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 N12 N16	plant, ratoons 1,2	24	4,4	8,1	185	111	98	16	70
Eston	Inanda	N12 N16	plant, ratoons 1,2	30	5,1	5,5	96	138	134	34	45
Dalton	Magwa	N12 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 $cmol_c$/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 ($cmol_c$/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,

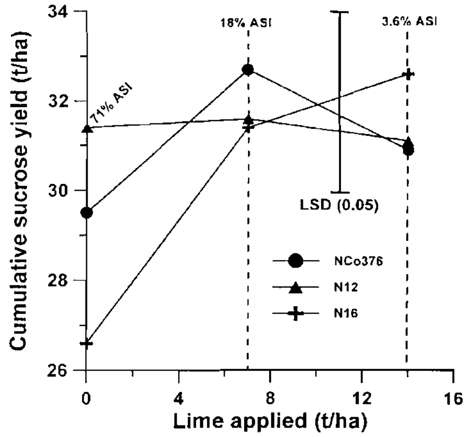

Figure 2. Cumulative sucrose yield (plant + ratoons 1 and 2) on limed and unlimed acid soil from 1992 - 1997 at Paddock.

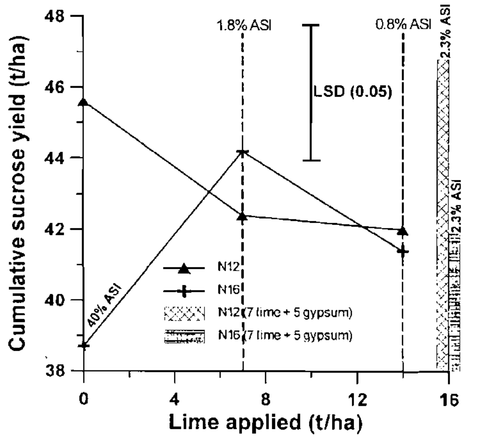

Figure 3. Cumulative sucrose yield (plant + ratoons 1 and 2) on limed, unlimed and gypsum treated acid soil from 1990 - 1997 at Eston.

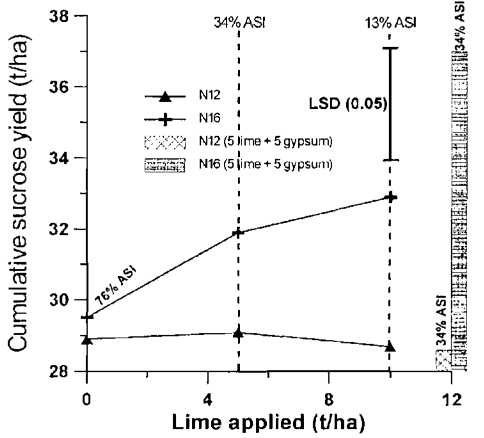

Figure 4. Cumulative sucrose yield (plant + ratoons 1) on limed, unlimed and gypsum treated acid soil from 1995 - 1998 at Dalton.

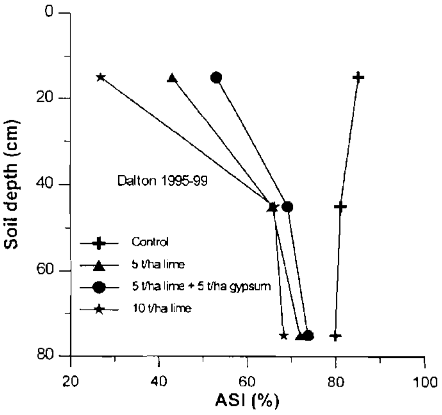

Figure 5. Amelioration of soil ASI at three measured depths by lime and gypsum treatments in the Dalton experiment (1995 - 1998).

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 over-liming 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

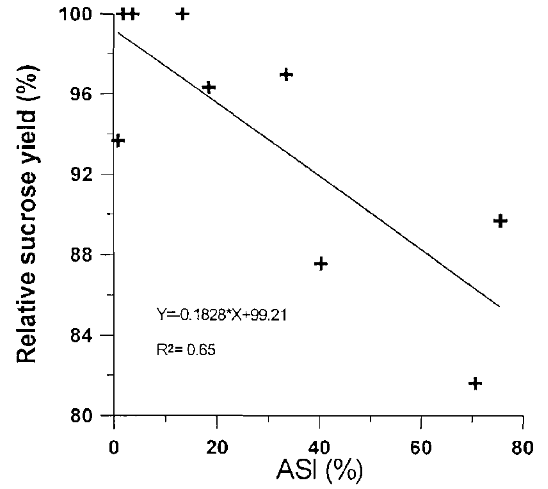

Figure 6. Relative cumulative sucrose yield of N16 crops from Paddock, Eston and Dalton trials at a range of measured soil ASI values.

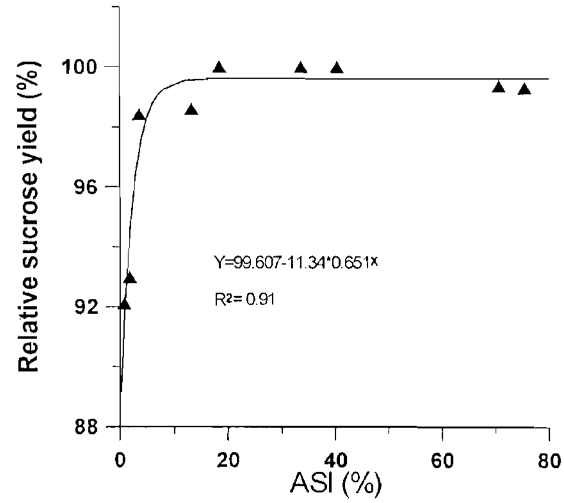

Figure 7. Relative cumulative sucrose yield of N12 crops from Paddock, Eston and Dalton trials at a range of measured soil ASI values.

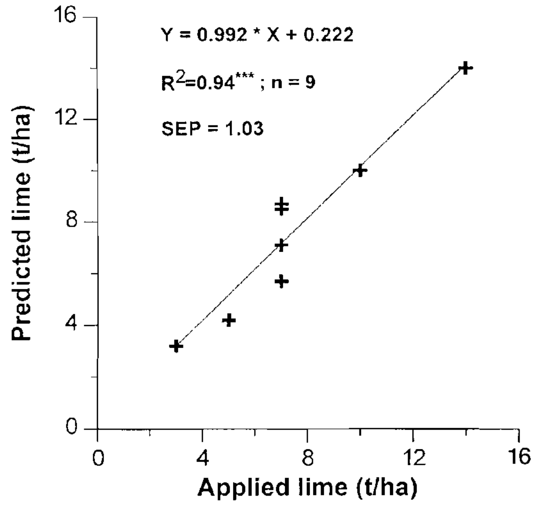

Figure 8. Performance of the lime program calibration with nine unlimed acid soils.

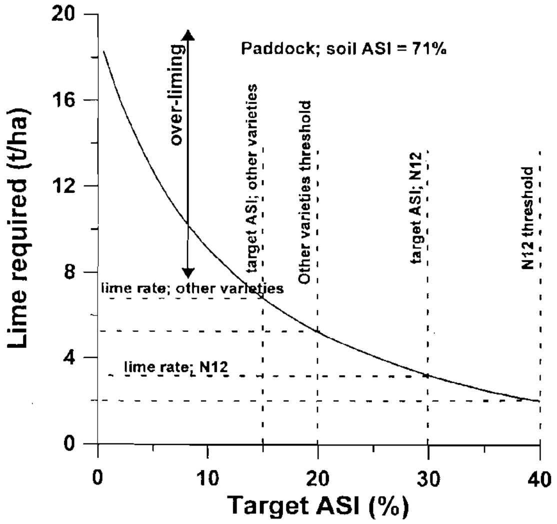

Figure 9. Prediction of lime requirement with the new lime program over a range of target ASI values on the unlimed acid soil at Paddock.

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).

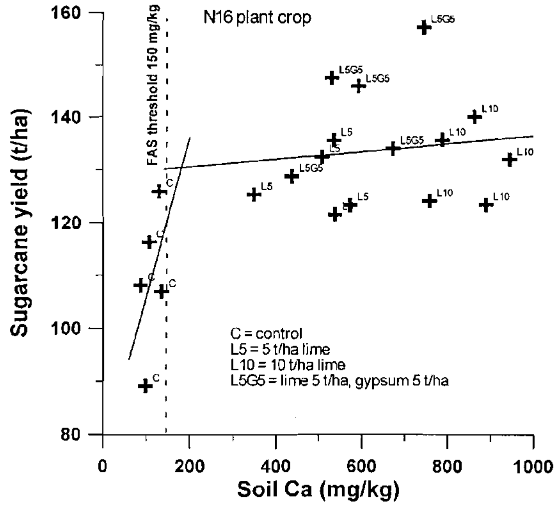

Figure 10. Relationship between sugarcane yield and soil Ca in all plots of the Dalton experiment. A broken stick model was used to indicate the threshold Ca value.

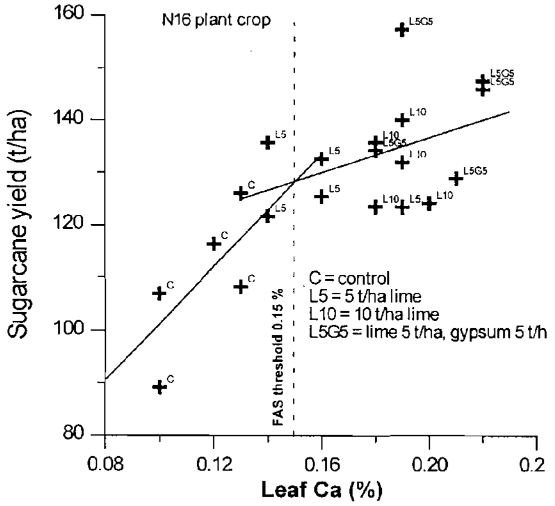

Figure 11. Relationship between sugarcane yield and leaf Ca in all plots of the Dalton experiment. A broken stick model was used to indicate the threshold Ca value.

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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