

NITRIFICATION IN RELATION TO pH—ITS IMPORTANCE IN FERTILIZER NITROGEN UTILIZATION BY CANE IN SOME SUGAR BELT SOILS*

By R. A. WOOD

Introduction

The importance to the cane plant of an adequate supply of inorganic nitrogen, during the first few months of growth, either in the ammonium (NH₄-N) or nitrate (NO₃-N) form, has been clearly demonstrated by recent work at the Experiment Station, both in the field² and the greenhouse⁹.

It is well known, however, that leaching losses of fertilizer nitrogen applied at the onset of growth, are able to deprive the plant of much of its N supply before this can be fully utilized, especially on sandy soils. These losses can be reduced where the applied N is retained by the soil in the NH₄-N form for a reasonable period before being wholly converted to NO₃-N which is subject to more pronounced leaching.

The conversion of NH₄-N to NO₃-N in the soil by bacteria of the genera Nitrosomonas and Nitrobacter is referred to as nitrification. Providing that conditions such as soil moisture, temperature, and oxygen supply are optimum for nitrate production, the other most important factor governing the rate of nitrification is soil pH. Robinson⁷ has pointed out that if pH is not limiting and NH₄-N is readily available, then it will be converted to NO₃-N quite rapidly. Where pH is too low for optimum growth of nitrifying bacteria, the population will be slow to develop and NO₃-N will only accumulate gradually.

Since the Sugar Belt contains a wide range of soils of variable pH, their rates of nitrification must influence the utilization by cane of added fertilizer N, particularly on sandy soils. With this in mind various aspects of nitrification in relation to pH for some of the main soil groups were investigated.

Delayed Nitrification During Soil Nitrogen Mineralisation

It had been previously demonstrated⁸ from a series of N mineralisation studies on a range of cane soils, that while ammonification usually proceeded rapidly some of them showed a marked delay in nitrification. Comparative figures giving the amount of NH₄-N and NO₃-N present before and after an eight week period of incubation are presented in Table I.

From this data it is clear that in the soils of low pH a partial or virtually complete delay in nitrification had occurred, being most noticeable on the highly acid Lytton and Cartref sands.

The Effect of Liming on Delayed Nitrification

To confirm that soil acidity was primarily responsible for the delay in nitrification just described, the following experiment was carried out.

Procedure. Duplicate air dry samples of six soil groups, of which four had previously shown delayed

TABLE I
Variable Nitrification during Mineralisation of Soil Nitrogen
(incubated at 35° C. and 60% W.H.C.)

Soil Group and Series	pH	INITIAL		AFTER 8 WEEKS	
		ppm.		ppm.	
		NH ₄ -N	NO ₃ -N	NH ₄ -N	NO ₃ -N
<i>No Delay</i>					
Alluvium	5.50	1.0	34.0	—	122.5
Dolerite — Rydalvale	5.90	18.0	4.0	—	117.5
T. schist — Logoza	5.80	10.0	7.5	—	89.5
L. Ecce — Milkwood	5.80	5.5	8.0	—	61.5
<i>Partial Delay</i>					
Recent Sand (red) — Lytton	4.80	3.5	3.5	75.5	6.0
T.M.S. (ord.) — Cartref	4.85	5.5	1.0	35.0	8.5
Granite — Glenrosa	5.10	4.5	2.5	39.5	24.5
M. Ecce — Windermere	5.20	5.5	2.5	44.0	16.5

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nitrification, were treated with limestone (CaCO_3) at the following rates; nil, 2, 4 and 8 tons per acre. The soils were moistened to 60 per cent water holding capacity and incubated for a period of four weeks at 35°C , after which the amounts of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ present were determined.

Results. The data obtained for the various soil groups is shown in Table II. This clearly indicates that once the pH has been raised sufficiently by the limestone to allow the nitrifying bacteria to proliferate, the changeover to $\text{NO}_3\text{-N}$ rapidly occurs, and that in some cases liming apparently gives rise to increased production of nitrate during mineralisation.

The Effect of Ammonium Nitrogen Carriers on Nitrification in Sandy Soils

Just as liming affects the rate of nitrification in acid soils by changing their pH, it can be expected that the

addition of various types of ammonium fertilizers will also influence pH and nitrification rate. This could be particularly important in sandy soils subject to marked leaching losses especially of $\text{NO}_3\text{-N}$ (see Table III). Soil pH and the fertilizers themselves might well be responsible for differential utilization of fertilizer N by cane on these soils, so affecting eventual yield.

Some evidence for the existence of this differential utilization was recently obtained from a nitrogen carrier trial, on a Cartref sand (pH 5.7), which was designed to test the efficiencies of four ammonium fertilizers among themselves and against a control with no nitrogen. The yields obtained from the plant cane crop harvested at 19 months are given in Table IV

TABLE II
The Effect of Liming (CaCO_3) on Nitrification
(ppm. N* present after four weeks incubation at 35°C . and 60% W.H.C.)

Soil Group and Series	pH	Initial		Control		2 Tons		4 Tons		8 Tons	
		ppm.		ppm.		ppm.		ppm.		ppm.	
		$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$
Dolerite — Rydalvale	5.90	20.5	4.0	—	116.0	—	112.5	—	108.0	—	124.0
T.M.S. (mist belt)—Inanda	5.50	8.5	11.5	2.5	49.0	1.0	50.5	1.0	57.0	2.5	60.5
Recent Sand (red)—Lytton	4.80	4.0	—	54.0	—	—	57.0	—	56.5	—	58.5
T.M.S. (ord.)—Cartref	4.85	6.0	1.0	32.0	—	37.0	5.0	—	37.5	12.0	30.0
Granite — Glenrosa	5.10	7.0	—	54.0	8.0	11.0	52.0	—	65.0	—	64.0
M. Ecce — Windermere	5.20	7.5	2.0	36.0	15.5	—	69.5	—	92.0	—	84.0

* Mean of duplicate determinations.

TABLE III
Relative Leaching Losses of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ from Two Sandy Soils
(2 in. water applied to pots one week after N fertilization)

Soil Series	Treatment (1,500 g. soil)	mg. $\text{NH}_4\text{-N}^*$ Leached	mg. $\text{NO}_3\text{-N}^*$ Leached	Per Cent N Leached
Lytton sand (pH 4.60)	150 mg. N as $(\text{NH}_4)_2\text{SO}_4$	55.5	7.5	42.0
	150 mg. N as NaNO_3	4.5	100.5	70.0
Clansthal sand (pH 6.15)	150 mg. N as $(\text{NH}_4)_2\text{SO}_4$	64.0	25.0	59.0
	150 mg. N as NaNO_3	2.5	112.5	76.5

* Mean of duplicate pots.

TABLE IV
Efficiency of Ammonium Fertilizers on a Cartref Sand
(120 lb. N/acre)

Treatment	T.C.A.*	T.S.A.†
1. Control — no nitrogen	29.6	4.63
2. Ammonium sulphate	41.4	6.46
3. Urea	40.7	6.41
4. Ammonium nitrate	37.0	5.64
5. Limestone ammonium nitrate	34.9	5.47
S.E. (treatment mean)	1.3	0.22
L.S.D. (0.05)	4.0	0.67
(0.01)	5.5	0.94

*T.C.A.= tons cane per acre. †T.S.A.=tons sucrose per acre

From these results it is apparent that while all the N carriers significantly outyielded control, both for tons cane per acre (T.C.A.), and tons sucrose per acre (T.S.A.), the ammonium fertilizer treatments differed significantly amongst themselves. In an attempt to try and explain these differences a laboratory experiment was designed to follow the nitrification pattern occurring in sandy soils of variable pH, after addition to them of the ammonium nitrogen carriers used in the above field trial.

Procedure. 800 g. air dry samples of three series of sands widespread in the Sugar Belt, namely Lytton (pH 4.60), Cartref (pH 4.80) and Clansthal (pH 6.15), were subject to the following treatments:

- (1) Control — no fertilizer.
- (2) 80 mg. N as $(NH_4)_2SO_4$ — 100 ppm.
- (3) 80 mg. N as urea — 100 ppm.
- (4) 80 mg. N as NH_4NO_3 — 100 ppm.
- (5) 80 mg. N as L.A.N. (limestone NH_4NO_3) — 100 ppm.
- (6) 80 mg. N as NH_4NO_3 — 100 ppm. + 4 tons $CaCO_3$ per acre.

The soils were moistened to 30 per cent water holding capacity with solutions of the above fertilizers and incubated at 30° C. After periods of 0, 7, 14, 21 and 28 days duplicate samples of all treatments were withdrawn and pH, NH_4-N and NO_3-N determinations carried out.

Results. Changes in pH, and amounts of NH_4-N and NO_3-N over four weeks following the various fertilizer additions are presented in Figure 1. The main effects of the different treatments are now briefly detailed.

Control. While nitrification was partially delayed during the first two weeks in the Lytton sand little delay was noted in the other two control soils.

$(NH_4)_2SO_4$. Apparently the acidifying action of this fertilizer coupled with the highly acid Lytton sand effectively prevented nitrification from occurring even after four weeks, while on the Cartref sand slow conversion to NO_3-N commenced after the first week. The slightly acid Clansthal sand started nitrifying immediately, only 10 ppm. NH_4-N remaining after 28 days.

Urea. The initial rise in pH due to the hydrolysis of the urea was obviously responsible for providing a more favourable environment for nitrification in both the acid sands. As a result over 30 ppm. and 60 ppm. NH_4-N respectively had been nitrified in the Lytton and Cartref soils after four weeks. Nitrification was rapid in the Clansthal sand being complete within the first two weeks of incubation.

NH_4NO_3 . Addition of this fertilizer also had an acidifying effect and in consequence patterns of NH_4-N changeover in the three soils, were closely similar to those obtained when $(NH_4)_2SO_4$ was applied.

L.A.N. The presence of limestone with the NH_4NO_3 , raised the pH sufficiently on both the strongly acid sands to bring about an increase in their rate of nitrification, compared to that when NH_4NO_3 only was used. Despite this, conversion to NO_3-N in the Lytton sand was still very slow.

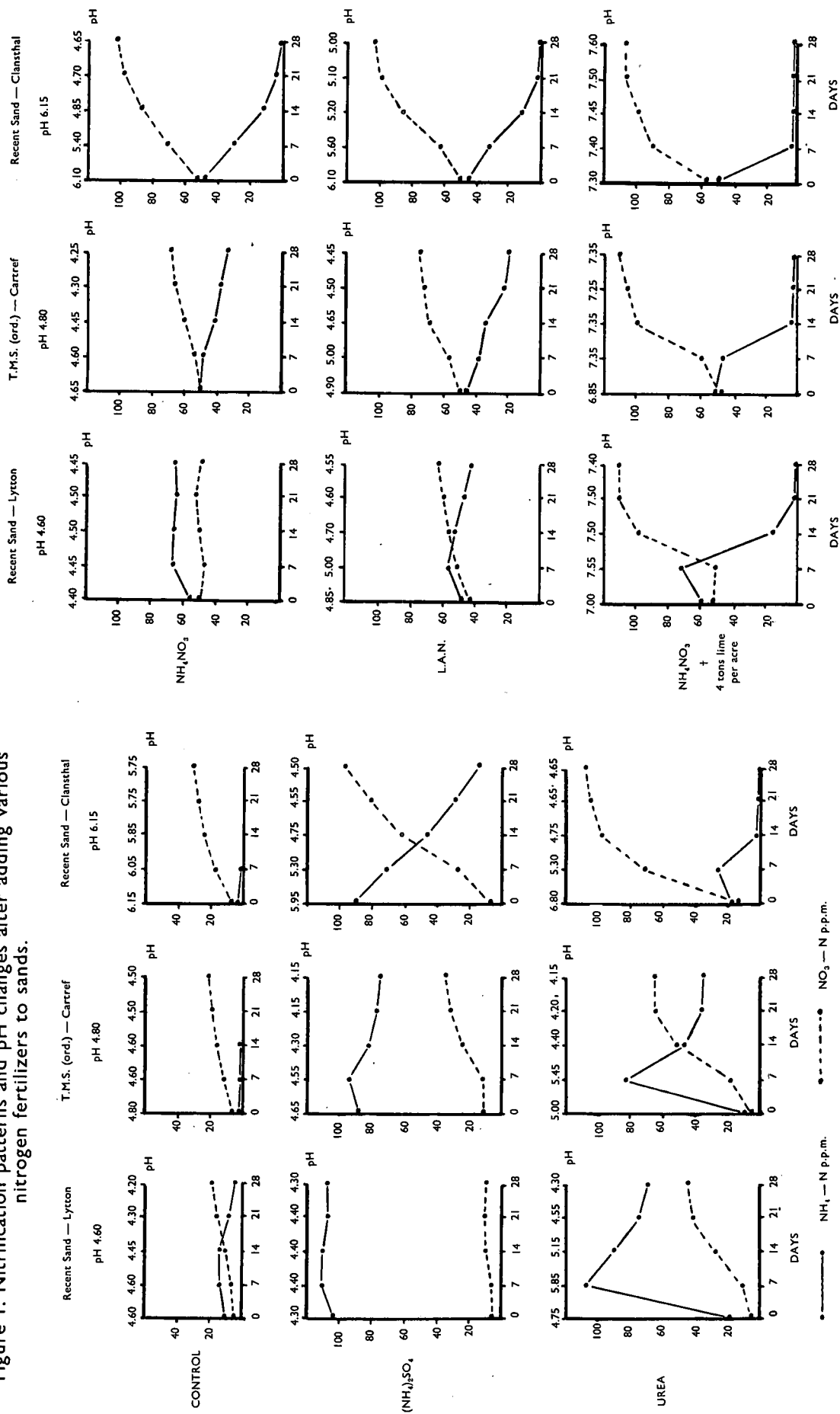
$NH_4NO_3 + 4$ tons $CaCO_3$ per acre. The effect of this treatment on the pH of all soils is clearly seen and nitrification was greatly accelerated being complete within 21, 14 and 7 days for the Lytton, Cartref and Clansthal sands respectively.

The pH data reveals that after an initial reduction in acidity following the application of certain of the treatments, acidity gradually increased as nitrification proceeded except where the equivalent of 4 tons of limestone was added. This is due to the release of hydrogen during the process so that these weakly buffered sands eventually tend to be more acid than they were before ammonium fertilizer was applied.

Discussion and Conclusions

Results confirming those cited above have been obtained by workers elsewhere. Munk⁶ found that nitrification was considerably better in an acid soil (pH 4.40), with L.A.N. or urea than with $(NH_4)_2SO_4$, and Dijkshoorn⁵ showed in pot experiments with $(NH_4)_2SO_4$, that nitrification was complete within 21 days at pH 7.0, considerably retarded at pH 5.3, and inhibited at pH 4.3. Ayres and Humbert¹ studied nitrification patterns of two ammonium fertilizers in Hawaiian soils in relation to pH, while Botha³ showed that urea nitrified more readily than $(NH_4)_2SO_4$ when applied to three soils of widely differing pH and texture. Broadbent *et al.*⁴ suggested that inhibition of nitrification might result from the presence of high concentrations of free ammonia in the soil at low pH exerting selective inhibition on nitrate forming bacteria. This may partly explain the complete absence of nitrification in the highly acid Lytton sand when $(NH_4)_2SO_4$ and NH_4NO_3 were added. At low NH_4-N concentrations (see control treatment) a population of nitrifiers is gradually able to develop.

Figure 1. Nitrification patterns and pH changes after adding various nitrogen fertilizers to sands.



Fertilizer N applied at rate 100 p.p.m. (200 lb. N/acre)

It would appear that in soils of pH 5.2 or below considerable delays in nitrification are likely to occur. Apart from the pH effect of the soil as such, the particular ammonium nitrogen carrier applied can apparently influence to a greater or lesser extent the rate of nitrification in the soil. This may well be beneficial from the aspect of N utilization by the cane plant, particularly in the case of acid sandy soils, and provides an explanation for the yield differences between treatments on the nitrogen carrier trial previously mentioned.

The $\text{NH}_4\text{-N}$ fraction from both the $(\text{NH}_4)_2\text{SO}_4$ and urea was probably available to the developing cane for a longer period than that from NH_4NO_3 or L.A.N., as double the amount was present initially. The $\text{NO}_3\text{-N}$ fraction of the two latter fertilizers would have been prone to immediate leaching following rain and could easily have been lost before much of it was utilized, thus leaving the plant with only half the original quantity of N applied. Enhanced nitrification in the case of L.A.N. due to the presence of limestone would increase the possibility of even greater leaching losses from this fertilizer than from NH_4NO_3 alone.

Therefore laboratory and field data so far obtained indicates that the application of L.A.N. or NH_4NO_3 to acid sandy soils may not always be completely effective, and that under these conditions the use of urea, or $(\text{NH}_4)_2\text{SO}_4$ on slightly acid sands, would seem to be preferable. If the plant is able to fully utilize $\text{NO}_3\text{-N}$ immediately it is applied, and subsequent leaching losses are slight, then yield reductions from these N carriers would probably be insignificant. Also the possibility that part of the leached $\text{NO}_3\text{-N}$ may be taken up at a later stage of development by cane roots penetrating to depth on the sands should not be discounted. Seasonal effects and stage of plant development therefore play an extremely important part in deciding whether or not maximum use will be made of the fertilizer N applied.

Summary

During N mineralisation studies on several Sugar Belt soils, delays in nitrification were noted where pH was 5.2 or below, being particularly marked in the Lytton and Cartref series of sands.

Limed at the rate of 2, 4 and 8 tons per acre, and incubated for four weeks, soils previously showing delayed nitrification, nitrified rapidly, the decrease in acidity due to liming providing an environment favourable to the development of nitrifying bacteria.

Patterns of nitrification were examined during a four-week period of incubation, after several ammonium nitrogen carriers had been added to three sandy soils of variable pH. Apart from the soil pH effect as such, it was shown that a specific carrier can markedly influence the rate of nitrification in any particular soil, which in turn may accelerate or retard susceptibility to leaching and subsequently affect plant utilization of applied N.

These results are discussed with regard to the manner in which they affect choice of N fertilizers for cane in acid sandy soils.

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Mr. Wardle: Does not Mr. Wood think there is a case for split applications of nitrogen on sand?

Mr. R. A. Wood: The data we have is not such as to give a clear answer to this. All we know definitely is that cane requires most of its nitrogen during the early stages of growth.

Professor Orchard: One should be careful not to generalise from the results of a single experiment. The pattern of response to nitrates in the Cartref soil shown in Table IV need not necessarily be the same for other soils.

Mr. R. A. Wood: I agree, and the results of the Cartref trial have not been recommended for general guidance. I was careful to point out that application of nitrates may not always be completely effective in acid sandy soils.

Mr. du Toit: I agree with Professor Orchard that we must not generalise on the results from one experiment but we should certainly not ignore them.

Mr. Wyatt: In the Cartref experiment the interesting point is that the application of nitrogen was split—60 lb. in March 1963 and another 60 lb. the following spring.

Mr. Odendaal: I note that the Cartref sand used in the nitrogen carrier trial had a pH of 5.7, while that used in the Laboratory experiment was only 4.8. Therefore nitrification patterns occurring in the

field would be different to those found in the laboratory.

Mr. R. A. Wood: This is true, in fact the chances of more rapid nitrification taking place in the field trial and possibly enhancing leaching losses would seem likely.

Mr. Sherrard: Is there any danger of loss of nitrogen if urea is applied on top of the soil in dry weather as at present?

Mr. R. A. Wood: If it became wet, from dew for instance, there could be considerable loss due to volatilisation of ammonia, in warm sunny conditions.

Mr. Gilfillan: Surely in the case Mr. Wyatt mentioned nitrification is not so important as it was a split application.

Mr. Wyatt: The experiment is being repeated; not only on the same soil but also in others.

Mr. King: Does cane take up nitrogen in the ammonium form?

Mr. R. A. Wood: Yes we have been able to demonstrate this by successfully growing cane in soils to which an organic compound called N-Serve has been added, that is capable of inhibiting nitrification for several weeks.