASEX records. Fertiliser was spread on the soil surface in the experiment, so there would have been loss of N from volatilisation of ammonia in the years when urea was used as the N source (from 1973), particularly in the trash blanketed treatment. These losses were estimated for both treatments using the model of Schumann (2000) and the N applications reduced accordingly so that only net N fertiliser applications were made in the model. After harvest of each crop, trash weights were reduced by 95% in the burnt treatment to simulate trash burning both pre- and post-harvest (Mitchell *et al*., 2000).

To investigate the response of cane yields to N fertiliser applications at the site, additional simulations were conducted over 60 years (1940-2000) with different rates of N fertiliser application. Nine different rates of N fertiliser were applied, with the plant crop receiving 75 % of that applied to the ratoon crops. The N rates for the ratoon crops commenced with 20 kg/ha and incrementing by 30 kg/ha to a maximum of 260 kg/ha. The N was applied as nitrate, to overcome issues of ammonia volatilisation, at a depth of 0.1 m. The initial soil conditions, climate data and variety (Co376) were the same as those used in the simulation of experimental results. In all there were 10 cropping cycles simulated with each cropping cycle composed of a 14 month plant crop followed by four 12 month ratoon crops and a 10 month fallow.

## Results

*Simulations of experimental cane yield and soil carbon*

In the BT1 experiment, predicted cane yields generally agreed with measured yields (Figure 1), with the mean predicted yield less than 2 t/ha different from the mean measured yield over the whole experiment. Simulated yields were markedly different from measured yields in both treatments in 1956, 1987 and 1990, and in the burnt treatment in 1974, 1976 and 2000. Management records for the experiment did not indicate any apparent reason for these differences. The mean measured cane yield in the trash blanketed treatment was 13.9 t/ha greater than in the burnt treatment, with this difference being 11.5 t/ha for the simulated yields. The simulations indicate that greater water availability in the trash blanketed treatment was a significant factor in this yield increase.

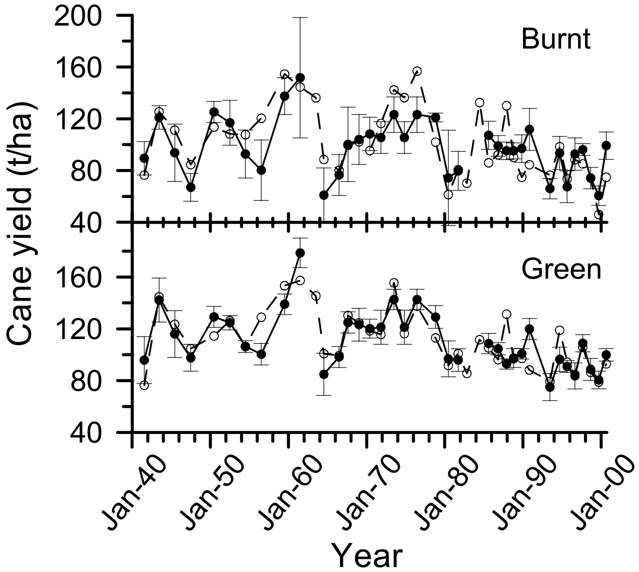


**Figure 1. Measured (solid symbols) and simulated (dashed lines – open symbols) cane yield in burnt and trash blanketed (Green) treatments of the BT1 trash management experiment. Bars about the measured data points show the +95% confidence interval.**

Total C measured in studies conducted since 1980 is well predicted by the model, while there are substantial differences between measured and predicted values in 1945 and 1962 (Figure 2). It is possible that these differences may be due to methodological factors. The difference between the burnt and trash blanketed treatments is well predicted, even for these early studies. The simulations of total C indicate that soil organic matter has declined in both treatments of the BT1 experiment. The rate of this run down was greater in the burnt treatment, but became negligible in the trash blanketed treatment during the latter part of the experiment (i.e. the 1990s).

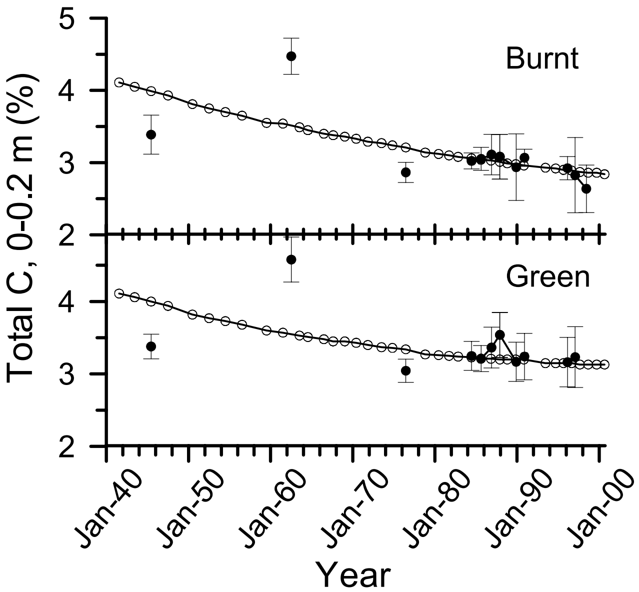


**Figure 2. Measured (solid symbols) and simulated (dashed lines – open symbols) total soil organic carbon in burnt and trash blanketed (Green) treatments of the BT1 trash management experiment. Bars about the measured data points show the +95% confidence interval.**

*Simulated impact of different nitrogen fertiliser applications*

The simulated response of cane yield to N fertiliser application varied markedly between each crop (data not shown) in response to climatic differences over the different growing seasons. This variability did not overshadow the more consistent impacts of trash and N fertiliser, and mean yields for the five crops in each crop cycle are shown in Figure 3. In all crop cycles and at all N application rates, simulated cane yields were higher where trash was retained, with the increase averaging 18 t/ha when adequate N was applied.

The response to trash retention varied between crop cycles and between different rates of applied N (Figure 3). The differing response to trash between crop cycles was not simply due to the average rainfall during the crop cycle. For example, the greatest simulated response to trash occurred in crop cycle 6 (Figure 3), which had close to average rainfall (Figure 4). The simulated response of cane yield to trash also varied with varying N application rates (Figure 3). Generally, the response to trash was lowest at the lowest rate of applied N, although over some crop cycles the response was nearly independent of N (e.g., crop cycle 5, 1964-1969). The low response to trash at low rates of applied N is the result of the system being N-limited and not able to fully respond to the increased water availability when trash is retained.

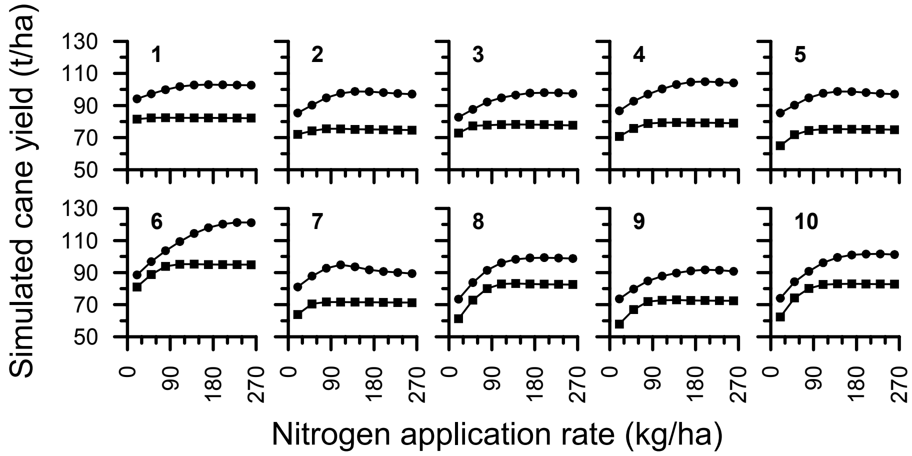


**Figure 3. Mean simulated cane yield in response to different application rates of N fertiliser over 10 cropping cycles (defined in the text) and two trash management practices (circles – trash retained; squares – trash removed).**

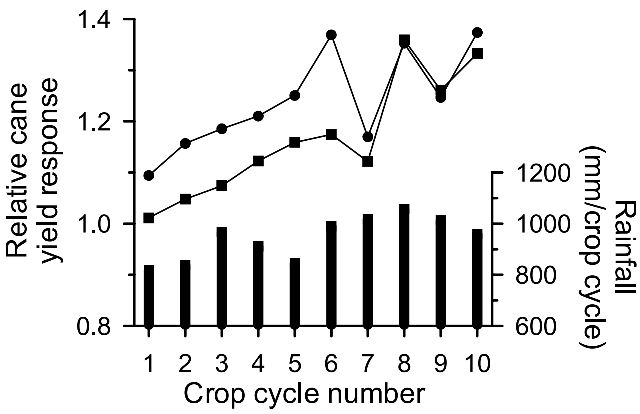


**Figure 4. Simulated relative response to N fertiliser application over 10 cropping cycles under two trash management practices (circles – trash retained; squares – trash removed). The average annual rainfall in each cropping cycle is also shown (bars).**

During the first crop cycle, there was little simulated response (< 1 t/ha) in cane yield to applied N if trash was burnt but a substantial response (7.4 t/ha) if trash was retained (Figure 3). The ratio of the maximum and minimum cane yields for the crop cycle, i.e. the relative cane yield response to applied N, was 1.01 where trash was burnt and 1.09 where trash was retained (Figure 4). The small response where trash was burnt shows that the soil's fertility was adequate to supply the crops' N requirements during this crop cycle. Where trash was retained, the additional moisture in the trash system produced larger crops that required more N than could be supplied by the soil. In subsequent crop cycles, the relative response to applied N generally increased with each crop cycle. The responses were greater where trash was retained in the first six crop cycles (i.e. over the first 35 yr of the simulation), but similar whether trash was burnt or retained after that as soil N fertility declined. Also in these later crop cycles, responses ceased to rise continually, suggesting that the soil-crop system was approaching equilibrium.

It should be noted that, despite the recycling of N where trash is retained, in all crop cycles maximum cane yields were simulated to occur at higher rates of applied N fertiliser where trash was retained than where it was burnt (Figure 3). In the final five cropping cycles, when cane yields were markedly responding to N fertiliser application when trash was burnt, maximum yields in the burnt system were obtained with the application of 80 or 110 kg/ha of N (to ratoon crops). Over the same (and earlier) crop cycles, maximum yields were generally obtained with applications of 140 to 170 kg/ha of N (to ratoon crops) if trash was retained. The additional N is required when trash is retained to supply N to the larger crops that result from the increased moisture conservation. However, where N fertiliser applications are the same the additional water and N in the trash retained system results in greater yields.

The decline in soil N fertility through time is illustrated by the decline in soil C during the simulation (Figure 5). The decline is greater where trash is burnt than where it is retained, and is also affected by the application of N fertiliser. The application of N fertiliser slows the decline in soil C during the simulation (data for the 20 and 260 kg/ha application rates shown in Figure 5) because crop size increases, hence increasing returns of organic matter (from root turnover, detached dead leaves or trash) to the soil.

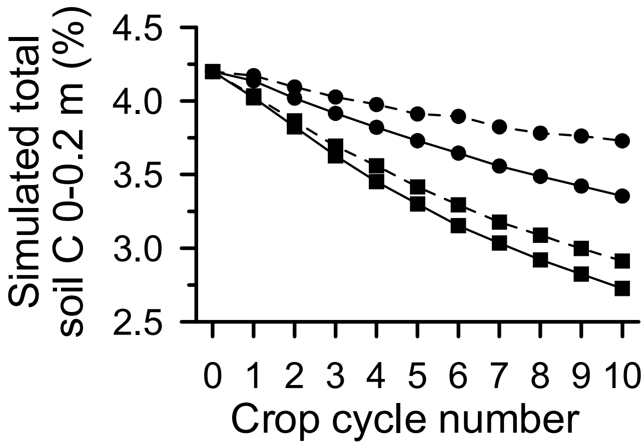


**Figure 5. Variation in simulated total soil organic carbon over 10 cropping cycles under two different trash management practices (circles – trash retained; squares – trash removed) and two different rates on N fertiliser, 260 kg/ha (dashed lines) and 20 kg/ha (solid lines).**

## Discussion

This study illustrates the additional insights that can be gained into the complexities of agricultural systems with the aid of a comprehensive simulation tool. The BT1 experiment showed clearly the benefits of retaining trash in a sugarcane system, whether or not fertiliser was applied (van Antwerpen *et al*., 2001). However, the practical limitations of field experimentation meant that BT1 was not able to explore fertiliser response in more detail. In this study we have been able to take the soil, crop and climatic characteristics of that experiment and represent them adequately in a cropping systems model (Figures 1 and 2) in order to address questions of how trash management is likely to interact with N fertiliser management at the site. We have also been able to overcome some of the uncertainties encountered in the experiment, such as likely volatilisation of N from the trash retained treatments (Schumann, 2000) resulting in different **net** rates of N being applied to the different trash treatments.

The simulations conducted in is study have shown that cane production does not only respond positively to trash retention at the BT1 site, but that the magnitude of the response is dependent on the amount of N fertiliser applied to the crops. To maximise the cane production benefits from trash retention, the simulation results suggest additional N (approximately 60 kg/ha) should be applied where trash is retained compared to where trash is burnt. However, it must be realised that this additional N will increase production costs and have possible environmental impacts (such as soil acidification; Van Antwerpen et al. 2001). Thus the most sustainable and economic production system will have to integrate these costs and benefits.

The study also illustrates the time scales involved in the response of soil N fertility to different trash and N fertiliser management practices. It took three to four decades for the relative response of cane yields to N fertiliser application to stabilise in the simulations (Figure 4). However, even after this time soil organic C is still simulated to be declining (as occurred in the experiment, van Antwerpen *et al*., 2001), although the rate of decline is much lower where trash is retained and high rates of N fertiliser are applied (Figure 5). Further work is required to better identify the time to reach equilibrium soil organic matter conditions.

While direct comparison of the simulation results with those of the experiment is not possible because of the differences in crop and cropping cycle length, N application rates, varieties, etc., some evaluation is warranted. van Antwerpen *et al*. (2001) found that there was no significant ($P < 0.05$) response to fertiliser application for 18 yr in the BT1 experiment. However, over this time there were consistent trends towards an increase in cane yield when fertiliser was applied. In the first three crops (i.e. 6 yr) the relative response was 2 and 7 % where trash was burnt and retained, respectively. These trends compare favourably with the relative responses (1 and 9%, Figure 4) simulated for the first crop cycle in this study. More importantly, this comparison illustrates that the impacts of spatial variability (i.e. between replicate plots in the BT1 experiment) were not accounted for in the simulations, and so the simulated results should be viewed as mean trends. Other factors not considered in the simulations are the effects of pests and diseases, lodging, varietal differences, and processes that are not currently well enough understood to be quantitatively represented. Thus the simulation results should be viewed as indicative rather than prescriptive.

Another feature of this study is that it is confined to the soil and climate of the BT1 experimental site. Responses to trash retention will depend on soil and climatic characteristics and thus there is a need to expand the analysis of trash management across soils and climates. Cropping systems models offer an efficient means of undertaking a broader scale analysis of trash impacts, and such an analysis is reported for the South African sugar industry in a companion paper (van Antwerpen *et al*., 2002).

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