

# EVALUATION OF THE SIMTRANS MODEL AND ITS USE IN A WORKING ENVIRONMENT

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## Introduction

Simtrans, a computer software model which simulates the road haulage of sugarcane, was developed by the Department of Agricultural Engineering at the University of Natal, Pietermaritzburg. This communication deals with the evaluation and validation of the model.

To perform model simulations using Simtrans, inputs include the profile of the route to be represented, a speed curve, vehicle parameters and payload. The route profile deals with the gradients of the route and not any corners or sharp bends. The speed curve restricts the vehicle's speed to predetermined realistic values.

The research undertaken included assembling route profiling methods, evaluating the effects of varying the speed curve and comparing the model simulations with real data measured using a Machine Performance Monitor.

## Summary

Two route profiles, namely Kevard to Sezela and Ashbrook to Sezela, were studied. These routes represent a mixture of highway (Ashbrook), and hilly areas (Kevard). Each route was profiled in three ways, namely, off orthophotos (1:10 000), by hand held Global Positioning System (GPS) and using a more sophisticated GPS. A specialist GPS firm, Green Belt Mapping, did the sophisticated GPS profiling. For the purposes of this report, the Kevard to Sezela route with its observed and simulated data will be examined.

The orthophoto method involved using a measuring wheel to find distances between contours and manually calculating the heights along the route. This was a lengthy and tedious process. A Trimble Geo Explorer was used for the hand held GPS method. The route was driven and height readings were taken wherever possible. The readings were put together to form the profile. This proved to be difficult because the GPS needed to sight at least four satellites before it could register a reading. Due to the hilly areas, this was a great problem. It was also not safe to stop the vehicle in traffic to wait for satellites to register. The route profile done by Green Belt Mapping proved to be very accurate and not far off the profiles of the other two methods.

Simulations were run with each of the profiles, using the same parameters (vehicle type, payload and speed curve) for

all the simulations. Comparisons of simulations were made, with respect to trip time and fuel consumption.

Actual data were collected by means of the Machine Performance Monitor, which was attached to a Mercedes Benz 2636 that was hauling cane along the routes that had been profiled. The device was set up to measure fuel consumption, gear, vehicle speed and engine speed. However, problems due to the harsh working conditions were encountered. For instance, ash from the cane and dust from the roads caused problems with the computer, and the fuel consumption device caused fuel starvation to the engine.

The collected data could then be observed and compared with simulated data. The software allowed the user to call up an observed data file and a simulated file, with its route profile and speed curve, and graph them together to be analysed. The Green Belt Mapping route profile was used for these simulations, as it was believed to be the most accurate. Simulations and comparisons were performed using three different speed curves for each of the two routes, so as to see the sensitivity of the simulation in the region where power is not limiting.

The speed curves used were (i) 80 km/h throughout, (ii) a slightly more accurate curve which ranged between 50 and 80 km/h, and (iii) an accurate and realistic speed curve which closely represented actual speeds obtained.

### Results of comparison for Kevard to Sezela route

The observed and simulated times, speeds and fuel consumption are shown in Table 1.

**Table 1. Comparison of observed and simulated times, speeds and fuel consumption.**

		Time (seconds)	Avg speed (km/h)	Fuel cons (litres)
Observed		3 416	37,4	18,626
Simulated	(i)	3 603	34,3	31,163
	(ii)	4 670	27,2	33,781
	(iii)	4 147	30,6	32,818

### Discussion of results for speed curves (i) to (iii)

(i) This speed curve did not take into account any slowing down for corners and downhill, and was set at 80 km/hr throughout the route. As a result, the two graphs (simulated and observed) were quite far off in parts where

power was not the limiting factor, and in real life the driver could have been using the exhaust brake while travelling down a hill or approaching a corner.

- (ii) Here the average speed of the simulation had been reduced, which is understandable as the downhill speed had been effectively reduced to a more realistic one. This also shows that the close simulations which were obtained using a simple speed curve were in fact incorrect, as the simulations were taking less time on the downhills and more on the uphills.
- (iii) This was the most accurate speed curve of all. The travel times, fuel consumption and average speed were still far from the actual ones. Here some aspects of the speed curve were altered to give a more representative speed than for (ii). Once again this shows how important the speed curve is for accurate and meaningful results.

The comparisons for the Kevard to Sezela route are shown in Figure 1. The full profile is shown in the top section of the view. The two vertical lines indicate the segment of the profile which was exploded and is shown beneath.

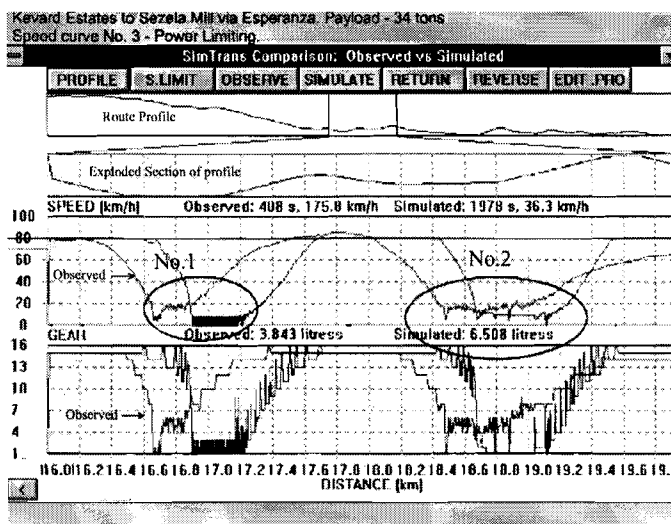


Figure 1.

The vast differences in fuel consumption may be related to a gear change issue. The two areas indicated in the figure, are areas where power was limiting, and are discussed below.

Area 1: For about 250 m the simulator constantly changes between gears one, two and three and then suddenly gears up to no. 16, stabilising in gear no. 15. The actual data show the vehicle in gears one and two for 50 m and then sitting in gears five and six for 150 m before slowly gearing up to gear 16 and stabilising in gear 15. More research needs to be done on the area where the vehicle gears up. While simulating, the simulator cannot select a gear and stay in it until a change in gradient occurs. It is always trying to gear up. This trend is very clearly shown on all the uphill sections which have been exploded.

Area 2: This hill is steeper and longer than the hill in area one, and here again the difference between the gear selection by the simulator and the actual data can be seen clearly. The slope of the simulated data compared with the actual data is much steeper here than for area one. One reason for this is that the drivers are familiar with the long downhill on the other side, whereas the simulator is not. This is where a 'look ahead' facility would be very beneficial to the programme.

Analyses similar to these were performed for the two routes and resulted in a sound picture of the capabilities of the model.

## Conclusion

From the exercises done when collecting and evaluating the data, the following conclusions and recommendations can be made:

- Simtrans is a useful tool, but special care needs to be given in assigning speed limits to the vehicle being simulated, especially in areas where power is not limiting.
- There appeared to be a problem with gear selection as shown in the data. This needs to be refined and possibly a change in gradient should be used to stimulate a gear change.
- Fuel consumption is highly dependent on the driver. For the two drivers on the Kevard run, results showed fuel consumptions of 69,4 litres/100 km and 82 litres/100 km. This poses a problem for the mechanics of the fuel consumption parameter in the model.
- Some thought needs to be given to having a 'read ahead' mechanism in the programme, and possibly a built-in nomograph to allocate a speed to a gradient consistent with the payload and braking power of the vehicle in question. This would eliminate guesswork in setting up the correct speed curve.
- Decisions resulting in large capital expenditure need to be thoroughly investigated. A programme such as Simtrans has the potential to be a valuable tool, provided the data collection of the routes can be done more cheaply and to a more refined standard. The basic mechanisms of the programme need to be tested thoroughly and completely before attention is diverted to other issues which may not have as much impact on the overall results.

## Acknowledgements

Thanks are due to S. Ndimande and F. Shange, the two drivers who participated in the simulation, for their patience and enthusiasm; to T. Reid for many hours of sorting out wiring problems and nursing fuel flow metres; to D. Clark and E. de la Harpe for programming work; to C. Tredrea for his efforts in keeping the Machine Performance Monitor working; and to SASEX for funding the research project.

# EFFECTS OF SUGARCANE PRODUCTION ON SOIL QUALITY: A SYNTHESIS OF WORLD LITERATURE

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## Abstract

The world literature on the effects of sugarcane production on soil quality are reviewed and discussed. Invariably, conversion of virgin land to sugarcane production results in a progressive loss of soil organic matter and soil acidification. The loss of organic matter is much less pronounced where green cane harvesting with the retention of a trash blanket is practised rather than conventional burning. The main cause of soil acidification is the use of acidifying nitrogenous fertilisers such as urea and ammonium sulphate, coupled with nitrate leaching losses that occur under the high rainfall conditions that often prevail in cane growing areas. Whether available soil nutrient levels increase or decrease is dependent primarily on whether fertiliser inputs exceed or are less than nutrients removed in harvested cane. Because of the large removal of K in the cane there is often a decline in exchangeable soil K levels. In relatively low rainfall areas soil salinisation and sodification can limit cane production. A rise in the water table due to drainage of excess irrigation allows salts to reach the soil surface by capillary movement. Compaction of topsoil, particularly in the interrow space, is common under sugarcane. It is caused mainly by wheeled traffic during harvest and other field operations, particularly where these are performed when soils are very wet.

## Introduction

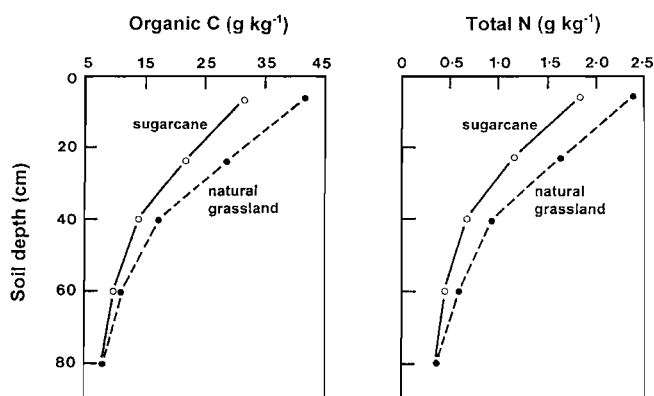
Concerns regarding soil degradation and agricultural sustainability have kindled interest in assessment of soil quality (Doran and Parkin, 1994; Nannipieri, 1994). An assessment of soil quality that includes soil biological, chemical and physical properties can provide valuable information for evaluation of the sustainability of land management practices (Doran and Parkin, 1994). Soil chemical properties that define soil fertility (e.g. pH, organic C, extractable P, exchangeable cations) are often well documented for agricultural soils since routine soil testing is carried out. Soil physical properties are normally less well documented since they often need to be measured under field conditions and they can change markedly during the season (e.g. after cultivation). Least is normally known about the biological properties of soils. There is, however, increasing evidence that measures of the size and activity of the soil biological community hold considerable promise as early indicators of soil degradation or improvement (Pankhurst *et al.*, 1997; Sparling, 1997).

Sugarcane is an important plantation crop in many tropical countries and its production has increased dramatically in the past few decades (Hartemink and Wood, 1998). Nonetheless, in many localities the sugar yield has, when expressed on a per hectare basis, reached a plateau or even begun to decline. This phenomenon, which has become known as 'sugar yield decline', has been reported in Australia (Garside, 1997), USA (Coleman, 1974) and Barbados (Anderson *et al.*, 1995) as well as South Africa (Meyer *et al.*, 1996). Research into the causes of sugar yield decline has concentrated efforts on the study of the effects of long term sugarcane production on soil quality (Bramley *et al.*, 1996; Skjemstad *et al.*, 1999).

The purpose of this paper is to review and discuss the known effects that sugarcane production has on soil quality using data from the major sugar producing areas of the world.

## Soil organic matter

An initial decrease in soil organic matter when virgin land is put under sugarcane is commonly observed. Such a decline has been observed in Fiji (Masilaca *et al.*, 1985), the Philippines (Alaban *et al.*, 1990), Swaziland (Henry and Ellis, 1996), Papua New Guinea (Hartemink and Kuniata, 1996; Hartemink, 1998a), Australia (Wood, 1985) and South Africa (van Antwerpen and Meyer, 1996). A decline in soil organic C and total N content in the surface 40 cm of soil after seven years of sugarcane production in Papua New Guinea is demonstrated in Figure 1.

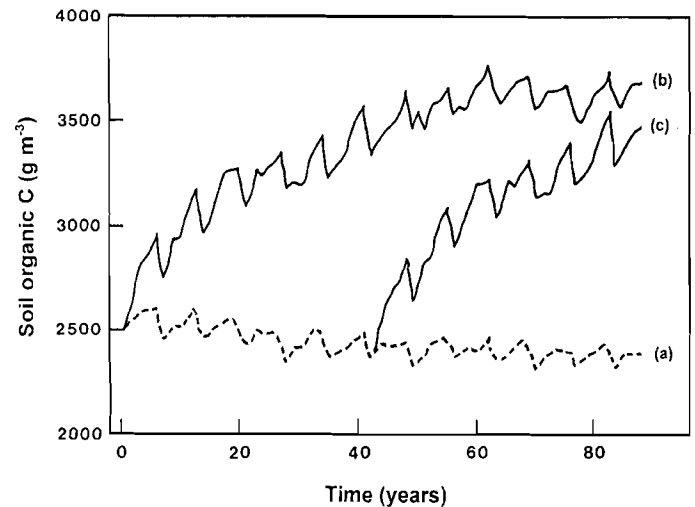


**Figure 1.** Soil organic C and total N content down the soil profile after seven years of sugarcane production compared with natural grassland on an Entisol in Papua New Guinea (redrawn from Hartemink, 1998).

In Fiji, Masilaca *et al.* (1985) observed that when three Oxisols were put under sugarcane production there was a marked decline in soil organic C content in the topsoil (0-12 cm). After an initial decrease, organic matter contents stabilised at about two-thirds of the original levels. In the Herbert Valley in northern Queensland, Wood (1985) found that losses of soil organic matter in the surface 10 cm of soil were very marked under sugarcane production. Mean values for soil organic C content for 19 paired sites were 1.5% for virgin sites and 0.7% for those under sugarcane. Returns of organic matter to the soil were low in the Herbert Valley since crops were burnt prior to harvest and following harvest; crop residues were often raked up and burnt as well. Similarly, in a survey of soil condition under sugarcane in northern KwaZulu-Natal, van Antwerpen and Meyer (1996) found that, in both dryland and irrigated areas, a loss of organic matter under sugarcane relative to virgin sites was very common.

A decline in soil organic matter content when virgin sites are converted to arable cropping systems is common (Johnston, 1986). The decline is characteristically rapid in the first few years and a new equilibrium level is usually reached after about 20 to 50 years (Haynes and Beare, 1996). Such a decline is the result of both reduced inputs of organic material and an increased rate of organic matter decomposition. The amount of organic material returned to the soil is considerably less than under virgin natural vegetation since crop plants are usually spaced widely in rows (so there is less root and top material produced per unit of ground area) and often much of the above-ground plant material is removed from the field with, or as, the harvested crop. In addition, the soil is regularly tilled. Tillage favours decomposition of soil organic matter because the improved aeration resulting from cultivation stimulates microbial activity and decomposition processes. In addition, cultivation breaks up soil aggregates and exposes organic matter, previously physically protected within the aggregate structure, to microbial attack. This also stimulates breakdown of soil organic matter.

In some recent studies in Queensland, Australia, little change in soil organic C content was measured under long term sugarcane production (Bramley *et al.*, 1996; Skjemstad *et al.*, 1990). These workers suggested that the relatively recent adoption of green cane harvesting with retention of a trash blanket may have improved otherwise depleted soil organic matter levels. Indeed, a shift from burning to trash retention is a practice that can significantly increase soil organic matter levels (Wood, 1991; van Antwerpen and Meyer, 1998). Large amounts of organic matter are returned to the soil rather than lost during burning; up to 10 t/ha of crop residues are left on the soil surface after harvesting (Ng Kee Kwong *et al.*, 1987). Vallis *et al.* (1996) used the CENTURY model to simulate long term effects of sugarcane trash management on soil organic matter content (Figure 2). The model indicated that adoption of trash blanketing on old cane-producing soil would lead to an increase of approximately 40% in soil organic matter after 60 to 70 years, and about half of this increase would occur during the first 20 years.



**Figure 2.** Changes in soil organic C simulated using the CENTURY model in response to (a) continued burning, (b) green cane harvesting or (c) burning for 40 years followed by conversion to green cane harvesting, under northern Queensland conditions (redrawn from Vallis *et al.*, 1996).

Some evidence suggests that there can be accumulation of organic matter in subsurface horizons (i.e. >30 cm) under cane in comparison with undisturbed sites (Masilaca *et al.*, 1986; McGarry *et al.*, 1996; Skjemstad *et al.*, 1999). To some extent this could be due to a downward redistribution of topsoil due to ploughing and deep ripping. However, growth of sugarcane, which is a reasonably deep-rooting crop, may also facilitate accumulation of organic matter at depth through continual turnover of root material (Masilaca *et al.*, 1986).

### Soil biological properties

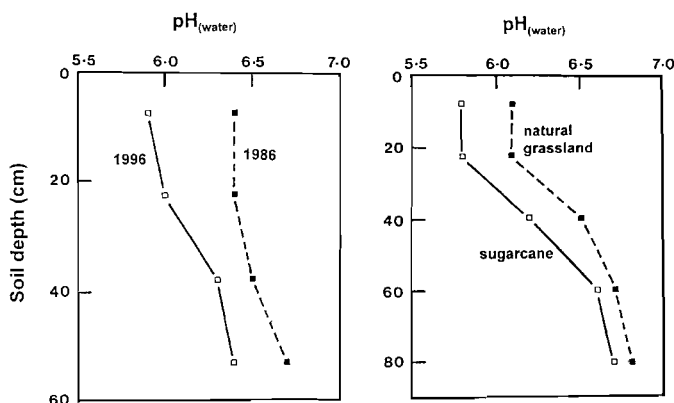
As noted by Hartemink and Wood (1998), very little is known about the changes in soil biological properties that occur under sugarcane cultivation. In a comparison between paired old and new land sites for sugarcane in Queensland, Garside *et al.* (1997) observed that the soil microbial biomass was significantly lower on old sugarcane land. They concluded that there is a rapid loss of soil microbial biomass C when sugarcane is established. Australian research has also shown that retention of a trash blanket, rather than burning, markedly increases the size of the soil microbial biomass in the surface soil and also the size of the earthworm community (Wood, 1991; Sutton *et al.*, 1996).

Current research on soil quality is centred mainly on the use of biological indicators (Pankhurst *et al.*, 1997). The effect of sugarcane production systems on such indicators is therefore an area requiring considerable future research.

### Soil acidification

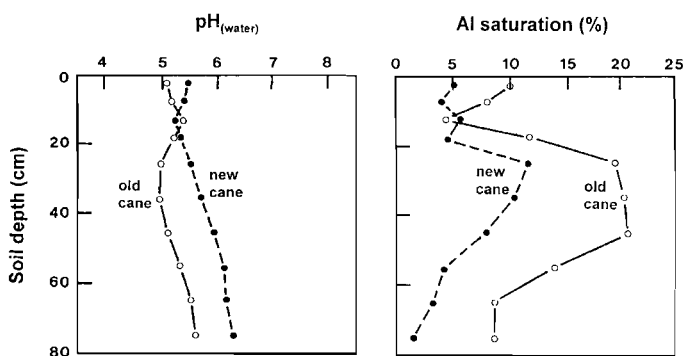
When soils under sugarcane are compared with those under virgin vegetation a decrease in pH under sugarcane is generally demonstrated. Such a decrease in pH has been observed in Papua New Guinea (Hartemink and Kuniata, 1996;

Hartemink, 1998a, 1998b), Australia (Maclean, 1975; Wood, 1985), Puerto Rico (Abruna-Rodriguez and Vicente-Chandler, 1967), Florida (Coale, 1995), Fiji (Masilaca *et al.*, 1985) and South Africa (Schroeder *et al.*, 1994). A decrease in soil pH over a 10-year period under sugarcane production and a similar decrease compared with natural grassland on Entisols from Papua New Guinea is shown in Figure 3.



**Figure 3.** Soil pH down the profile in a field of sugarcane sampled in 1986 and 1996 and of natural grassland and an adjoining 10 year old sugarcane field on an Entisol in Papua New Guinea (redrawn from Hartemink and Kuniata, 1996).

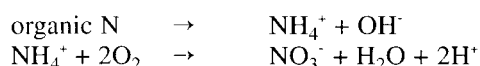
In general, changes in soil chemical properties under sugarcane production are consistent with soil acidification occurring. That is, a decline in soil pH is accompanied by an increase in exchange acidity, exchangeable and extractable Al and a decline in exchangeable bases (Ca, Mg and sometimes K) and a decrease in cation exchange capacity (Wood, 1985; Bramley *et al.*, 1996; van Antwerpen and Meyer, 1996; Hartemink, 1998a, 1998b). Wood (1985), for example, compared 19 paired sites in the Herbert Valley in northern Queensland and showed that sites under sugarcane had lower pH, exchangeable Ca and Mg and cation exchange capacity and higher exchange acidity than adjacent virgin, uncultivated land. As shown in Figure 4, a decrease in soil pH below 20 cm depth under sugarcane production in northern Queensland (Bramley *et al.*, 1996) was accompanied by a marked increase in Al saturation percentage.



**Figure 4.** Soil pH and Al saturation percentage in the soil profile on a paired old and new sugarcane site from Northern Queensland (redrawn from Bramley *et al.*, 1996).

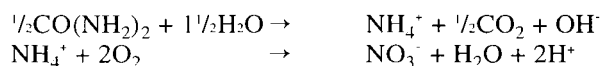
In South Africa, soil acidification has been clearly demonstrated under cane production. Schroeder *et al.* (1994) reported a general decline in pH values with an accompanying decrease in base cation concentrations and an increase in extractable Al on commercial cane fields on the south coast of KwaZulu-Natal. They suggested that a decrease in pH is common irrespective of soil type, although it was most apparent for cane grown on Recent Sand deposits. More recently, Meyer *et al.* (1998), using data collected from the Fertiliser Advisory Service of the South African Sugar Association Experiment Station, showed that in the last decade there has been a marked increase in soil acidification. Average soil  $\text{pH}_{(\text{water})}$  values declined from 6.2 in 1980-81 to 5.6 in 1996-97. The extent of acidification was shown by an increase in the proportion of soil samples that were below pH 5.0 from 18% in 1980 to 43% in 1997. The trend towards soil acidification was centred on samples originating primarily from the northern and southern coastal areas of KwaZulu-Natal.

There are likely to be at least two important sources of  $\text{H}^+$  ions for soil acidification under sugarcane production. Firstly, as already discussed, when virgin veld is put under cultivation there is an initial decline in soil organic matter content. During mineralisation of organic matter, organic N is converted to  $\text{NH}_4^+\text{-N}$ , which is then nitrified to  $\text{NO}_3^-\text{N}$  and accumulates in the soil:



The overall process results in the net release of one  $\text{H}^+$  ion per unit of N mineralised. This could contribute to any initial acidification that occurs during the first five years after veld is converted to sugarcane.

However, the most likely cause of acidification in established cane plantations is the routine use of ammonium-containing or forming fertilisers (e.g. ammonium sulphate  $(\text{NH}_4)_2\text{SO}_4$  and urea  $\text{CO}(\text{NH}_2)_2$ ). Nitrogenous fertilisers are routinely applied to cane at rates commonly ranging from 50 to 200 kg N/ha/year. When ammonium-containing fertilisers, such as ammonium sulphate, are used, two  $\text{H}^+$  ions are released per unit of  $\text{NH}_4^+\text{-N}$  applied through the process of nitrification. Since  $\text{OH}^-$  is produced during hydrolysis of urea to  $\text{NH}_4^+$ , urea is half as acidifying as ammonium sulphate per unit of N applied:



It is interesting to note that Hartemink (1998a) observed a rapid decline in pH under sugarcane on a Papua New Guinea plantation during the 1990s which coincided with a change in fertiliser use from urea to ammonium sulphate.

From the above discussion it is clear that the major source of acidity is likely to be through the soil microbial process of nitrification in which both  $\text{NO}_3^-$  and  $\text{H}^+$  ions are produced. If the  $\text{NO}_3^-$  is taken up by the crop then active uptake of  $\text{NO}_3^-$  by plant roots is accompanied by concomitant excretion of  $\text{OH}^-$  ions. This neutralises  $\text{H}^+$  ions produced during nitrifica-

tion. However, if the  $\text{NO}_3^-$ , which is highly mobile in soils, is subsequently leached then no  $\text{OH}^-$  will be produced to neutralise the acidification. Acidification will therefore be permanent. The  $\text{H}^+$  ions have a strong affinity for negatively charged soil surfaces and displace exchangeable cations such as  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  from exchange sites. These cations move into soil solution and balance the  $\text{NO}_3^-$  which leaches out of the soil; essentially in the form of calcium and magnesium nitrates. The high rainfall in many sugarcane areas favours leaching losses of  $\text{NO}_3^-$  and thus permanent acidification (Moody and Aitken, 1975).

### Available nutrients

Large quantities of nutrients are removed from sugarcane fields annually in the cane harvest. Annual removals of nutrients in a 100 t/ha crop are about 120 kg N/ha, 33 kg P/ha and 125 kg K/ha (De Geus, 1973). Whether available soil nutrient levels increase or decline under cane depends largely on whether fertiliser inputs exceed or are less than nutrient removals in harvested cane plus any other losses (e.g. leaching). For example, in a study area in Papua New Guinea where no fertiliser P was applied, available soil P levels declined with increasing years under sugarcane production (Hartemink, 1998a). By contrast, in the Herbert Valley in northern Queensland, where large fertiliser P applications were regularly made, there was a large increase in available P levels in cane producing soils compared with virgin land (Wood, 1985).

Potassium removals in harvested cane are notably high and, where fertiliser K applications are inadequate, there is a rapid decline in levels of exchangeable soil K. Thus, declines in exchangeable K have been observed under cane production in a number of localities including those in the Philippines (Alaban *et al.*, 1990), Fiji (Masilaca *et al.*, 1985), Swaziland (Henry and Ellis, 1996) and Papua New Guinea (Hartemink, 1998a). In Fijian soils containing 2:1 clay minerals, declines in non-exchangeable 'fixed' K under sugarcane have also been documented (Naidu *et al.*, 1995). In South Africa, however, plant available soil K levels are generally high and Meyer *et al.* (1998) recently suggested that there may well be over-application of this nutrient in many areas.

As already noted, there is often a progressive decline in exchangeable  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in soils under sugarcane due to soil acidification. That is, as acidification occurs solubilised  $\text{Al}^{3+}$  moves onto the exchange sites, displacing the exchangeable  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  which are then leached down the profile.

### Soil salinisation/sodification

Excessive salt concentrations in the soil under irrigated sugarcane production have been induced in relatively low rainfall areas of Australia (Ham *et al.*, 1997; Nelson and Ham, 1998), Egypt (Nour *et al.*, 1989), Iraq (Sehgal *et al.*, 1980), United States (Bernstein *et al.*, 1966), India (Tiwari *et al.*, 1997), Swaziland (Workman *et al.*, 1986) and South Africa

(Maud, 1960; von der Meden, 1966). Saline soils are those where the concentration of soluble salts is sufficient to restrict plant growth. They are normally characterised as those where the electrical conductivity of a saturation paste extract exceeds 4 d S/m (Sumner, 1997). Many saline soils are also sodic (i.e. the percentage of the exchangeable cations present as  $\text{Na}^+$  (ESP) is greater than 15%). Sodic soils tend to disperse in the presence of rainfall or irrigation water and are difficult to manage.

Improper irrigation and drainage are the main causes of salinisation (Johnston, 1977; Workman *et al.*, 1986). That is, inadequate drainage is provided for irrigation excesses and as a result there is a rise in the water table. Salts dissolved in the groundwater reach the soil surface by upward capillary movement and then accumulate there. Soils where this occurs are often naturally poorly drained and in many instances are marginally affected by salts in their natural state (Johnston, 1977). There are also situations where waters available for irrigation are highly saline, particularly during the dry season (von der Meden, 1966). Use of this water for irrigation can also induce and/or exacerbate salinity.

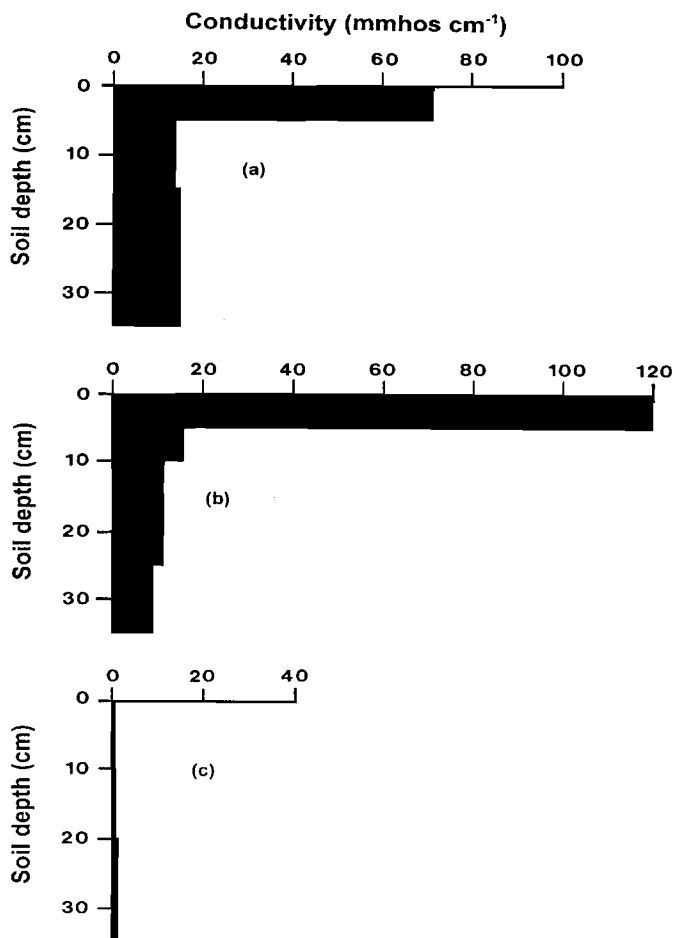
The presence of soil salinity under irrigation at two sites in a low rainfall area of northern KwaZulu-Natal is demonstrated in Figure 5. A rise in the water table from 10 to 15 m deep to just below the surface resulted in accumulation of salts in the surface 5 cm. By contrast, at a non-irrigated site salt concentrations were very low and tended to increase with soil depth.

Serious declines in sugarcane yield linked to salinity and/or sodicity have been reported by a number of workers (Bernstein *et al.*, 1966; Sehgal *et al.*, 1980; Culverwell and Swinford, 1986; Nouret *et al.*, 1989; Ham *et al.*, 1997; Nelson and Ham, 1998). For example, Nelson and Ham (1998) recorded a significant negative correlation between soil salinity and cane yields in northern Queensland. They also observed that cane yield was reduced by about 2.4 t/ha for every 1% increase in ESP in the 0-75 cm of soil.

The control and amelioration of soil salinity is largely a question of controlling soil water. Careful and accurate scheduling of irrigation is essential. In salinised areas, drainage works need to be installed and excess salts can then be leached away by periodic irrigation (Sumner, 1997). Where sodic soils become impermeable it is also necessary to replace some of the exchangeable  $\text{Na}^+$  with  $\text{Ca}^{2+}$  by the addition of gypsum (Johnston, 1977; McMahan *et al.*, 1996). The excess of  $\text{Na}^+$  is then leached out with irrigation water.

### Soil physical properties

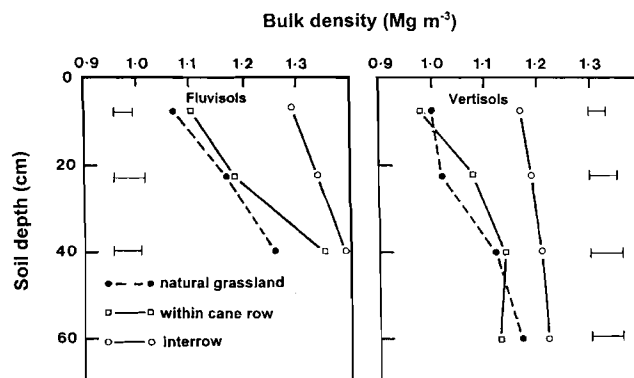
Generally, topsoil bulk density is significantly greater in the interrow spaces than in the rows of sugarcane fields or under virgin undisturbed vegetation (Braunack, 1997). Such compaction in the interrows has been reported in Australia (Wood, 1985; McGarry *et al.*, 1996, 1997), Fiji (Masilaca *et al.*, 1985), Papua New Guinea (Hartemink, 1998a), India



**Figure 5.** Conductivity of saturation paste extracts of soils from northern KwaZulu-Natal under two irrigated sugarcane sites (a and b) and a nearby non-irrigated site (c) (redrawn from Maud, 1960).

(Srivastava, 1984), Hawaii (Trowse and Humbert, 1961), Colombia (Torres and Villegas, 1993) and South Africa (Johnston and Wood, 1971; Swinford and Boevey, 1984). Australian research of Maclean (1975) and Wood (1985) showed significant increases in bulk density of 0,15 to 0,18 Mg/m<sup>3</sup> in the surface 8 cm of soil in comparison with uncultivated land.

South African research (Swinford and Boevey, 1984; Swinford and Meyer, 1985) found that compaction in sandy loam soils caused an increase in bulk density and soil strength and a decrease in air-filled porosity. Hartemink (1998a) found that bulk density and water infiltration rate were similar under natural grassland and within the sugarcane rows on Fluvisols and Vertisols in Papua New Guinea. The interrow, however, had a significantly higher bulk density (Figure 6) and a markedly lower infiltration rate. He also observed that roots were absent in the interrow, which is commonly found in compacted soils under sugarcane (Trowse and Humbert 1961; Juang and Uehara, 1972). Trowse and Humbert (1961) showed that the limits at which bulk density restrict root growth of sugarcane vary depending on soil type, but for Hawaiian Andosols and Ferralsols limits were about 1,08 and 1,52 Mg/m<sup>3</sup> respectively.



**Figure 6.** Mean bulk density down the soil profile from Fluvisols and Vertisols under sugarcane for 10 years compared with natural grassland in Papua New Guinea (redrawn from Hartemink, 1998).

Compaction in the interrows is generally caused by wheeled traffic during harvesting and other field operations. In wet harvesting seasons farmers are forced to harvest some of their cane when soils are very wet (and subject to greatest damage through compaction). Maud (1960), for example, showed that for South African sugar belt soils, the tendency to become compacted is greatest when the moisture content was near field capacity. Research has shown that use of conventional wheeled harvester and haulout equipment in wet fields causes severe rutting and compaction which can result in yield reductions in the following crop (Wood, 1985; Torres and Villegas, 1993). When large mechanical harvesters are used, interrow compaction can be a serious problem, since each sugarcane row is straddled during the harvesting operation. There are at least two passes along each interrow area by the harvester and two passes by the field haulout unit (Prove *et al.*, 1995). Nevertheless, compaction and/or stool damage within the rows during harvesting in wet conditions causes considerably higher reductions in subsequent cane yields than interrow compaction (Torres and Villegas, 1993).

Soil compaction will be a particular problem under zero tillage systems, since the soil is not loosened by tillage between crops. Nonetheless, on sloping land in high rainfall areas, zero tillage can greatly reduce losses of soil through erosion. Soil loss rates measured in the Mackay region of Queensland were found to range between 42 and 227 t/ha/year on conventionally cultivated slopes of up to 8% (Sallaway, 1979, 1980). Similarly, soil erosion from conventionally cultivated cane in north eastern Queensland on slopes of 5 to 18% were found to be in the range of 47 to 505 t/ha/year, with an average annual loss of 148 t/ha/year (Prove *et al.*, 1995). Zero tillage practices reduced this erosion to less than 15 t/ha/year.

## Conclusions

A diminution of soil quality under sugarcane production is common throughout the sugarcane producing areas of the world. The indicators of such soil degradation include loss of soil organic matter, soil acidification, soil salinisation, soil

compaction and sometimes a reduction in available soil nutrient levels, particularly K. Sustainable systems of sugarcane production which maintain or improve soil quality as well as sugar yields are required to ensure the future of the industry. Such systems could include green cane harvesting, additions of organic amendments such as filtercake and animal manures, calculation of fertiliser requirements based on nutrient removals in harvested cane, use of split applications of fertiliser N to reduce the opportunity for  $\text{NO}_3^-$  leaching and thus permanent soil acidification, and the regular application of lime to counteract acidification. Very little is known about the effects of sugarcane production on soil biological activity and this is an area that requires further research.

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