CHANGES IN SOIL FERTILITY INDUCED BY TRASH RETENTION AND FERTILISER APPLICATIONS ON THE LONG-TERM TRASH MANAGEMENT TRIAL AT MOUNT EDGECOMBE

M.H. GRAHAM[1], R.J. HAYNES[1] AND J.H. MEYER[2]

[1]*School of Applied Environmental Science, University of Natal, Pietermaritzburg, Private Bag X01 Scottsville,3209.*

[2]*South African Sugar Association Experiment Station, Private Bag X02 Mount Edgecombe, 4300.*

Abstract

The long-term effects of green cane harvesting with trash retention, compared with burning, on soil fertility were evaluated using data from the long-term trash management trial at Mount Edgecombe (BT 1). Total and potentially mineralisable soil N were greater under green cane harvesting than burning in the surface 0-10cm layer of soil. As expected, fertiliser applications induced increases in extractable soil P and also some accumulation in soil organic P (particularly under trash retention). Both exchangeable and non-exchangeable soil K concentrations were higher in fertilised than non-fertilised treatments. Exchangeable K concentrations were also increased markedly by trash retention reflecting the large amounts of K that are returned in trash and demonstrating their positive effect on K fertility. Soil pH was lowered considerably by fertiliser applications and this effect was evident to 30cm. Mean pH to a depth of 20cm was 6.0 for unfertilised plots and 5.4 for those fertilised. Fertiliser induced acidification is attributed to annual applications of nitrogenous fertilisers at a rate of 140 kg N/ha. Trash retention also tended to result in a decline in pH due to the greater amount of N cycling in the system. It was concluded that recommended fertiliser rates are likely to be reduced under green cane harvesting and that regular lime applications are important when acidifying nitrogenous fertilisers are being used routinely.

Introduction

The practice in much of the South African sugar industry is to burn standing cane and scatter the burnt cane tops or other crop residues. During burning, large amounts of C, N and S present in crop residues are lost by volatilisation (Raison, 1979). The ash that is returned has a high basic cation (Ca, Mg, K) and P content, is alkaline, and its nutrient content is generally released rapidly to the soil (Raison, 1979). Thus, returns of ash to the soil, rather than unburnt crop residues, tend to lead to a decline in organic matter content and a rise in soil pH (Biederbeck, 1980; Rasmussen and Collins, 1991).

A decrease in soil organic matter (and thus total N) content under long-term sugarcane production has been recorded in many parts of the world and it is considered to be the major factor associated with soil degradation in most sugar producing areas (Van Antwerpen and Meyer, 1996, Hartemink and Wood, 1998; Haynes and Hamilton, 1999). There is also concern regarding soil acidification under sugarcane monoculture (Schroeder *et al*., 1994, Haynes and Hamilton, 1999). The most common cause of such acidification is thought to be the use of high rates of ammonium-containing or forming nitrogenous fertilisers.

Green cane harvesting with retention of a trash blanket is a common practice in several sugar producing countries (Hudson, 1984; Ng Kee Kwong *et al.*, 1987; Wood, 1991) and its adoption has been advocated in South Africa. In general, very little information exists on this practice on soil fertility. However the long-term trash management trial at SASEX, Mount Edgecombe after 25 years cropping provided useful information on the effects of burning and trashing in the presence and absence of fertiliser treatment on soil fertility (Thompson 1965, 1966). This trial which has now continued for 61 years and offered a further opportunity for re-assessing the effects of these cultural practices on soil fertility. The purpose of this paper is to provide a report and discussion on how soil fertility has been affected by trash retention and fertilisation.

Material and Methods

The trial (designated BT1) is situated on a Vertisol (Acardia form, Lonehill family: Soil Classification Working Group, 1991) with an A horizon about 500 mm deep and it was established in 1939 (Thompson, 1965). Mean annual rainfall at the site (longitude 31° 04′ 29″ and latitude 29° 43′ 20″ is 950 mm.

The main experimental treatments are: (i) green cane harvested with retention of a trash blanket (100% cover) (T), (ii) burnt with tops left scattered on plots (Bt) and (iii) burnt with tops raked off (Bto). The treatments are either (a) unfertilised (Fo) or (b) fertilised annually with 140 kg N/ha, 20 kg P/ha and 140 kg K/ha (F). The treatments are replicated four times in a randomized split-plot design.

Three replications of the experiment were sampled in March 1998, 59 years after the experiment was initiated. Plots were sampled within the inter-rows using a 50 mm diameter soil sampler (10 samples per plot, 0 - 30 cm) and sectioned into the 0 - 2.5, 2.5 - 5, 5 - 10, 10 - 20 and 20 - 30 cm layers. Samples from each plot were bulked. Soil samples were sieved (< 2 mm) in a field moist state. A subsample was air-dried and a further subsample was ground (< 150 µM) for subsequent analysis of total N.

Total N was determined by semi-micro Kjeldahl digestion with colorimetric determination of the liberated ammonium (Foster, 1995). Readily mineralisable N was estimated as the difference between the quantity of mineral N (ammonium and nitrate - N) extracted from field-moist soil before and after aerobic incubation at 25°C for 10 days. Mineral N was extracted from soil samples with 2 *M* KCl and exchangeable ammonium and nitrate were determined using a steam distillation apparatus (Keeney and Nelson, 1982).

Available P was determined by extraction with Truog reagent (0.05 *N* H_4SO_4) (Beater, 1962). Organic soil P was determined by an ignition method (Olsen and Sommers, 1982). Exchangeable K, Ca, Mg and Na were extracted by shaking 50 g of soil with 200 ml of 1 *N* ammonium acetate for two hours (Beater, 1962) and cations in the extracts were analysed by atomic absorption spectrophotometry. Nitric acid-exchangeable K was extracted with 1 *N* boiling HNO_3 over a period of 25 min (Helmke and Sparks, 1996), and the extract was filtered and analysed by atomic absorption spectrophotometry. Non-exchangeable K was calculated as the difference between HNO_3-extractable and exchangeable K. Soil pH was determined in a 1:2.5 soil:water extract using a glass electrode.

Results and Discussion

In this paper, the burnt cane treatments with tops removed (BtoFo and BtoF) treatments were compared with the trash retention treatments (TFo and TF). The burnt cane treatments with tops scattered over the surface (BtFo and BtF) generally showed results intermediate between the Bto and T treatments and are not presented here.

Both trash retention and fertilisation caused an accumulation of total N in the surface 10 cm of soil (Figure 1). The pattern of accumulation of N was similar to that for organic C (Graham *et al.*, 1999) although there was a tendency for the C/N ratio to be lower under trash retention. The mean C/N ratio (0-10 cm) for burnt treatments was 19 and for those trashed was 16.

Fertilisers are applied to soils in order to maintain or improve crop yields. In the long-term, increased crop yields usually result in increased returns of organic matter to soils (i.e., from roots and tops) and thus a higher soil organic matter content (Haynes and Naidu, 1998). Indeed, in this study mean cane yields (1978-1990) were 41, 97, 43, 103, 54 and 106 t/ha for the BtoFo, BtoF, BtFo, BtF, TFo and TF treatments respectively (J.H. Meyer, personal communication, 1999). Accumulation of soil organic matter induced by fertiliser applications has been noted on several other long-term field trials (Johnston, 1986). As noted previously (Graham *et al.*, 1999) the large inputs of organic matter under green cane harvesting have induced a substantial accumulation of organic matter, and particularly N, in the surface soil. In comparison with burning, where large amounts of C and N are lost to the atmosphere, up to 10t/ha of crop residues are left on the soil surface after green cane harvesting (Ng Kee Kwong *et al.*, 1987).

Readily-mineralisable N was also increased by fertilisation (Figure 1) and there was a notable positive interaction between fertilisation and trash retention. Indeed, readily-mineralisable N was higher under trash retention than burning, to a depth of 30 cm and this effect was much amplified under fertilisation. This suggests that N inputs originating from either organic (i.e., from trash) or inorganic (i.e., from urea fertiliser) forms are preferentially accumulated into a readily mineralisable pool of soil organic N. In general, recently immobilized N is more readily mineralized than the bulk of the native soil organic N (Haynes, 1986). Certainly, the data presented here suggest that soil N availability under green cane harvesting will be considerably greater than that under burning.

As expected, Truog-extractable P concentrations were much higher in fertilised than unfertilised treatments (Figure 2). Thus, over the 59-year period of the trial, the annual applications of P resulted in an accumulation of residual P in the soil (Barrow, 1980). Interestingly, Troug P accumulation, induced by fertilisation, was evident in the 5 - 10 and even 10 - 20 cm soil layers. Such a downward redistribution of applied P is surprising since P is known to be extremely immobile in soils and it characteristically accumulates near the soil surface (Barrow, 1980). However, this probably reflects the downward redistribution of applied P during tillage which may have occurred in the earlier years of the trial. In fact, the experimental site was conventionally tilled prior to replanting, every 7 - 10 years for the first 30

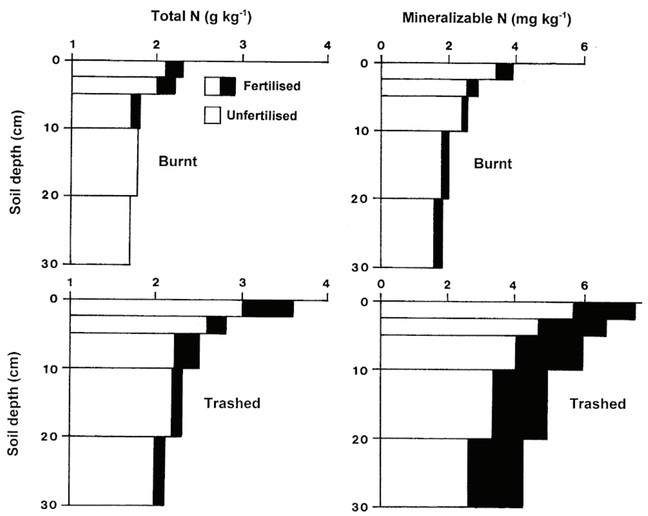

Figure 1. Effect of burning or green cane harvesting with trash retention on fertilised and unfertilised plots on the total N and readily mineralisable N content in the soil profile.

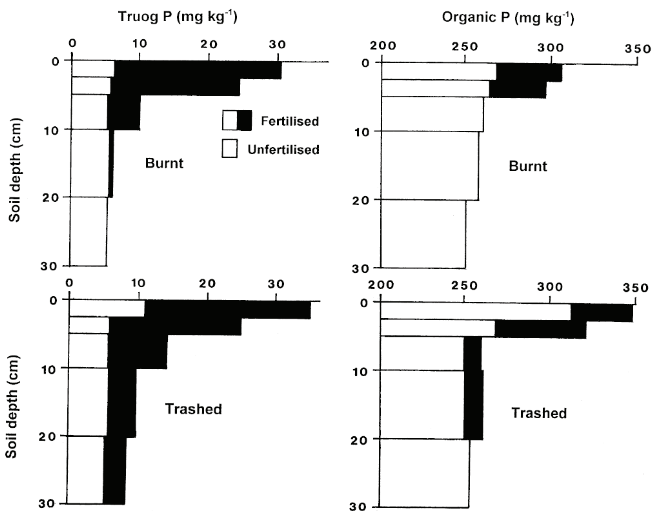

Figure 2. Effect of burning or green cane harvesting with trash retention on fertilised and unfertilised plots on the Truog-extractable P and organic P content in the soil profile.

years, after which minimum tillage has been used. The tendency for Truog P to accumulate in the surface 5 cm of soil (Figure 2) under trash retention is attributable to the addition of P held in the trash. This P is released during trash decomposition.

Accumulation of P in soil organic forms, due to long-term annual applications of fertiliser P (Figure 2), has been observed in other long-term experiments (Haynes and Williams, 1992). As expected, accumulation of organic P was much more pronounced in trashed than burnt plots (due to the higher soil organic matter content). Accumulation of P from fertiliser and trash inputs into soil organic forms essentially represents a removal of P from plant-available forms. This organic P is released into plant-available mineral forms through the process of mineralisation during soil organic matter decomposition (for example following tillage of the field).

Concentrations of exchangeable K were notably lower in unfertilised than fertilised plots (Figure 3). Such an effect is not unexpected since K removal during sugarcane cropping is notably high (i.e., 125 - 250 kg K/ha per 100t/ha cane crop) and this can result in depletion of both exchangeable and non-exchangeable K reserves (Naidu *et al.*, 1995). Vertisols contain 2:1 clay minerals which include K as part of their mineral structure. When soil solution K concentrations become depleted, the clay lattice may partially open and non-exchangeable K can be released to the exchangeable form in order to supply the demands of the sugarcane crop (Wood and Meyer,1986).

Non-exchangeable K concentrations were considerably higher under trash retention than burning and accumulation of non-exchangeable K in the TF treatment was very marked to a depth of 30 cm (Figure 4). This suggests that added K has been fixed into non-exchangeable forms thus building up reserves of soil K. Data presented here suggest that non-exchangeable K can act as both a source and sink for plant-available K in this soil.

Potassium is not lost via volatilisation during burning. The lower exchangeable and non-exchangeable K concentrations on burnt compared with trashed plots do, however, suggest a loss of K during burning. This loss is possibly as a result of ash being blown off burnt plots by strong winds (R. Van Antwerpen, personal communication, 1999). An assessment of the nutrient content of third leaf cane samples generally confirmed the soil findings that trash retention improved nutrient uptake relative to burnt cane harvesting under similar fertiliser treatments (see Table 1).

Where fertiliser was applied, trash retention improved N, P, K and S uptake by 11, 17, 29 and 17% respectively. In the absence of fertiliser, the advantage due to trash retention was lower for N (5%) and S (14%), but higher for P (23%) and K (37%). While much of the additional nutrient uptake from the trash treatment is due to recycling of these nutrients from trash, Thompson (1966) suggests that the improved uptake may also be due indirectly to improved efficiency brought about by better moisture relationships in trashed areas. Whatever the reason there appears to be some justification for modifying fertiliser recommendations for cane fields under trash management. In Australia, field evidence suggests that after 10 years or more of trash conservation ,that lower fertiliser N rates may well be justified (Chapman 1994). In studying the fate of the N contained in the trash blanket , Thorburn *et al* 1999, concluded from longterm field trial measurements and results from a soil carbon modelling excercise, that as much as 200 kg N/ha could be made available through each cropping cycle under a long-term trash management system.

This implies that N fertiliser recommendations may be reduced by up to 40kg N/ha for cane grown under a continuous trashing cycle.

Under the fertilised plots of this experiment, significant soil acidification has been previously reported (Van Antwerpen and Meyer, 1997; Graham *et al.*, 1999). As shown in Figure 4, acidification was evident to a depth of 30 cm and it was more pronounced under trash retention than burning. The main cause of this acidification is likely to be nitrification of the annual

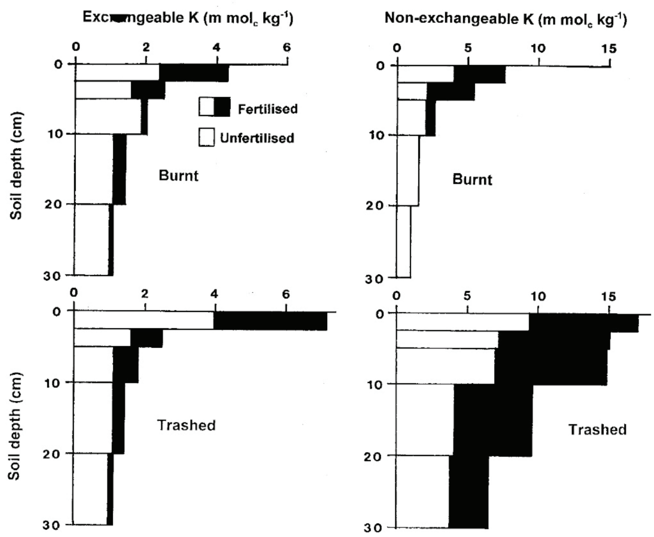

Figure 3. Effect of burning or green cane harvesting with trash retention on fertilised and unfertilised plots on the exchangeable and non-exchangeable K content in the soil profile.

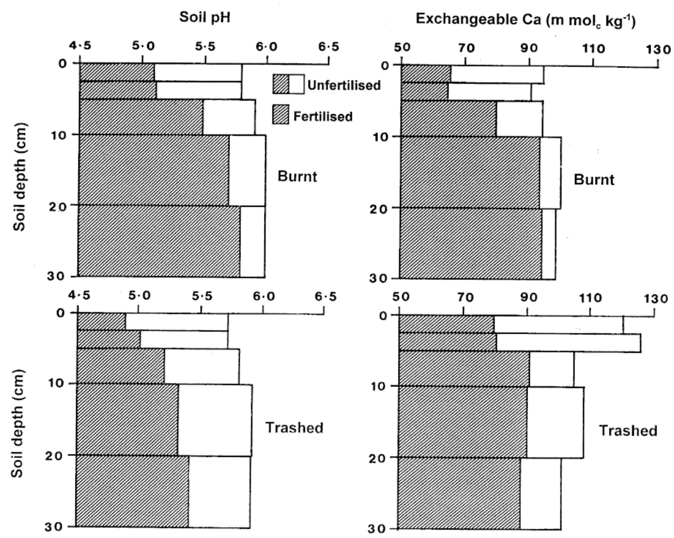

Figure 4. Effect of burning or green cane harvesting with trash retention on fertilised and unfertilised plots on the soil pH and exchangeable Ca content in the soil profile.

Table 1. Effect of burning or green cane harvesting with trash retention on third leaf nutrient content of third ratoon cane (var. N16), sampled in November aged 4.6 months.

Treatment	Leaf nutrient content (%)					
	N	P	K	S	Ca	Mg
Burnt Unfertilised	1.49	0.13	0.72	0.14	0.29	0.2
Burnt Fertilised	1.55	0.18	0.99	0.17	0.27	0.19
Trashed Unfertilised	1.57	0.16	0.93	0.16	0.28	0.19
Trashed Fertilised	1.72	0.21	1.28	0.19	0.26	0.19

applications of ammonium sulphate which are applied at 140 kg N/ha.

Soil acidification produced by nitrification will only be permanent if the nitrate is lost from the system (e.g., by nitrate leaching) effectively leaving the H^+ ions produced behind (Wild, 1994). Thus, the substantial acidification observed suggests that there is a considerable loss of nitrate from the soil through leaching. The greater acidification under trash retention compared with burning is presumably attributable to nitrification of ammonium produced during mineralisation as the trash blanket decomposes. Thus, the greater quantity of N cycled by the practice of trash retention probably causes greater nitrate leaching and more acidification. As shown in Figure 4, acidification resulted in a loss of Ca (and Mg; data not shown) from the soil. The higher exchangeable Ca content under trash retention compared with burning may therefore reflect loss of Ca in ash which has been wind blown.

Acidification under sugarcane is not usually considered a problem since the crop is relatively tolerant to soil acidity and thus high concentrations of exchangeable and soluble soil Al (Hetherington *et al.*, 1988). The crop is, however, sensitive to Ca deficiency (Baver and Ayres, 1962) so the loss of exchangeable Ca that accompanies soil acidification is of concern. Furthermore, if less acid tolerant crops are to be grown following sugarcane there may be a problem. Regular lime applications to counteract the acidifying effect of fertiliser N seem desirable. In this connection, acidification of the soil profile to a depth of 30 cm is of concern. Subsoil acidity is characteristically difficult to ameliorate, due to the immobility of lime, and the use of other ameliorants such as gypsum may need to be considered (Summer, 1997).

Conclusions

Green cane harvesting with retention of a trash blanket results in an accumulation of soil organic matter. As a consequence of this, there is an accumulation of total N in the surface soil and a substantial increase in the size of the pool of readily-mineralisable soil N to a depth of 30 cm. Crop residues play an important role in the cycling of nutrients in agricultural systems and as a result, there is an increase in available P and exchangeable and non-exchangeable K under trash retention compared with burning. In the long-term, recommended N,P and K fertiliser rates for sugarcane are likely to be lowered if there is a shift from burning to green cane harvesting.

Soil acidification is induced by annual applications of fertiliser N and by trash retention. This is thought to be caused by nitrification of N originating from fertiliser and trash applications and the subsequent leaching of nitrate. Improved management of soil N in sugarcane production systems with improved fertiliser recommendations (e.g., split applications of fertiliser-N) will be required in order to minimize this effect. While sugarcane is relatively tolerant of soil acidity it is susceptible to Ca deficiency. The loss of exchangeable Ca that accompanies soil acidification is therefore a concern.

REFERENCES

Barrow, NJ (1980). Evaluation and utilization of residual phosphorus in soils. Pp 333-359. In: FE Khasawheh, EC Sample and EJ Kamprath (eds). *The Role of Phosphorus in Agriculture*. American Society of Agronomy, Madison, Wisconsin.

Baver, LD and Ayres AS (1962). Soil analysis as a basis for fertiliser recommendations in sugarcane. Joint Meet Comm IV and V, *Inter Soc Soil Sci New Zealand, Trans*, pp. 835-841.

Beater, BA (1962). The sampling and analyses of field soils. South African Sugar Association Experiment Station, Mount Edgecombe, Natal.

Biederbeck, VO, Campbell, CA, Bowren, KE, Schnitzer, M, McIver RN (1980). Effect of burning cereal straw on soil properties and grain yields in Saskatchewan. *Soil Sci Soc Am* 44: 103-111.

Chapman, LS (1994) Fertiliser N management in Australia. Proc Aust Soc Sugar Cane Technol 1994 Conf. pp 83-92.

Foster, JC (1995). Soil Nitrogen. pp 79-87. In: Alef, K and Nannipieri, P (eds). *Methods in Applied Soil Microbiology and Biochemistry*, Academic Press, San Diego.

Graham, MH, Haynes RJ and Meyer JH (1999). Green cane harvesting promotes accumulation of organic matter and an improvement in soil health. *Proc S Afr Sug Technol Ass* 73: 52-56.

Hartemink, AE and Wood AW (1998). Sustainable land management in the tropics: the case of sugarcane plantations. *Proc 16th Int Congr Soil Sci*, Montpellier.

Haynes RJ (1986). The decomposition process: mineralization, immobilization, humus formation, and degradation. pp 52-126 In: Haynes RJ (ed). *Mineral Nitrogen in the Plant-Soil System*. Academic Press, Orlando.

Haynes, RJ and Hamilton CS (1999). Effects of sugarcane production on soil quality: a synthesis of world literature. *Proc S Afr Sug Technol Ass* 73: 45-51.

Haynes, RJ and Naidu, R (1998). Influence of lime, fertiliser and manure applications on soil organic matter content and soil physical conditions - a review. *Nutrient Cycling Agroecosystems* 51: 123-137.

Haynes RJ and Williams PH (1992). Long term effects of superphosphate on accumulation of soil phosphorus and exchangeable cations on a grazed, irrigated pasture site. *Plant Soil* 142: 123-133.

Helmke, PA and Sparks, DL (1996). Boiling nitric acid extraction method. pp 561-562. In: Bartels, JM (ed). *Methods of Analysis*. Part3, Chemical Methods, SSSA, Madison.

Hetherington, SJC, Asher, CJ and Blamey, FPC (1988). Comparative tolerance of sugarcane, navybean, soybean and maize to aluminium toxicity. *Austr J Agric Res* 38: 171-176.

Hudson, C (1984). The Barbados Sugar Industry fights back. *Sug Azucar*, December 14, 22.

Johnston, C (1986). Soil organic matter effects on soil and crops. *Soil Use Management* 2: 97-105.

Keeney, DR and Nelson, DW (1982). Nitrogen inorganic forms. pp 643-698. In: Page, AL, Miller, RH, and Keeney DR (eds). *Methods of Soil Analysis, part 2. Chemical and Microbiological Properties*. American Society of Agronomy, Madison, Wisconsin.

Naidu, R, Haynes, RJ and Gawandar, JS (1995). An evaluation of the potassium status of some Fijian soils used for sugarcane production. pp 79-89. In: *Proc Int Soc Sug Cane Technol 21: 79 - 89.*

Ng Kee Kwong, KF, Deville, J, Cavalot, PC and Riviere, V (1987). Value of cane trash in nitrogen nutrition of sugarcane. *Plant Soil* 102: 79-83.

Olsen, SR and Sommers, LE (1982). Perchloric Acid Digestion. pp 216-217. In: Carter, MR (ed). *Soil Sampling and Methods of Analysis*. CRC Lewis Publishers, Boca Raton.

Raison, RJ (1979). Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformations: A Review. *Plant Soil 51*: 73-108.

Rasmussen, PE and Collins, HP (1991). Long-term impacts of tillage, fertiliser and crop residue on soil organic matter in temperate semi-arid regions. *Adv Agron* 45: 94-134.

Schroeder, BL, Robinson, JB, Wallace, M and Turner, PET (1994). Soil acidification: Occurrence and effects in the south African sugar industry. *Proc S Afr Sug Technol Ass* 68: 70 - 74.

Soil Classification Working Group (1991). Soil classification. A taxonomic system for South Africa. Soil and Irrigation Research Institute, Department of Agricultural Development, Pretoria.

Summer, ME (1997). Opportunities for amelioration of soil physical and chemical constraints under intensive cropping. pp 305-326. In: Keating, BA and Wilson, JR (eds). *Intensive Sugarcane Production: Meeting the Challenges Beyond 2000.* CAB International, Wallingford.

Thompson, GD (1965). Mulching in sugarcane. Ph.D. Thesis, Department of Crop Science, University of Natal, Pietermaritzburg.

Thompson, GD (1966). The production of trash and its effects as a mulch on the soil and on sugar cane nutrition. *Proc S Afr Sug Technol Ass* 40: 333 - 337.

Thorburn, PJ, Probert, ME, Lisson, S, Wood, AW and Keating, BA (1999) Impacts of Trash Retention on Soil N and Water: An Example from the Australian Sugarcane Industry. *Proc S Afr Sug Technol Ass* 73: 75 - 79.

Van Antwerpen, R and Meyer, JH (1997). Soil degradation: effect of fertiliser use on penetrometer resistance. *Proc S Afr Sug Technol Ass* 71: 18-21.

Van Antwerpen, R and Meyer, JH (1996). Soil degradation under sugarcane cultivation in northern KwaZulu-Natal. *Proc S Afr Sug Technol Ass* 70: 29 - 33.

Wild, A (1994). Soil and the Environment: an Introduction. Cambridge, Cambridge University Press.

Wood, AW (1991). Management of crop residues following green harvesting of sugarcane in north Queensland. *Soil Till Res* 20: 69-85.

Wood, RA and Meyer, JH (1986) Factors Affecting Potassium Nutrition of Sugarcane in South Africa. . *Proc S Afr Sug Technol Ass* 60: 198 - 204.