# GREEN CANE HARVESTING PROMOTES ACCUMULATION OF SOIL ORGANIC MATTER AND AN IMPROVEMENT IN SOIL HEALTH

MH GRAHAM[1], RJ HAYNES[1] AND JH MEYER[2]

[1] *School of Applied Environmental Sciences, University of Natal, Pietermaritzburg*
[2] *South African Sugar Association Experiment Station, P/Bag X02, Mount Edgecombe, 4300*

## Abstract

Analysis of data from the long term trash management trial at Mount Edgecombe (BT1) has shown that, after 59 years of green cane harvesting, with trash retention there was a significant increase in soil organic matter content in the surface 10 cm of soil compared with burning. The size of the microbial biomass, and its respiratory rate, dehydrogenase activity and arginine ammonification rate were also increased by trash retention. Fertilised treatments tended to have a higher organic matter and microbial biomass C content than unfertilised treatments, reflecting the higher yields and greater organic matter returns under fertilisation. Soil microbial activity was however decreased by fertiliser applications. This inhibitory effect was attributed to fertiliser N-induced soil acidification.

## Introduction

Soil quality or health can be broadly defined as the capacity to accept, store and recycle nutrients and water, maintain economic yields and environmental quality. Soil quality is evaluated using soil quality indicators. These indicators can be divided into those which define soil biological, chemical and physical properties. Much is known regarding the chemical properties of sugarcane soils since routine soil testing is commonly carried out through the Fertiliser Advisory Service (FAS) laboratory at Mount Edgecombe. Changes in soil chemical and physical properties under sugarcane monocropping at the BT1 trail are currently being studied at the South African Sugar Association Experiment Station (SASEX) (Van Antwerpen and Meyer, 1997). By contrast, very little research has centered on the management of soil organic matter in South African agriculture or on the biological aspects of soil fertility. Biological indicators of soil quality are now considered central to determining soil health and identifying sustainable soil management practices (Elliot, 1997). Their role as indicators of the sustainability of sugarcane production has recently been discussed (Haynes, 1997).

The most practicable way of maintaining or improving soil organic matter (and sometimes increasing crop yield) under cane production is green cane harvesting with trash retention. Both Wood (1985) and Meyer *et al.* (1996) have advocated the practice as a long term strategy to reduce soil degradation and improve soil quality. Nonetheless, green cane harvesting is an uncommon practice in South Africa and the vast majority of the crop is burnt. Green cane harvesting is slower and therefore more expensive than burning, particularly where hand harvesting is carried out. Cooler climatic conditions in the higher lying Midlands areas also limit adoption of green cane harvesting. Its benefits to soil fertility, soil quality and the long term sustainability of cane production therefore need to be investigated and demonstrated before the practice will be adopted on a large scale.

At SASEX, Mount Edgecombe, there is a long term trash/fertiliser management trial that was established in 1939 on a black vertisol derived form dolerite parent material (Thompson, 1965). The experiment is thought to be the oldest sugarcane management trial in the world, having continued for 60 years. The purpose of this paper is to provide a preliminary report and discussion on the changes in soil organic matter content, soil quality and soil microbial activity that have occurred at this experiment site, as affected by trash management (burning versus green cane harvesting) and fertiliser application (annual N, P and K fertiliser application versus none).

## Materials and Methods

The trial (designated BT1) is situated on a vertisol (Arcadia form, Lonehill family; Soil Classification Working Group, 1991) with an 'A' horizon of about 500 mm. Mean annual rainfall at the site (longitude 31° 04' 29" and latitude 29° 43' 20") is 950 mm.

The main experiment treatments are: (i) green cane harvested with retention of a trash blanket (100% cover) (T), (ii) burnt with tops left scattered on plots (67% cover) (Bt) and (iii) burnt with tops raked off plots (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 experiment is 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 randomly over the whole area 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.

Areas between the experimental blocks that have been under grass for the duration of the experiment (no fertiliser applied) were also sampled. These sites were considered to be as close to the condition of undisturbed ground as it is possible to find in the vicinity of the trial site.

The field-moist soil was sieved (< 2 mm) for subsequent microbial and biochemical analysis. A sub-sample was air-dried and finely ground (< 150 µm) and used for organic C analysis. Organic C was determined by a dichromate wet oxidation procedure (Yeomans and Bremner, 1988).

Microbial biomass C was estimated by the method of Vance *et al.* (1987) based on the difference between C extracted with 0.5 M $K_2SO_4$ from chloroform-fumigated and unfumigated soil samples using a $K_C$ factor of 0.38. The microbial quotient was calculated by expressing microbial biomass C as a percentage of total soil organic C. Basal respiration was determined by placing 30g oven-dry equivalent of field-moist soil in 50ml beakers and incubating the sample in the dark at 25°C in a 1 litre air-tight jar along with 20 ml of 0.5M NaOH. The $CO_2$ evolved was determined after seven days by titration (Anderson, 1982).

The metabolic quotient (q $CO_2$) was calculated as basal respiration (µg $CO_2$ - C $h^{-1}$) per mg of microbial biomass C. Arginine ammonification rate was measured by the method described by Franzluebbers *et al.* (1995), using an incubation time of 3 h and a temperature of 25°C. Dehydrogenase enzyme activity was assayed as described by Tabatabai (1994).

## Results and Discussion

Soil organic C content increased in the order BtoFo < BtoF < BtFo = BtF < TFo = TF in the surface 10 cm of soil (Table 1). Differences were most pronounced in the 0 - 2.5 cm soil layer. The trashed treatments (TFo and TF) had higher soil organic C contents than the grass site whilst the burnt treatments all had lower values. Such results demonstrate the importance of trash retention in maintaining and improving soil organic matter status. Indeed, if the soil at the grass site is considered similar to that of undisturbed ground, then long term sugarcane production with trash retention has, in fact, increased soil organic matter content. By contrast, burning, particularly where tops are then removed, has caused a marked loss of soil organic matter over the 59 year period. Thus, the greater the returns of organic residue in the form of trash and tops, the greater the accumulation of soil organic matter.

Results for microbial biomass C, microbial quotient, basal respiration and metabolic quotient for the 0 - 2.5 cm layer are presented in Figure 1. Treatment effects were most pronounced in this layer and became progressively less clear with increasing soil depth. Microbial biomass C showed similar treatment effects to soil organic C except they were greatly amplified. As a result, the microbial quotient also showed a similar trend following the order: BtoFo < BtoF < BtFo = BtF < Tfo < TF (Figure 1). The microbial biomass accounted for between 0.4 and 1 % of total soil organic C,which is lower than is normally encountered in soils (Sparling, 1997). This may be attributable to the low proportion of labile organic matter present in Vertisols due to its stabilization by smectitic clays (Puentes *et al.*,1988).

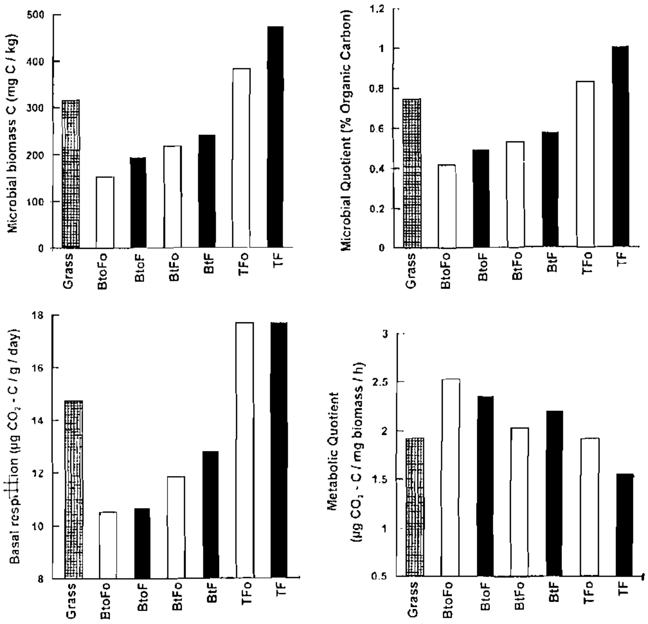

**Figure 1.** Effect of experimental treatments on microbial biomass C, microbial quotient, basal respiration and metabolic quotient in the 0 - 2.5 cm soil layer (T = trashed; B = burnt; F = fertilised; Fo = no fertiliser applied; t = tops scattered; to = tops removed).

Microbial biomass C represents the C held in the soil bacteria and fungi and is therefore a pool of soil C that can change rapidly. Indeed, due to its dynamic nature, microbial biomass C responds rapidly to changes in C supply brought about by changes in crop residue management, tillage practice or cropping rotation (Carter, 1986; Powlson *et al.*, 1987; Haynes and Francis, 1994) and effects are evident long before changes in total organic C content can be detected. Because changes occur rapidly, it has been suggested that the microbial quotient is a good index for monitoring changes in organic matter status (Carter, 1991). According to Gregorich *et al.* (1994), a ratio above or below the baseline level (i.e. that for an undisturbed site) would indicate that soil C is increasing or decreasing respectively. In agreement with this, results presented in Figure 1 show that trashed plots have a higher microbial quotient than the grassed area, while the burnt treatments have lower values.

Since microbial biomass C represents the living portion of total soil organic C, it is the most universally used indicator of soil health (Sparling, 1997; Pankhurst *et al.*, 1997). Results presented in Figure 2 clearly show the effect of trash management on microbial biomass C to a depth of 30 cm. Trash retention has increased soil microbial biomass C to that depth, compared with grass, whilst there has been a marked reduction in biomass C in the upper 10 cm under burning with tops removed.

There was a tendency for fertilised plots to have higher organic C contents than non-fertilised (Table 1) and the effects were more obvious for microbial biomass C (Figures

**Table 1. Effect of experimental treatments on soil organic C (g/kg) content to a depth of 30 cm.**

| Soil depth (cm) | Grass | BtoFo | BtoF | BtFo | BtF | TFo | TF |
|---|---|---|---|---|---|---|---|
| 0 - 2.5 | 42.43 | 36.67 | 39.53 | 41.33 | 41.67 | 46.17 | 47.07 |
| 2.5 - 5.0 | 41.23 | 35.43 | 38.43 | 37.13 | 40.37 | 41.20 | 42.50 |
| 5.0 - 10 | 36.50 | 34.57 | 36.03 | 36.47 | 38.40 | 34.90 | 39.97 |
| 10 - 20 | 34.00 | 34.13 | 35.47 | 35.37 | 36.30 | 35.53 | 37.07 |
| 20 - 30 | 31.60 | 33.77 | 35.70 | 34.03 | 38.10 | 34.83 | 36.47 |

T = trashed; B = burnt; F = fertilised ; Fo = no fertiliser applied; t = tops scattered; to = tops removed.

1 and 2). In general, the long term effect of annual fertiliser applications is to increase soil organic matter content (Haynes and Naidu, 1998). This is because fertilisers are applied to maintain or improve crop growth and yields. The increased plant biomass from fertilisers results in increased returns of organic residues in the form of decaying roots, litter, trash and tops. Small increases in soil organic matter content due to long term applications have also been noted for wheat and pasture production (Johnston, 1986; Haynes and Williams, 1992).

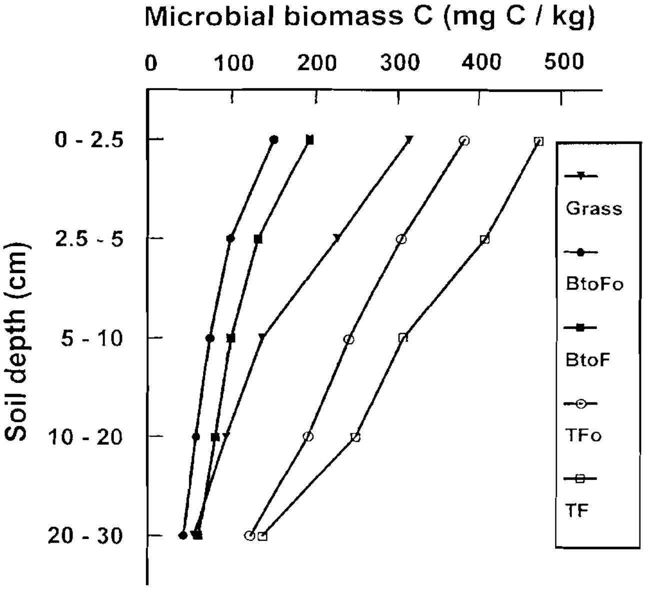

**Figure 2.** Effect of burning or green cane harvesting and retention of a trash blanket on microbial biomass C down the soil profile compared with long term grass (T = trashed; B = burnt; F = fertilised; Fo = no fertiliser applied; t = tops scattered; to = tops removed).

Determination of the size of the microbial biomass does not necessarily provide information on its activity. That is, soil microorganisms can be present in resting states or in active, rapidly reproducing states. The most common method of measuring microbial activity is to measure respiratory activity of the soil. Basal respiration (Figure 2) showed the trend, Bto < Bt < Grass < T, with fertiliser applications having no measurable effect. Thus, as soil organic matter content and microbial biomass C increased due to trash retention, so too did basal respiration.

The metabolic quotient is a measure of microbial respiration ($\mu g\ CO_2$ - C / h) per unit of microbial biomass which incorporates both changes in microbial population size and respiratory rate in one value (Wardle and Ghani, 1995). It has been proposed that the metabolic quotient can be used as a measure of changes in microbial activity in response to adverse environmental conditions (either environmental stress or disturbance); the microbial population is less metabolically efficient when it is stressed and the metabolic quotient is consequently higher (Anderson and Domsch, 1985, 1993). In this study, the metabolic quotient was higher in the burnt than grass treatment, indicating stress particularly in the BtoFo treatment (Figure1). Since this treatment has the lowest organic C content (i.e. lowest supply of C substrate for microbial activity) and is also nutrient deficient (Van Antwerpen and Meyer, 1997) a stressed microbial population is not unexpected. On the other hand, the trashed fertilised treatment had the lowest metabolic quotient. This treatment had the highest organic C and microbial biomass C content and was also fertilised.

Whereas fertilised plots generally had lower metabolic quotients than unfertilised ones (Figure 1), indicating less microbial stress, the use of dehydrogenase activity or arginine ammonification rate (Figure 3) indicated that microbial activity was decreased by fertiliser applications. Dehydrogenase activity is often used as an indicator of soil microbial activity (Alef, 1998) since it is an enzyme group common to most microorganisms and is predominantly endocellular (located within the organism). Arginine ammonification rate is also commonly used as an indicator of microbial activity (Alef and Kleiner, 1987). Most heterotrophic microorganisms possess intracellular enzymes capable of deamination of amino acids such as arginine with the liberation of $NH_4^+$.

The inhibitory effect of fertiliser application on soil enzyme activity is explicable in terms of the marked soil acidification that occurred in fertilised treatments. Mean $pH_{(water)}$ in the unfertilised treatments was 5.8 and that in the fertilised treatments was 5.1. As shown by Van Antwerpen and Meyer (1997), acidification has occurred to a depth of 20 cm. Such acidification is attributable to the continual use of acidifying nitrogenous fertilisers for 49 consecutive years without concomitant use of lime. These results underline the negative effects that soil acidification can have on soil microbial activity.

## Conclusions

Although there are several reports of degradation of soil organic matter under continuous sugarcane production (Wood, 1985; Bramley *et al.*, 1996; Van Antwerpen and Meyer, 1996), the results of this study suggest that where green cane harvesting with retention of a trash blanket is practiced, there can be an increase in soil organic matter and

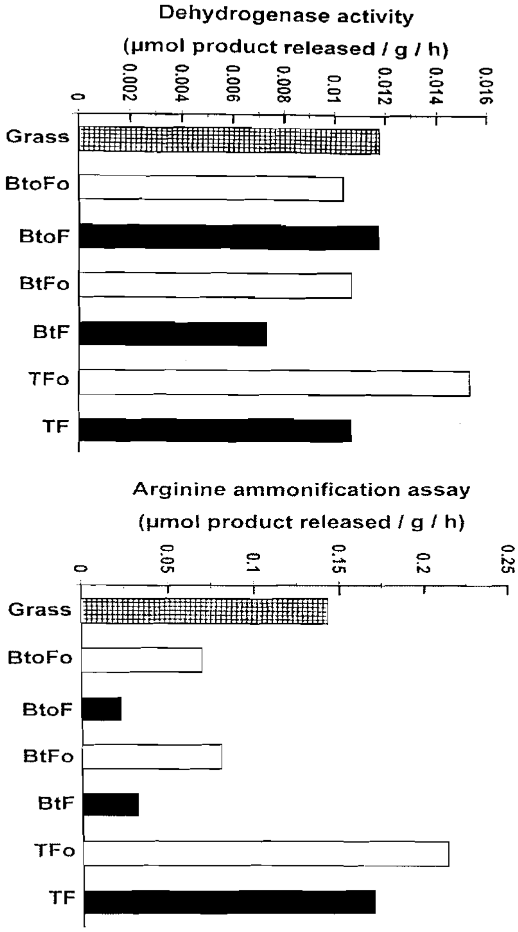

**Figure 3. Effect of experimental treatments on dehydrogenase activity and arginine ammonification rate in the 0 - 2.5 cm soil layer (T = trashed; B = burnt; F = fertilised ; Fo = no fertiliser applied; t = tops scattered; to = tops removed).**

a concomitant increase in the activity of the soil microbial biomass. These increases are likely to impact positively on the fertility and physical condition of the soil and these aspects will be the focus of future research at the experimental site. Certainly, Sutton *et al.* (1996) suggested that the higher productivity of green cane harvesting compared with burning is due to the higher soil microbial activity, greater soil organic matter turnover, and greater storage and release of nutrients.

The negative effect that fertiliser applications had on soil enzyme activity exemplifies the negative effects that soil acidification can have on soil microbial activity. Where acidifying nitrogenous fertilisers are used, regular lime application will however, counteract such effects.

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# FURTHER REVISION OF LIME RECOMMENDATIONS USED IN THE SOUTH AFRICAN SUGAR INDUSTRY

AW SCHUMANN[1], D McARTHUR[2] AND JH MEYER[1]

[1] *South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300, South Africa*
[2] *Union Co-operative Ltd, PO Box 1, Dalton, 3236, South Africa*

## Abstract

Current lime recommendations made by the Fertiliser Advisory Service (FAS) at Mount Edgecombe are based primarily on Aluminium Saturation Index (ASI), and exchangeable calcium and magnesium in the soil; the Al:S ratio, pH ($H_2O$), organic matter and sugarcane variety are also used to modify the recommendations. Recent evidence from trials of large varietal differences in acid tolerance, and cumulative yield suppression in the most acid tolerant variety, N12, even at moderate liming rates, has prompted further revision of lime recommendations. The current procedure for calculating lime rates does not estimate the final soil ASI status after lime application, so that the resulting ASI is unpredictable, and may be reduced excessively below the threshold value of 40% used for N12, and the 20% used for all other varieties. A new recursive calculation method incorporating both lime and gypsum has corrected this problem, and the ability now to predict final soil ASI after liming should help prevent yield losses from over-liming. Recent trial evidence has also indicated the need to increase the soil Ca threshold from 150 to 200 mg/kg.

## Introduction

Methods for establishing lime requirement in the South African sugar industry have recently undergone several changes. The introduction of the Al:S ratio for light textured humic soils led to a considerable reduction in lime requirement on these soils (Schroeder *et al.*, 1993). Further modification took place in 1996 following a review by Schroeder et al. (1995). This involved a change from using the Exchangeable Aluminium Index (EAI) for different soil clay categories (Moberly and Meyer, 1975), to an approach based on Aluminium Saturation Index (ASI) in conjunction with Al:S.

A good relationship between ASI and sugarcane yield was found when varieties were considered separately or in groups and it was established that N12 (and to a lesser extent NCo376 and N16) were markedly tolerant to aluminium. It was, however, concluded that more data were required for N12 at very high ASI values and that the poor correlation between yield and ASI in the case of N16 was due to insufficient data (Schroeder *et al.*, 1995). Interim ASI threshold values used were 40% for N12 and 20% for all other varieties. Recent evidence from lime trials of large varietal differences in acid tolerance, and cumulative yield suppression from liming in the most acid tolerant variety N12 has prompted further revision of lime recommendations.

The purpose of this paper is to re-examine the above threshold values in the light of recent additional data and to improve the method of calculating lime requirements from ASI thresholds to obtain the best possible lime recommendations for growers. A further objective is to introduce the option of gypsum/phosphogypsum mixed with dolomitic lime into FAS recommendations since this treatment has outperformed lime in a number of trials with sugarcane.

## Materials and Methods

*Recent liming trials*

Recent yield and soil data from three liming trials on different acid soils in the KwaZulu-Natal Midlands (Table 1) were compared. All trials used two rates of Umzimkulu dolomitic lime, and an additional gypsum + lime treatment was included at Dalton and Eston. Cumulative sucrose yields for up to three crops (plant and two ratoons) were related to lime application rates and ASI to evaluate the performance of lime recommendations. Relative sucrose yields (yield as a percentage of the maximum for each site and variety) were then pooled for the three experiments to establish updated relationships with soil ASI for the varieties N12 and N16. Leaf and soil calcium concentrations were compared with sugarcane yield using linear regression methods (Anon, 1993).

**Table 1. Selected topsoil properties of recent lime trials conducted in the KwaZulu-Natal Midlands.**

| Location | Soil form | Variety | Crops | Clay (%) | pH ($H_2O$) | Organic matter (%) | EAI | K | Ca | Mg | ASI (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (mg/kg) | | | | |
| Paddock | Nomanci | NCo376<br>N12<br>N16 | plant, ratoons 1,2 | 24 | 4,4 | 8,1 | 185 | 111 | 98 | 16 | 70 |
| Eston | Inanda | N12<br>N16 | plant, ratoons 1,2 | 30 | 5,1 | 5,5 | 96 | 138 | 134 | 34 | 45 |
| Dalton | Magwa | N12<br>N16 | plant, ratoon 1 | 59 | 4,2 | 6,8 | 397 | 76 | 111 | 53 | 75 |

Soil and leaf samples were analysed by standard FAS methods. Topsoil samples (0 to 0,15 m) were taken before planting and after harvest of each ratoon crop. In ratoon cane, topsoil samples were taken from the row and interrow using the standard ratio of 1:8 (row:interrow). Subsoils were also sampled at two depths on selected trials, using an open-bucket auger. Soil samples were dried overnight at 50°C in a forced draught oven, ground to pass a 2 mm sieve, and K, Ca, and Mg were determined by atomic absorption spectroscopy after extraction with 1 *M* ammonium acetate solution, using a soil:solution ratio of 1:10 and a shaking time of 20 min. Soil EAI was obtained colorimetrically with pyrocatechol violet after extraction with 0,2 *M* ammonium chloride (Reeve and Sumner, 1970). Soil pH (water:soil ratio of 2,5:1) was measured with a digital combination pH electrode. The ASI values were calculated according to equation 1, where EAI, K, Ca and Mg are in units of $\text{cmol}_c$/kg (Schroeder *et al.*, 1995).

$$ASI\,(\%) = \frac{EAI}{EAI + K + Ca + Mg} * 100 \qquad (1)$$

Composite third leaf samples (without midribs) were taken from plots during the first summer of each crop. Nitrogen was determined by near-infrared spectroscopy (NIRS) and the remaining elements were analysed by X-ray fluorescence spectroscopy after drying at 70°C in a forced-draught oven and grinding in a Cyclotec mill (Wood *et al.*, 1985).

*Computer program*

The existing FAS lime calculations are obtained by subtracting an amount from EAI which must be neutralised by lime in order to bring soil ASI down to a threshold 20% (for all varieties except N12, which is 40%). This amount is determined as the fraction (eg. 0,2) of the total cations (denominator in equation 1). The result of this subtraction (eg. EAI - 0,2 x [EAI+K+Ca+Mg]) is the milliequivalents ($\text{cmol}_c$/kg) of EAI which must be neutralised by the addition of lime. Four tons of lime is then assumed to neutralise one milliequivalent of EAI, and an efficiency factor of 2,5 is used to account for the incomplete representation of soil aluminium by the EAI. A shortcoming of this calculation is its inability to predict the final ASI resulting from the application of the calculated amount of lime to the soil. In the light of increasing evidence showing sugarcane yield suppression from over-liming, it is therefore necessary to have more control over final soil ASI.

As a major improvement to the ASI calculation would be to include the Ca and Mg added to soil as lime in the calculation (denominator in equation 1), a Pascal program was written to calculate lime rates based on a simple recursive loop to solve equation 1 for a given target ASI (Figure 1).

```
calcASI(K,newCa,newMg,oldEAI);   {calculate initial value for ASI}
newEAI:=oldEAI;
while ASI>targetASI+crit do begin   {start of main loop.  crit is tolerance parameter  = 0.0001}
        newEAI:=newEAI-incr;  {decrease EAI by a variable step size   incr}
        limerate:=((oldEAI-newEAI)/26.981539*3/10)*1.5*effic/purity; {   calculate lime in t/ha}
        newCa:=oldCa+xCa*(limerate*1000*limeCa/2.25);   {estimate the new Ca}
        newMg:=oldMg+xMg*(limerate*1000*limeMg/2.25);   {estimate the new Mg}
        calcASI(K,newCa,newMg,newEAI);    {re-calculate ASI with new EAI, Ca, Mg}
        incr:=abs(targetASI-ASI)*0.1;  {reduce step size as target ASI is approached}
end; {of main loop}
```

NOTES:

Dolomitic lime is assumed, with **limeCa**=26%, **limeMg**=4.3%, **purity** (CCE) = 80%.

Empirical efficiency factors **effic** = 5.0, **xCa**=1.3, **xMg**=1.4 were determined by calibration.

The top 0.15 m of soil is limed; a factor of 2.25 is therefore used to convert mg/kg to kg/ha, assuming a bulk density of 1.5 g/cm$^3$

**Figure 1. Portion of Pascal code used to calculate dolomitic lime rates for a given soil chemistry and target ASI.**

The method for calculation of lime (t/ha) in this program was adapted from Sims (1996), where 1 milliequivalent of Al is neutralised by 1,5 t/ha pure $CaCO_3$. An efficiency factor ***effic*** was introduced to account for the incomplete representation of phytotoxic Al by EAI, and ***purity*** of the liming material is also accounted for as Calcium Carbonate Equivalence (CCE), where 100% represents pure $CaCO_3$. Further efficiency factors (***xCa, xMg***) were introduced for the amounts of Ca and Mg released into and 'measured' in the soil after liming. These three efficiency factors were determined empirically by calibration, using nine representative control topsoil samples from previous liming trials (Table 2).

A customised version of the Pascal program was then devised to repeatedly calculate amounts of lime required to achieve the measured ASI recorded for each soil after the first crop. In this manner, the desired target ASI in the program was given the appropriate measured value for each site and lime rate. A triple nested loop structure was arranged to test all possible combinations of ***xCa, xMg*** from 0,1 to 2,0 in increments of 0,1, and ***effic*** from 1,0 to 6,0 in increments of 0,1. Calculated lime rates were then compared with actual

**Table 2. Selected properties of control topsoils used for calibration of the new lime program, and comparison with two other FAS lime calculation methods.**

| Experiment location | Soil form | Clay (%) | pH ($H_2O$) | K | Ca | Mg | Al | Control ASI (%) | Current FAS lime§ (t/ha) | Old FAS lime‡ (t/ha) | Lime used in expt. (t/ha) | Measured final ASI (%) | New program lime† (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (mg/kg) | | | | | | | | | |
| Paddock | Nomanci | 26 | 4,4 | 110 | 88 | 16 | 184 | 71 | 14 | 10 | 7; 14 | 18,4; 3,6 | 7 |
| Eston | Inanda | 28 | 4,8 | 118 | 121 | 42 | 95 | 46 | 7 | 4 | 7; 14 | 1,8; 0,8 | 3 |
| Dalton | Magwa | 59 | 4,2 | 95 | 28 | 28 | 316 | 86 | 14 | 14 | 5; 10 | 34; 13 | 12 |
| Eston | Inanda | 16 | 4,7 | 106 | 45 | 13 | 118 | 69 | 9 | 6 | 3 | 21 | 4 |
| Eston | Glenrosa | 27 | 4,6 | 95 | 116 | 27 | 150 | 62 | 11 | 7 | 7 | 7,2 | 5 |
| Umzinto | Inanda | 28 | 4,8 | 134 | 151 | 32 | 142 | 54 | 10 | 7 | 7; 14 | 19; 0,6 | 5 |

† lime calculated to neutralise ASI to a target of 15% (all varieties except N12)
‡ lime calculation based on milliequivalents of Al and clay % (Moberly and Meyer, 1975)
§ lime calculation based on ASI, without accounting for additional Ca and Mg from lime (Schroeder *et al.*, 1995)

lime rates for the nine soil samples for each combination, in order to determine the 'best fit'. Linear correlation coefficients (r) and residuals were used to select the best efficiency factors to give the best prediction of lime rates, and therefore of ASI.

Once the best efficiency factors were determined, they were incorporated into the original program, which was then further modified to allow the calculation of gypsum/phosphogypsum rates to supplement the lime rates. The final program calculates dolomitic lime required to neutralise ASI to an amount that is 20% higher than the target ASI (e.g. 24% ASI if the desired target is 20%). The remaining (eg. 4%) ASI is then neutralised with gypsum, using a Pascal procedure similar to that in Figure 1, which incorporates the Ca supplied by gypsum into the denominator of equation 1. The Ca content of gypsum is assumed to be 20%. The 20% proportion of ASI to be neutralised by gypsum was determined by trial and error to yield a lime:gypsum ratio of about 2:1. A further constraint to the use of gypsum is incorporated whereby the ratio of Ca:Mg ($cmol_c/kg$) in soil is restricted to less than 4,0. This precaution was devised to prevent nutrient imbalances of Ca:Mg.

## Results and Discussion

*Liming trials*

Soil ASI values measured at the end of the plant crops on the three acid sites were markedly different (Figures 2 to 4). The FAS recommended lime rates at Paddock, Eston and Dalton were 14, 7 and 14 t/ha dolomitic lime, respectively. The maximum lime rate at Dalton was in fact reduced to below the FAS rate at 10 t/ha. The corresponding measured final ASI values were quite variable, as expected (3,6%, 1,8% and 13%). The best long term cumulative sucrose yields were obtained from the more moderate lime rates (ASI >13%), and either lack of response or growth suppression occurred at the high lime rates (Figures 2 to 4). This was particularly evident for variety N12, which responded poorly to lime at the most acid sites (Paddock, Dalton), and was negatively affected by lime at the least acid site (Eston). Variety N12 always outperformed N16 and NCo376 in unlimed soil and, at Eston and Paddock, the unlimed N12 performed as well or better than the best limed treatment of any variety (Figures 2 and 3). A tentative ranking of acid tolerance for these varieties is N12 > Nco376 > N16. Gypsum addition at the moderate lime rate had a negligible effect on measured soil ASI,

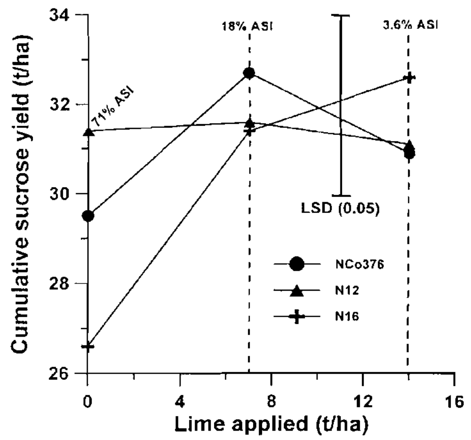

**Figure 2.** Cumulative sucrose yield (plant + ratoons 1 and 2) on limed and unlimed acid soil from 1992 - 1997 at Paddock.

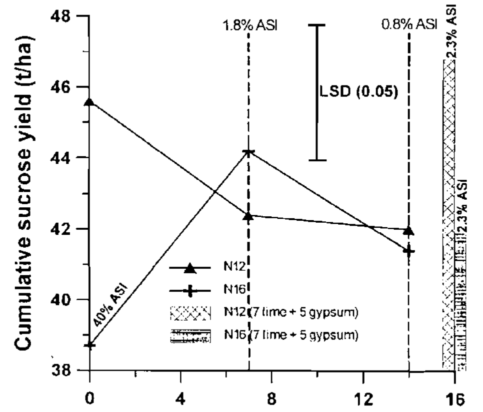

**Figure 3.** Cumulative sucrose yield (plant + ratoons 1 and 2) on limed, unlimed and gypsum treated acid soil from 1990 - 1997 at Eston.

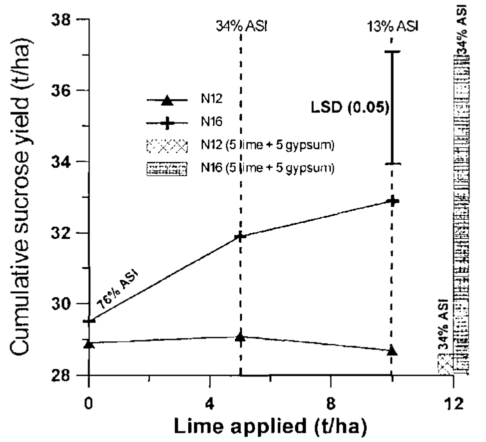

**Figure 4.** Cumulative sucrose yield (plant + ratoons 1) on limed, unlimed and gypsum treated acid soil from 1995 - 1998 at Dalton.

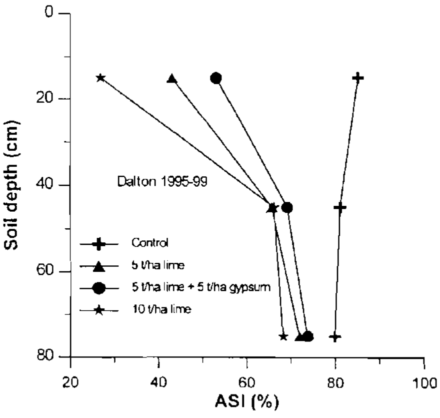

**Figure 5.** Amelioration of soil ASI at three measured depths by lime and gypsum treatments in the Dalton experiment (1995 - 1998).

but yields were either unimproved relative to the lime treatment, or greatly improved (variety N16, Figure 4). There was no additional effect of the gypsum on acidity in the topsoil or at depth in the highly acid Dalton trial (Figure 5).

Combined relative sucrose yields showed that the current ASI thresholds of 40% for N12 and 20% for all other varieties were still acceptable for N16 (Figure 6) and N12 (Figure 7) in these trials. The previous lack of data for N16 and of high ASI values for N12 appear to have been satisfied by these additional data. Although variety N12 shows exceptional tolerance to native soil acidity, and a negative response to liming treatments which reduce soil ASI below 10-15% (Figure 7), this apparent sensitivity to low ASI should not be confused with unlimed soils of naturally low ASI, where the performance of this variety is clearly uncompromised.

*Computer program*

Calibration results for the new liming program were highly satisfactory ($R^2$=0,94, SE=1,03; Figure 8). The new calibrated program may now be used to recommend lime rates to achieve specific target ASI values, which should help avoid yield losses from over-liming observed at the higher lime rates and lower ASIs (<10%) in the field trials. The program was used to predict a wide range of lime rates for a target ASI range of 0,5 to 40% on the Paddock soil (Figure 9). Since the relationship between lime addition and ASI reduction for a soil is clearly exponential, a small error in ASI prediction at the lower range (<20%) can cause expensive overliming additions (Figure 9). Suggested moderate target ASIs to avoid yield suppression are 30% (N12) and 15% (all other varieties), with threshold ASIs remaining as before. A comparison of this new calculation method with the current and previous FAS methods shows that the new method is by far

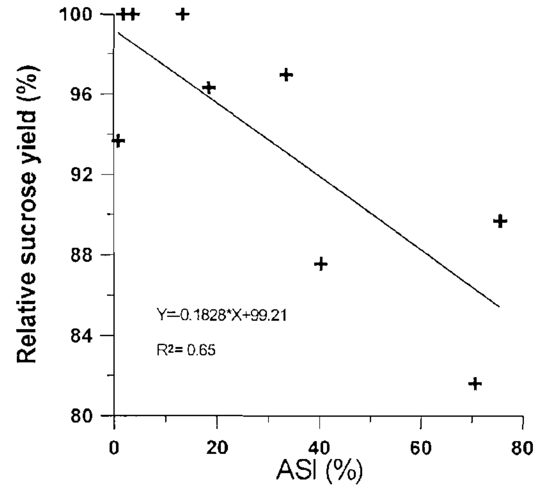

**Figure 6.** Relative cumulative sucrose yield of N16 crops from Paddock, Eston and Dalton trials at a range of measured soil ASI values.

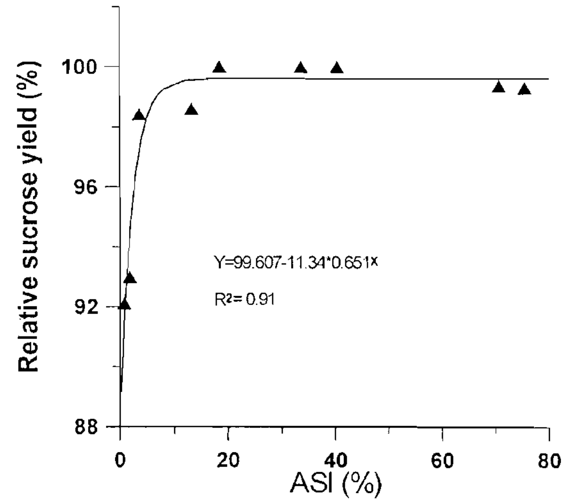

**Figure 7.** Relative cumulative sucrose yield of N12 crops from Paddock, Eston and Dalton trials at a range of measured soil ASI values.

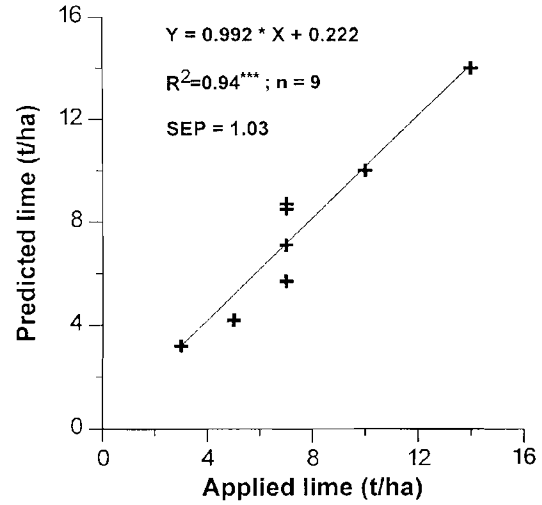

**Figure 8.** Performance of the lime program calibration with nine unlimed acid soils.

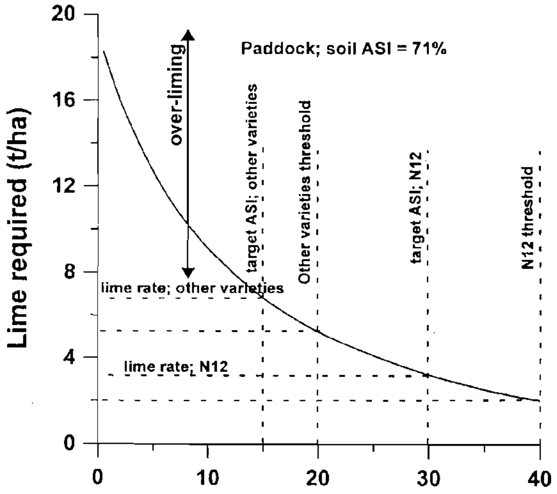

**Figure 9.** Prediction of lime requirement with the new lime program over a range of target ASI values on the unlimed acid soil at Paddock.

the most conservative (Table 2), and should reduce the risk of over-liming yield reduction and associated input costs. The program option to include gypsum in the lime recommendation performed satisfactorily when the gypsum fraction was restricted to neutralise about 5% ASI, subject to the final soil Ca:Mg ratio not exceeding 4,0.

### *Calcium thresholds*

Relationships between soil and leaf Ca and sugarcane yield were investigated in the highly acid Dalton trial, where Ca deficiencies were most likely. A good relationship at the lower Ca levels (control treatments) as indicated by the broken stick model, confirmed the importance of Ca nutrition in Midlands and other acid soils (Figures 10 and 11). While the leaf Ca threshold used by FAS (0,15%) was perfectly matched in the Dalton trial (Figure 11), the soil threshold value may need to be increased from 150 to 200 mg/kg (Figure 10).

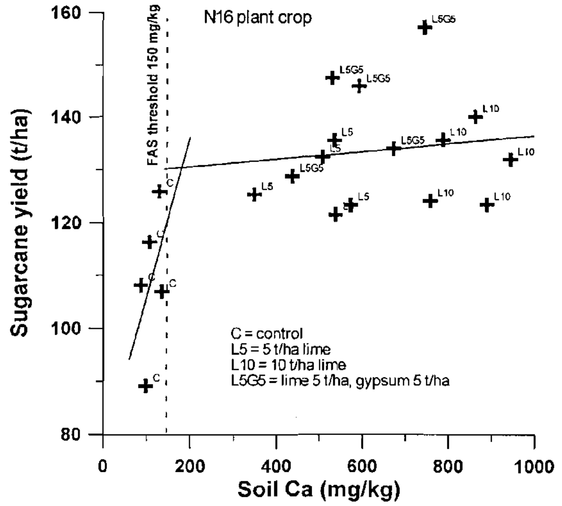

**Figure 10.** Relationship between sugarcane yield and soil Ca in all plots of the Dalton experiment. A broken stick model was used to indicate the threshold Ca value.

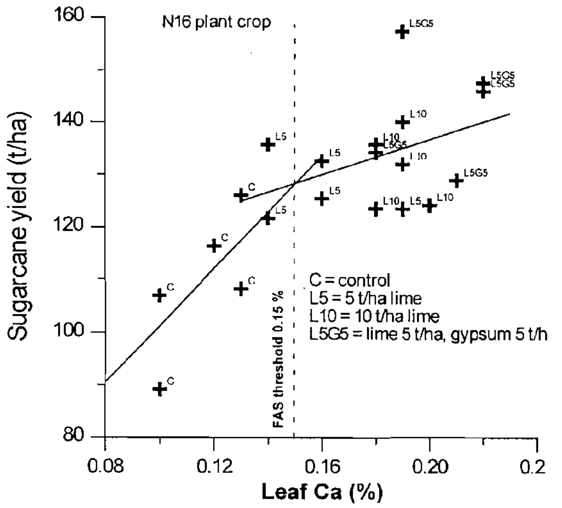

**Figure 11.** Relationship between sugarcane yield and leaf Ca in all plots of the Dalton experiment. A broken stick model was used to indicate the threshold Ca value.

## Conclusions

The proposed new computer program implements a realistic, mechanistic method for lime calculation, which should allow more precise lime applications to all acid soils and avoid the unprofitability of both yield reduction and over-liming. Test results indicate a more conservative lime prediction with the new program, and associated savings to the sugar industry are expected. The proposed inclusion of more gypsum in lime recommendations is also expected to have additional benefits of improved Ca and S nutrition. Current ASI thresholds used by FAS for differential variety responses to acidity were confirmed, especially for the acid tolerant variety N12, and the more sensitive variety N16. Although N12 may be grown with relative impunity without lime on the most acid soils, this 'minimum input' approach is not recommended in the long term because more sensitive varieties or alternative crops in the future will require extremely costly remedial lime inputs. The suitability of the leaf and soil Ca thresholds were ascertained, subject to a relatively minor increase of the soil Ca threshold from 150 to 200 mg/kg.

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