THE EFFECT OF LIME ON RELEASE AND PLANT UPTAKE OF NITROGEN FROM SOILS OF THE NATAL MIDLANDS

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Abstract

A range of soils from the cane growing areas of the Natal Midlands were treated with lime at rates equivalent to five and ten tons per hectare and controls were left untreated. They were then incubated at 30°C for two or four weeks. There was a significant linear correlation between amount of N mineralized and soil organic matter content, in the absence or presence of lime. N mineralization was greatly increased in the presence of lime, the quantity of N released increasing as the rate of lime increased. This stimulation of mineralization was confirmed in a glasshouse trial in which liming increased the uptake of N when sorghum was grown on several of the above soils. It is possible that increased mineralization of N which follows the liming of acid soils could lead to a low sucrose content of cane grown in the Natal Midlands, and N fertilizer recommendations for this region may therefore have to be adjusted.

Introduction

During the past decade it has been recognised that in terms of crop nutrition the keys to successful sugarcane production on many of the acid, highly leached soils of the Natal Midlands, are the elimination of aluminium toxicity and phosphorus fixation as primary causes of poor growth (Moberly and Meyer[6], Meyer[3], [5]). This conclusion has been reached largely as a result of a series of glasshouse experiments and field trials in which various amounts of lime were incorporated to different depths in the soil, the treatments being used in combination with high levels of superphosphate, filtercake and other ameliorants.

While large responses in cane yield both to liming and to superphosphate have been obtained, one experiment indicated that on average, liming had significantly depressed sucrose percent cane from 13,4% to 12,4%. This decline was accompanied by a general increase in foliar nitrogen values; low sucrose values (<12% sucrose) tended to be associated with leaf N levels in excess of 2,4% (Meyer[4]).

Growers in certain parts of the Natal Midlands have been concerned for some time about the low sucrose content of their cane. It was thought that increased mineralization of soil nitrogen following the application of lime could be a factor leading to excessive N uptake by the plant, which in turn might depress its sucrose content. It was therefore decided to study, both in the laboratory and glasshouse, the effect of liming on release of mineral N from a number of moderately to strongly acid Midlands soils which, because of their generally high organic matter content, were known to have a considerable potential for mineralizing N.

Experimental Procedure

Laboratory

Composite topsoil and profile samples were taken from various locations in the Natal Midlands (see Table 1), many of them from existing wattle plantations or adjacent fields now under sugarcane. Soils under wattle, which is a legume, are generally strongly acid, and characterised by high levels of total N, organic matter and aluminium to depth (see Table 1). The soils were air dried, then crushed and passed through a 2 mm sieve, after which they were stored in plastic bottles until ready for use. Before incubation, full chemical and textural analyses were carried out on all samples and the results are shown in Table 1. The pH (2,5:1 water:soil) ranged from 4,0 to 5,6, total N content from 0,07% to 0,40% and organic matter content from 1,86% to 8,05%.

Bulk samples of the air-dry soils were treated with reagent quality lime ($CaCO_3$) at rates equivalent to five and ten tons per hectare and control samples were left untreated. Subsamples of these soils weighing 25 g were moistened to 60% of water holding capacity, and incubated in stoppered flasks for periods of 2 and 4 weeks at 30°C. The stoppers were removed at weekly intervals and the flasks aerated. After incubation the soils were extracted with N K_2SO_4 in 0,1 N H_2SO_4 (2:1 solution:soil), the samples being shaken for 15 minutes before filtration. Aliquots of the filtrate were analysed for mineral N (NH_4—N+NO_3—N), by steam distillation with magnesium oxide and Devarda's alloy. Before incubation, control samples (no lime) were similarly extracted and the mineral N content determined. The difference in mineral N between the incubated and unincubated samples represented the N mineralised under the various treatments.

Glasshouse

Although the laboratory incubation study revealed that there was an increase in release of soil N following the application of lime, it was considered that the results obtained would be more meaningful if such a release could be demonstrated in terms of plant uptake of N and increase in leaf N content. Bulk samples (0-150 mm) of several of the soils used in the laboratory investigation were therefore collected. These were air dried, passed through a 2 mm sieve and thoroughly mixed.

Sorghum (babala) was grown in pots containing 1,2 kg of the soils. Lime ($CaCO_3$) was added to the soils at rates equivalent to 2,5; 5 and 10 tons per hectare and there was a control treatment which received no lime. For each of the soils these treatments were replicated three times. A nutrient solution containing all the essential elements apart from nitrogen was applied to all pots which were maintained at 60% of water holding capacity by daily watering. A plant crop was harvested five weeks after planting and a first ratoon seven weeks later. The harvested sorghum was oven-dried, weighed and analysed for N content.

Results and Discussion

Laboratory investigation

Figures 1A and 1B show that, throughout the four week incubation period, there was a significant linear correlation between amount of N mineralised and soil organic matter content, in the absence or presence of lime. N mineralization was considerably enhanced in the presence of lime irrespective of soil pH, the quantity of N released increasing as the rate of lime increased. In most soils the major release of mineral N took place during the first two weeks of incubation, though

TABLE 1

Chemical composition of soils used in the incubation studies

Soil No.	Parent material	Soil series	Location	Depth mm	Clay %	pH (H_2O)	N %	O.M. %	Ca (ppm)	Mg (ppm)	K (ppm)	EAI* (ppm)	P (ppm)	PDI**
1	Dolerite	Dolerite	Umbumbulu	0–150	40	5,6	0,21	5,78	480	>220	68	8	3	0,05
2	TMS	Fountainhill	Upper Tongaat	0–150	20	5,5	0,25	6,40	443	152	68	12	3	0,04
3	Dolerite	Doveton	Umbumbulu	0–150	36	5,5	0,23	5,57	679	>220	106	4	4	0,18
4	TMS	Trevanian	Mid-Illovo	0–150	19	4,4	0,40	8,05	113	42	96	176	5	0,28
5	TMS	Swartland	Upper Tongaat	0–150	41	5,2	0,08	1,96	181	167	126	57	3	0,24
6	TMS	Trevanian	Mid-Illovo	0–150	21	5,5	0,18	4,13	532	>220	93	1	2	0,19
7	Dolerite	Doveton	Mooi River	0–150	57	4,8	0,22	5,88	605	>220	325	36	61	0,12
8	Dolerite	Farningham	Nottingham Road	0–150	44	5,5	0,20	4,64	858	188	209	3	37	0,15
9				150–300	45	5,5	0,19	4,13	795	174	168	4	32	0,16
10				300–450	46	5,4	0,15	3,20	535	130	106	22	16	0,13
11	Dolerite	Doveton	Baynesfield	0–150	51	5,6	0,15	4,02	695	140	83	2	19	0,06
12				150–300	52	5,6	0,15	4,18	640	128	66	4	11	0,05
13				300–450	55	5,6	0,12	3,51	464	99	42	3	5	0,05
14	TMS	Cartref	Samela Drive	0–150	12	4,5	0,22	4,13	26	26	50	160	3	0,42
15				150–300	21	4,7	0,14	3,10	6	10	25	137	3	0,36
16				300–450	18	4,7	0,10	2,37	6	8	25	118	2	0,28
17	TMS	Inanda	Montebello Road	0–300	22	4,4	0,26	5,78	125	47	41	158	4	0,23
18				300–600	26	4,9	0,16	3,72	68	50	21	125	4	0,21
19	TMS	Farningham	Harburg/Dalton Rd	0–150	23	4,0	0,16	2,99	51	17	30	189	8	0,48
20				150–300	26	4,1	0,13	2,68	39	10	27	186	4	0,44
21				300–600	27	4,5	0,10	2,37	95	26	21	140	3	0,36
22				600–900	40	4,9	0,07	1,44	159	85	15	98	2	0,18
23	Dolerite	Sprinz	Dalton/Seven Oaks Road	0–150	30	4,7	0,25	5,15	391	91	183	78	10	0,14
24				150–300	35	4,6	0,22	4,85	332	72	146	98	7	0,14
25				300–600	34	4,7	0,14	3,09	241	49	52	93	2	0,08
26				600–900	58	4,7	0,09	1,65	108	59	34	45	4	0,04
27	TMS	Cranbrook	Outside Dalton	0–150	20	4,9	0,11	1,86	385	98	65	10	10	0,65
28	TMS	Cartref	Dalton/Tongaat Rd (Forbesdale)	0–150	17	4,2	0,21	3,92	104	34	49	123	3	0,56
29				150–300	20	4,3	0,15	2,68	81	30	48	112	4	0,55
30				300–600	26	4,9	0,10	1,86	105	74	32	77	3	0,39

* Exchangeable aluminium index. ** Phosphorus desorption index.

TABLE 2

Changes in ammonium and nitrate N contents of two midlands soils after liming

Soil No.	Soil depth (mm)	Lime applied tons/ha	pH after liming	Mineral N ($NH_4 - N + NO_3N$) produced (ppm)					
				after 2 weeks		after 4 weeks		after 6 weeks	
				$NH_4 - N$	$NO_3 - N$	$NH_4 - N$	$NO_3 - N$	$NH_4 - N$	$NO_3 - N$
11	0–150	0	5,6	2	30	2	40	2	44
		5	6,3	2	38	2	49	2	61
		10	6,7	3	44	2	65	2	71
12	150–300	0	5,6	3	29	0	33	1	33
		5	6,3	3	36	1	44	2	49
		10	7,0	10	40	1	55	3	62
13	300–450	0	5,6	3	18	2	21	2	24
		5	6,1	9	16	0	29	2	33
		10	6,8	11	14	4	33	2	39
14	0–150	0	4,5	11	15	11	32	11	46
		5	5,3	26	16	15	34	13	57
		10	6,3	42	10	31	49	13	90
15	150–300	0	4,7	14	8	11	18	15	26
		5	6,1	16	6	21	18	20	26
		10	6,9	34	4	40	6	28	35
16	300–450	0	4,7	28	4	28	6	34	10
		5	6,2	28	4	32	4	35	10
		10	7,4	38	4	40	2	46	6

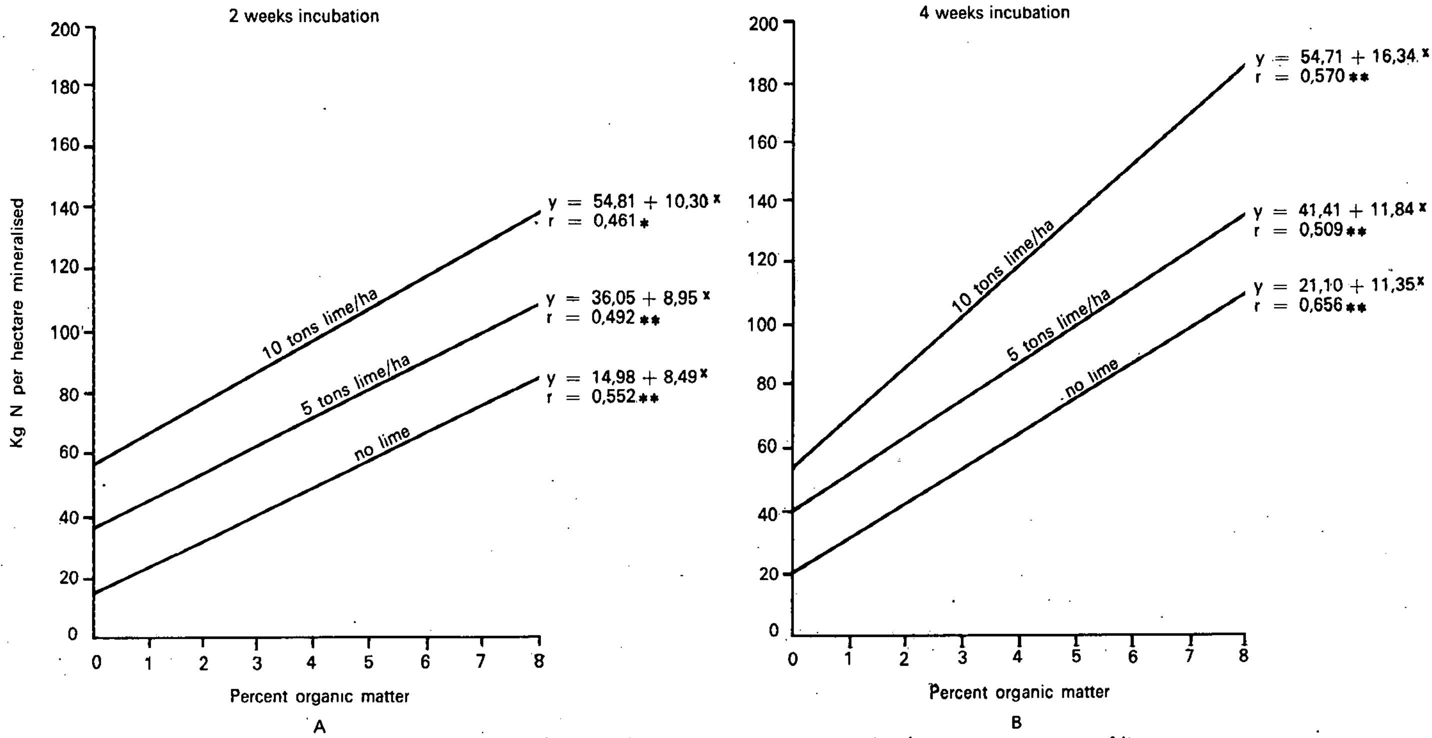

FIGURE 1 Relationship between N mineralised (kg/ha) and soil organic matter content, in absence or presence of lime.

mineralization continued at a steady but somewhat reduced rate after this (see Table 2).

Liming and nitrification

Table 2 provides comparisons of the changes in NH_4-N and NO_3-N content in two of the soil profiles, one moderately and the other strongly acid, after incubation for periods of two, four and six weeks. In the moderately acid profile, a substantial population of nitrifying bacteria was apparently present from the outset as no delays in nitrification were experienced to a depth of 450 mm, with or without lime. In the strongly acid profile, a partial delay in nitrification was evident in the top soil (0–150 mm) and immediate subsoil (150–300 mm), irrespective of change in soil pH following liming, which suggests a gradual build-up in the population of nitrifying bacteria with time. At the 300–450 mm soil depth, there was apparently no such build-up as, in the absence or presence of lime, little nitrification occurred during the entire six week incubation period.

Magnitude of N release

In most soils mineralization of soil N occurs almost exclusively in the 0–150 mm layer. However, soils from the Natal Midlands contain considerable amounts of organic matter well below this depth (see Table 1). Data obtained in this study indicate that there might be a considerable release of N in the subsoil which could be utilised by the cane plant especially where incorporating lime to a depth of 250–300 mm is practised.

Average organic matter contents of all soils used in this investigation from depths of 0–150 and 150–300 mm were found to be 4,7% and 3,6% respectively. These data were used to estimate from the graphs shown in Figure 1 the amounts of N that could be released due to mineralization in the field.

The results are shown in Table 3, together with total kg N per hectare released to a depth of 300 mm.

Incubation studies provide information about the potential mineralizing power of soils and, although the results are not strictly comparable with the mineralization process in the field, some interesting deductions can be made from the N release data that were obtained in this study. Assuming that the N mineralized during a two to four week incubation period is of the same order as that released under field conditions during a 24-month crop, then the data in Table 3 show that, even in the absence of lime, a substantial amount of N (90–136 kg) could become available to the crop. Lime at 5 tons per hectare, in comparison with no lime, increased potential N release by approximately 50% (146–181 kg N) while, at a rate of 10 tons lime per hectare, the release was almost doubled. This evaluation does not include the mineral N present in the soil before incubation. This ranged from 20–220 kg N per hectare in the 15 top soils studied, with an average of 65 kg N, and from 9–76 kg N in the subsoils, with an average of 31 kg N.

TABLE 3

Estimated release of N [kg/ha] to a depth of 300 mm from midlands soils incubated with and without lime

Soil depth (mm)	Average O.M.%	Lime applied tons/ha	kg N mineralized per/ha	
			after 2 weeks	after 4 weeks
0–150	4,7 *(15)	0 5 10	54 78 104	74 97 132
150–300	3,6 *(6)	0 5 10	46 68 92	62 84 114
0–300	Total	0 5 10	90 146 196	136 181 246

* Figures in brackets indicate number of determinations averaged for organic matter content.

Glasshouse trial

The effect of different rates of lime on leaf N content and uptake of N by sorghum grown on four Natal Midlands soils is shown in Table 4.

Apart from the yield response due to the removal of aluminium toxicity by liming on three of the soils, the leaf

TABLE 4

The effect of different rates of lime on sorghum leaf N content and plant uptake of N from four Natal Midlands soils

							Plant crop		First ratoon	
Location	Soil series	pH (H_2O)	OM %	Clay %	Al ppm	Lime tons/ha	*Leaf N %	*N uptake mg	*Leaf N %	*N uptake mg
Sweet Home	Farningham	4,5	4,95	27	87	0	2,20	55,0	1,15	30,0
						2,5	1,99	58,5	1,26	28,1
						5,0	2,66	63,4	1,26	32,7
						10,0	3,22	85,4	1,43	44,6
Harburg/Dalton corner	Farningham	4,2	5,57	18	155	0	2,51	45,8	1,22	14,6
						2,5	2,41	46,8	1,53	22,1
						5,0	2,64	48,8	1,47	28,5
						10,0	2,83	52,0	1,80	36,2
E. Nuss Field M	Kranskop	5,5	6,19	35	3	0	2,96	73,5	1,12	28,0
						2,5	3,13	64,9	1,37	27,0
						5,0	3,20	86,0	1,32	28,1
						10,0	3,47	92,0	1,49	46,3
Samela Drive	Cartref	4,4	7,22	17	162	0	3,09	93,8	1,58	51,4
						2,5	2,90	97,1	1,39	47,5
						5,0	3,13	102,6	1,49	49,3
						10,0	3,61	115,0	1,56	60,1

* Means of three replicates.

N content data show that lime applied at rates of 5 and 10 tons per hectare generally caused the release of considerable amounts of soil N. Had this not been the case the leaf N values might have been expected to decline with increasing yield, but generally these values increased quite substantially as the rate of lime increased, particularly in the plant crop, though a similar trend was apparent in the first ratoon crop. Of especial interest was the increased uptake of N in response to liming of the Kranskop series soil in which the aluminium content was negligible (3 ppm), the untreated soil having a pH value of 5,5.

Soil N mineralization following liming

The increase of N mineralization following liming of acid soils was recognised long ago and a comprehensive review of the subject was given by Harmsen and van Schreven[2]. The work of Frercks and Kosegarten[1], Mulder[7], and Thompson *et al*[8] indicates that the increase of organic matter decomposition, associated with increasing the pH of acid soils by liming, may be relatively short lived. Mulder[7] conducted a field experiment in which a strongly acid peat soil was limed to different pH values. Liming decreased the organic matter percentage in the soil and increased the availability of N to crops, but the effect disappeared after a period of five years. The pH effect appears to be due to an increase in susceptibility of a portion of the soil organic N to mineralization, but the mechanism of the effect has never been entirely explained.

Conclusions

Despite the fact that the increased mineralization of N which follows the application of lime to acid soils may only be of a temporary nature, the results of this study suggest that it could be a significant factor contributing to luxury uptake of N by cane grown in the Natal Midlands. If excessive uptake of N causes the sucrose content of sugarcane to be depressed, then it might also explain part of a low sucrose problem in the midlands. Even where no lime was applied the potential N mineralizing power of some midlands soils was shown to be considerable, and for this reason it may become necessary to adjust current N fertilizer recommendations for cane grown in this area. It seems probable that soils containing high levels of organic matter may mineralize most of the N requirement of a plant cane crop even in the absence of lime.

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