A PRELIMINARY INVESTIGATION INTO THE BEHAVIOUR OF SOLUBLE NITROGEN FERTILIZERS ON MULCHED AND UNMULCHED SOILS IN COASTAL NATAL

By R. R. MAUD

Summary

Nitrogenous fertilizers in the form of sulphate of ammonia, urea and nitrate of soda were applied to four bare and mulched soils in coastal Natal at the rate of 100 lbs. N per acre. Two of the soils were of a clayey texture, the other two being sandy.

It was found that there was a very rapid loss of the applied fertilizer from the sandy soils both on the bare soil and under mulch. In the clayey soils this process was not so rapid. Nitrification of the applied ammoniacal nitrogen was fairly rapid in the clayey soils and extremely rapid in the sandy soils. There was no ammonification of applied nitrate fertilizer in any of the soils.

The rapid loss of applied nitrogenous fertilizer is attributed to downward movement of the nitrate ion in the soil profile to a depth of at least six feet in some of the soils, although microbiological activity also very likely contributes significantly to the loss from the surface layers of the soil.

This loss of applied nitrogenous fertilizer therefore may considerably reduce the effectiveness of fertilizer applications. In addition the application of the fertilizers on to a mulch layer proved less effective than those applied to the bare soil.

Introduction

Nitrogen is generally considered to be the most important single nutrient necessary for the successful growth of sugar cane, which is cultivated on an industrial basis in coastal Natal and adjoining areas.

Although numerous fertilizer trials have been undertaken in this region in the past, little work has as yet been carried out on the fate of the applied nitrogenous fertilizer, a subject that may have considerable economic implications.

The literature on nitrogen fertilization and the behaviour of the various forms of nitrogen in the soil with respect to microbiological activity, soil pH, soil temperature and soil moisture is very extensive. Some of the more recent publications concerning nitrogenous fertilizers and the soil include Martin, Buchner and Caster (1943), Eno and Blue (1957), Tyler, Broadbent and Hill (1959), and Ishizawa and Matsuguchi (1962). Among the much more extensive literature concerning the behaviour of nitrogen in general in the soil may be cited Theron (1951, 1963) and Birch (1959, 1960) whose work is specifically related to African conditions.

The present study of the fate of applied nitrogenous fertilizer has been entirely chemical, although the author is fully aware of the enormous importance of the microbiological and related processes that are involved in any study concerning soil nitrogen.

Method of Study

Of the numerous widely differing soil series occurring in the coastal region of Natal, four were selected as giving the widest possible range in physical and chemical characteristics. These were:

(i) Rydal Vale series — Black clay loam derived from dolerite pH 6.2. (Typic Hapludoll, 5.520, U.S.D.A. 7th Approximation (1960).)

(ii) Inanda series — Reddish brown humic clay loam derived from plateau Table Mountain sandstone pH 4.9. (Udox, 9.310.)

(iii) Cartref series — Grey sandy loam derived from Table Mountain sandstone pH 5.6. (Typic Quartzopsamment 1.210.)

(iv) Clansthal series — Reddish brown sand derived from Recent Sands pH 6.5. (Typic Quartzopsamment 1.210.)

Thus two soils (i) and (ii) were of clayey texture although their clay mineralogy differed considerably, (i) — montmorillonite and kaolinite, (ii) — kaolinite and iron and aluminium oxides, the other two (iii) and (iv) being sandy, the small clay fraction being in both cases kaolinitic-illitic.

In view of prevailing practices in the sugar industry of Natal, whereby a mulch layer of cane trash is often left on the field after harvest and which may cause impedence to the subsequent application of fertilizer top-dressings, the study included consideration of both bare and mulched soils.

Growing of a sugar cane crop was purposely excluded from the experiment as constituting too great a complicating factor in a preliminary study.

The plots established on these soils were 1/200 acre in extent each consisting of six plots three of which were mulched with a normal trash blanket. Applications of sulphate of ammonia, urea and nitrate of soda, respectively, in solution were made to both bare and mulched soils at the rate of 100 lbs. Nitrogen per acre. In the case of the mulched plots the fertilizers were applied to the top of the trash blanket.

Experimental

Soil samples were taken initially both before, and after the application of the fertilizer at varying intervals, from the normal plough depth (9 inches) of each plot. Ten samples per plot were taken and combined for the immediate analysis of Ammonia and Nitrate nitrogen by the method of Olsen and Richardson (Piper, 1950). Subsequently samples were taken at intervals down to 6 feet beneath each plot and analysed by the same method.

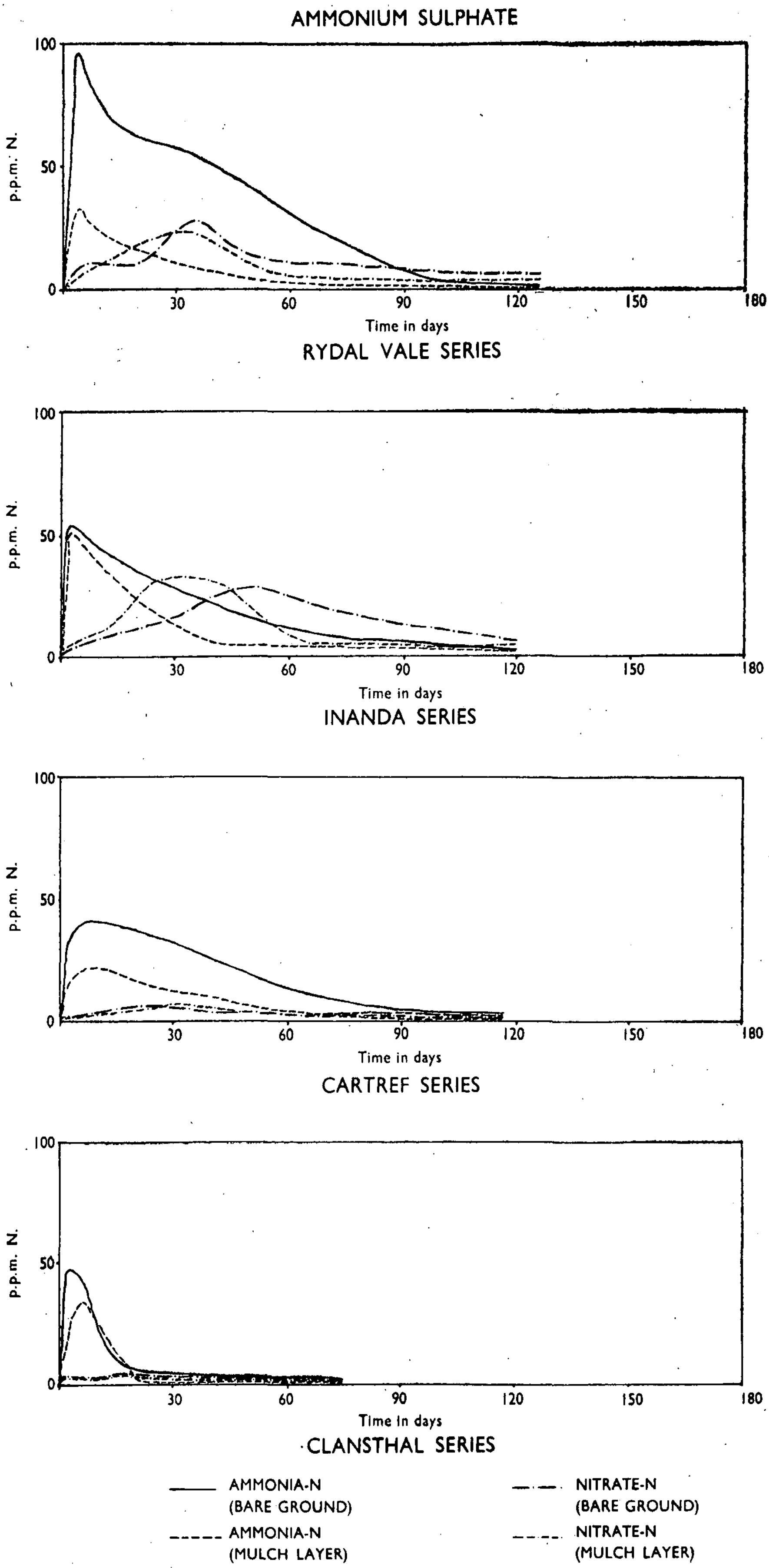
AMMONIUM SULPHATE
100
50
0
p.p.m. N.
30
60
90
120
150
180
Time in days
RYDAL VALE SERIES
INANDA SERIES
CARTREF SERIES
CLANSTHAL SERIES
AMMONIA-N (BARE GROUND)
AMMONIA-N (MULCH LAYER)
NITRATE-N (BARE GROUND)
NITRATE-N (MULCH LAYER)

FIG. I

Results

(a) *Behaviour of Applied Nitrogen in Plough Depth of Soil*

A. Sulphate of Ammonia (Fig. 1)

(i) Ammonia (NH_4) nitrogen.

In all cases the ammonia content of the bare soils was found to be higher than that of the mulched (trashed) soils. This was especially marked in the case of the clayey Rydal Vale series. On all soils there began a steady decline in the ammonia content of the soil both on bare ground and under mulch, very shortly after the application of the fertilizer. After some sixty days the Rydal Vale series showed an almost complete depletion under mulch, but a reasonable amount (25 ppm. N.) under bare ground conditions. In the case of the sandy Clansthal series, the ammonia content of the soil under mulch reverted to its original level before application within twenty days. The ammonia content of the bare ground, however, took somewhat longer for depletion.

It would therefore appear that the retention of ammonia nitrogen is related to the clay content of the soil.

(ii) Nitrate (NO_3) Nitrogen

The nitrate content of the soil under mulch behaved in a similar manner to that of the bare ground, except in the case of the Inanda series, where the amount of nitrate in the soil under mulch tended to be rather more than that in the bare soil initially.

The nitrate content of both the bare and mulched soils attained its maximum value thirty-five to forty days after application in the case of the more clayey Inanda and Rydal Vale series, but in the case of the sandy Cartref and Clansthal series there was hardly any accumulation of nitrate nitrogen, due possibly to leaching to lower levels in the soil.

Whereas in the case of the heavier Rydal Vale and Inanda series the build-up of nitrate content eventually exceeded the ammonia content under mulch (and also the ammonia content of the bare ground in the case of the Inanda series), in the sandier soils, the nitrate never surpassed the ammonium content of the soil.

In general, the build-up of both ammonia and nitrate nitrogen on both bare ground and under mulch was much less in the case of the sandy than was the case in the clayey soils, although all soils received the same unit value of nitrogen.

While the nitrogen content of the bare Rydal Vale series soil increased by the full amount applied, in the case of the Inanda series the increase was only 60 per cent. of the amount of nitrogen applied. In the case of the two sandy soils it was only 45 per cent.

Under mulch, because of the blanket hindering fertilizer reaching the soil, the total applied nitrogen content of the soil was lower and less regular.

The inability to recover the total amount of applied nitrogen in the sandy soils, even within a few days of application, indicates the extreme rapidity with which depletion takes place, due either to downward movement through the soil or microbiological activity or a combination of both these factors.

Microbiological activity is very probably largely responsible for the lack of applied nitrogen reaching the soil under the mulched plots.

B, Urea (Fig. 2)

(i) Ammonia (NH_4) Nitrogen

The most significant feature of this form of nitrogen application was the fact that even immediately after the application of similar amounts of nitrogen, the ammonia content of both bare and mulched urea plots never achieved the levels attained by the sulphate of ammonia plots. To some extent this may be partly attributable to microbiological activity or volatilisation. An exception, however, was the acid, humic Inanda series. In all cases the ammonia content of the bare ground soils was higher than that of the mulched soils.

The ammonia nitrogen level in the soil under mulch in all cases reverted to its initial content within twenty to thirty days. The ammonia content of the bare ground soils, however, except in the case of the Clansthal series, persisted for a considerably longer period.

(ii) Nitrate (NO_3) Nitrogen

In contrast to the lower ammonia values in the urea plots as compared with the sulphate of ammonia plots, the nitrate nitrogen content of the urea plots equalled and sometimes exceeded the nitrate content of the sulphate of ammonia plots.

There was essentially no difference in the behaviour of the nitrate nitrogen contents of both bare and mulched soils in all cases. In the clayey Rydal Vale and Inanda series, the build-up of nitrate continued for some forty days after application. In the sandy soils, the build-up attained a maximum in fifteen to twenty-five days.

As in the case of the sulphate of ammonia treatments, the nitrate content of both bare and mulched plots eventually exceeded the ammonia content of the clayey soils. In the sandier soils also, there was some tendency in this direction.

Of the total amount of nitrogen applied, the maximum attained in soils under bare ground was some forty, eighty, thirty and twenty per cent, respectively, for the Rydal Vale, Inanda, Cartref and Clansthal series. Under mulched soils the maximum percentage of applied nitrogen attained was some thirty, sixty, twenty and fifteen per cent, respectively.

C. Nitrate of Soda

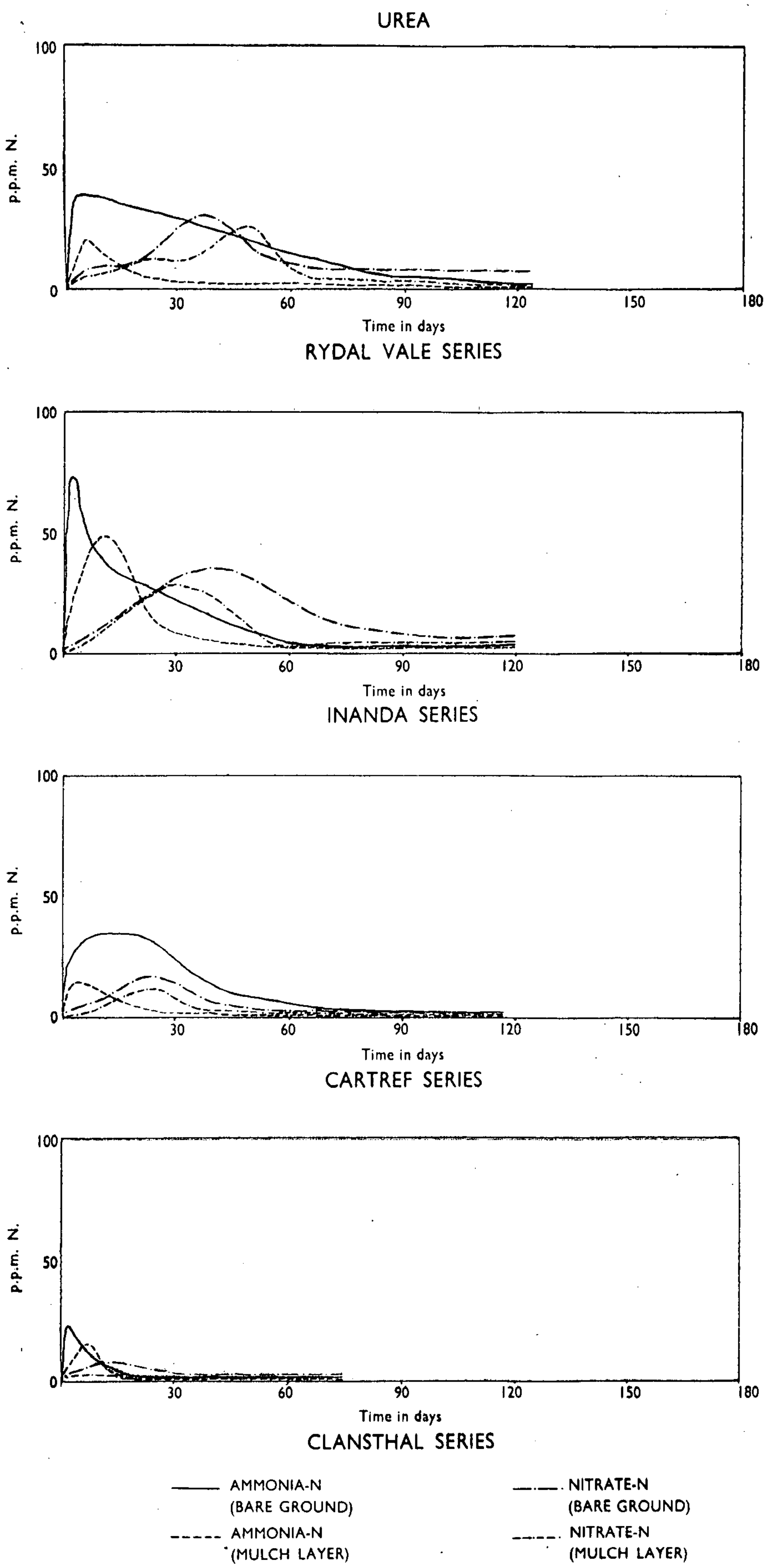
UREA
p.p.m. N.
100
50
0
30
60
90
120
150
180
Time in days
RYDAL VALE SERIES
INANDA SERIES
CARTREF SERIES
CLANSTHAL SERIES
AMMONIA-N (BARE GROUND)
AMMONIA-N (MULCH LAYER)
NITRATE-N (BARE GROUND)
NITRATE-N (MULCH LAYER)

FIG. 2

(i) Ammonia (NH_4) Nitrogen

In all cases, both on bare ground and under mulch, there was no build-up of ammonia nitrogen and ammonia contents remained at their initial values. Thus there has been no ammonification of the applied nitrate.

(ii) Nitrate (NO_3) Nitrogen

Nitrate of soda was included in the experiment to ascertain if there was any increase in the time that the applied nitrogen was available in the soil when applied as the ammonia ion which has to be nitrified as contrasted to the application of the nitrate ion alone. It was found that in general, the nitrogen applied as nitrate did not persist as long in the soil as that applied in the ammoniacal form.

The amount of nitrate nitrogen was in all cases lower in mulched than in bare soils. After application of the fertilizer, the steady decline of the nitrate content commenced immediately and proceeded at a steady rate in both bare and mulched soils.

In the clayey Rydal Vale and Inanda series, the decline in nitrate content was complete in some sixty days, whilst in the sandy Cartref series this decline was completed in thirty-five days. In the Clansthal series, however, the nitrate content returned to its original level in no less than fourteen days.

Of the total amount of nitrogen applied to the bare soils, the maximum amount attained in the soils was ninety per cent in the case of the Rydal Vale series, and sixty, forty and thirty-five per cent for the Inanda, Cartref and Clansthal series, respectively. The maximum amounts attained under mulch were some eighty, fifty, thirty and thirty per cent, respectively, for the series.

(b) Downward Distribution of Applied Nitrogen in Soil

Because of the rapid loss of applied fertilizer nitrogen from the surface layer of the soil (this being extremely marked in the sandy soils), the soils beneath the plots were sampled at varying depths to six feet to ascertain if indeed downward movement rather than microbiological activity was responsible for the removal of the nitrogen from the surface layer. Unfertilized adjacent control plots were also sampled.

The ammonia and nitrate nitrogen contents of the soil profiles two-and-a-half and five months after application of the fertilizer are given in Figs. 4 and 5.

These results indicate that whilst appreciable quantities of ammonium ions were retained in the surface layer, downward movements take place only in the form of the nitrate ion. This is in agreement with findings elsewhere, Krantz, Ohlrogge and Scarceth (1943), Larsen and Kohnke (1947), and Bates and Tisdale (1957). Thus for nitrogen in the ammoniacal form to be lost from the surface layers by downward leaching it has first to be nitrified by microbiological activity. The progress of this conversion with time may be seen by the comparison of the two figures.

There was a much more rapid loss of nitrogen in the sandier soils, most of the applied nitrogen being lost completely from the profile within five months. Movement of the nitrate ion to a depth of six feet was found in the sandier soils within two and a half months whilst in the case of one clayey soil (the Inanda series) the nitrate ion had moved to a depth of six feet in five months. The limit of downward movement in the Rydal Vale series, however, appeared to be about three feet.

The downward movement of applied nitrogenous fertilizers in the soils of coastal Natal, together with losses associated with microbiological activity, therefore, may considerably reduce the effectiveness of fertilizer applications.

Conclusions

From this preliminary series of experiments it is evident that there is a fairly rapid loss of applied soluble nitrogenous fertilizers from the surface layers of the soil especially in sandy soils in which downward movement may extent to six feet. The effect of microbiological activity in these soils, however, probably also makes a significant contribution to the loss.

The movement of nitrogen takes place only in the nitrate form and fertilizers that contain the ammoniacal form of nitrogen persist somewhat longer in the surface layers of the clayey soils than do fertilizers containing the nitrate form as microbiological nitrification has first to take place. Conversion to the nitrate form is very rapid in the sandy soils. There is no ammonification of fertilizer applied as the nitrate.

As might be expected, fertilizers applied to the surface of a mulch layer appear to be less effective than those applied to the bare soil. This no doubt results from mechanical impedance and microbiological activity with some possible volatilisation in the case of urea.

Bibliography

Bates, T. E. and Tisdale, S. L. (1957). The movement of nitrate nitrogen through columns of coarse textured soil materials. Soil Sci. Soc. Am. Proc., 21, 525-528.

Birch, H. F. (1959). Further observations on humus decomposition and nitrification. Plant and Soil, 11, 262-286.

Birch, H. F. (1960). Nitrification in soils after different periods of dryness. Plant and Soil, 12, 81-96.

Eno, C. F. and Blue, W. G. (1957). The comparative rate of nitrification of anhydrous ammonia, urea and ammonium sulphate in sandy soils. Soil Sci. Soc. Am. Proc., 21, 392.

Ishizawa, S. and Matsuguchi, T. (1962). Studies on the nitrifif cation in soil with special reference to the population o- nitrifiers. Parts 1 and 2. Soil Sci. and Plant Nutrition, 8, 240-252.

Krantz, B. A., Ohlrogge, A. J. and Scarceth, G. D. (1943). Movement of nitrogen in soils. Soil Sci. Soc. Am. Proc., 8, 189-195.

Larsen, J. E. and Kohnke, H. (1947). Relative merits of fall and spring applied nitrogen fertilizer. Soil Sci. Soc. Am. Proc., 11, 378-383.

Martin, W. P., Buchner, T. F. and Caster, A. B. (1943). Threshold pH value for the nitrification of ammonia in desert soils. Soil Sci. Soc. Am. Proc., 7, 223-228.

Piper, C. S. (1950). Soil and Plant Analysis, 3rd Ed. University of Adelaide, Adelaide, 202-212.

Theron, J. J. (1951). The influence of plants on the mineralisation of nitrogen and the maintenance of organic matter in the soil. J. Agr. Sci., 41, 289-296.

Theron, J. J. (1963). The mineralisation of nitrogen in soils under grass. S. Afr. J. Agr. Sci., 6, 155-164.

Tyler, K. B., Broadbent, F. E. and Hill, G. N. (1959). Low temperature effects on nitrification in four California soils. Soil Sci., 87, 123-129.

Soil Survey Staff (1960). Soil Classification — a comprehensive system. 7th Approximation. U.S. Dep. Agr., Soil Conservation Service, Washington, D.C.

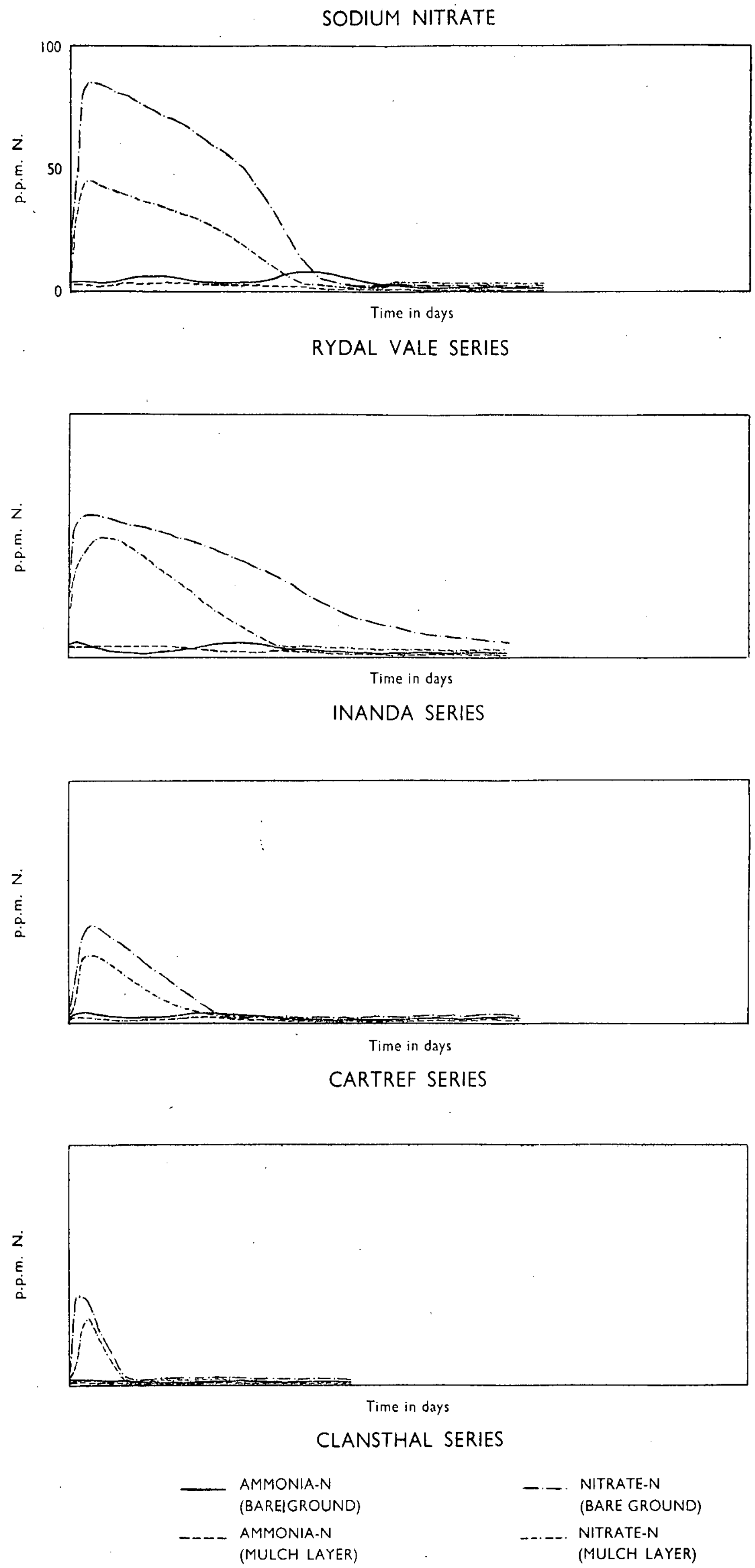
SODIUM NITRATE
100
50
0
p.p.m. N.
Time in days
RYDAL VALE SERIES
p.p.m. N.
Time in days
INANDA SERIES
p.p.m. N.
Time in days
CARTREF SERIES
p.p.m. N.
Time in days
CLANSTHAL SERIES
AMMONIA-N (BARE GROUND)
NITRATE-N (BARE GROUND)
AMMONIA-N (MULCH LAYER)
NITRATE-N (MULCH LAYER)

FIG. 3

DISTRIBUTION OF NH_4 & NO_3 IN SOIL 2½ MONTHS AFTER FERTILIZER APPLICATION

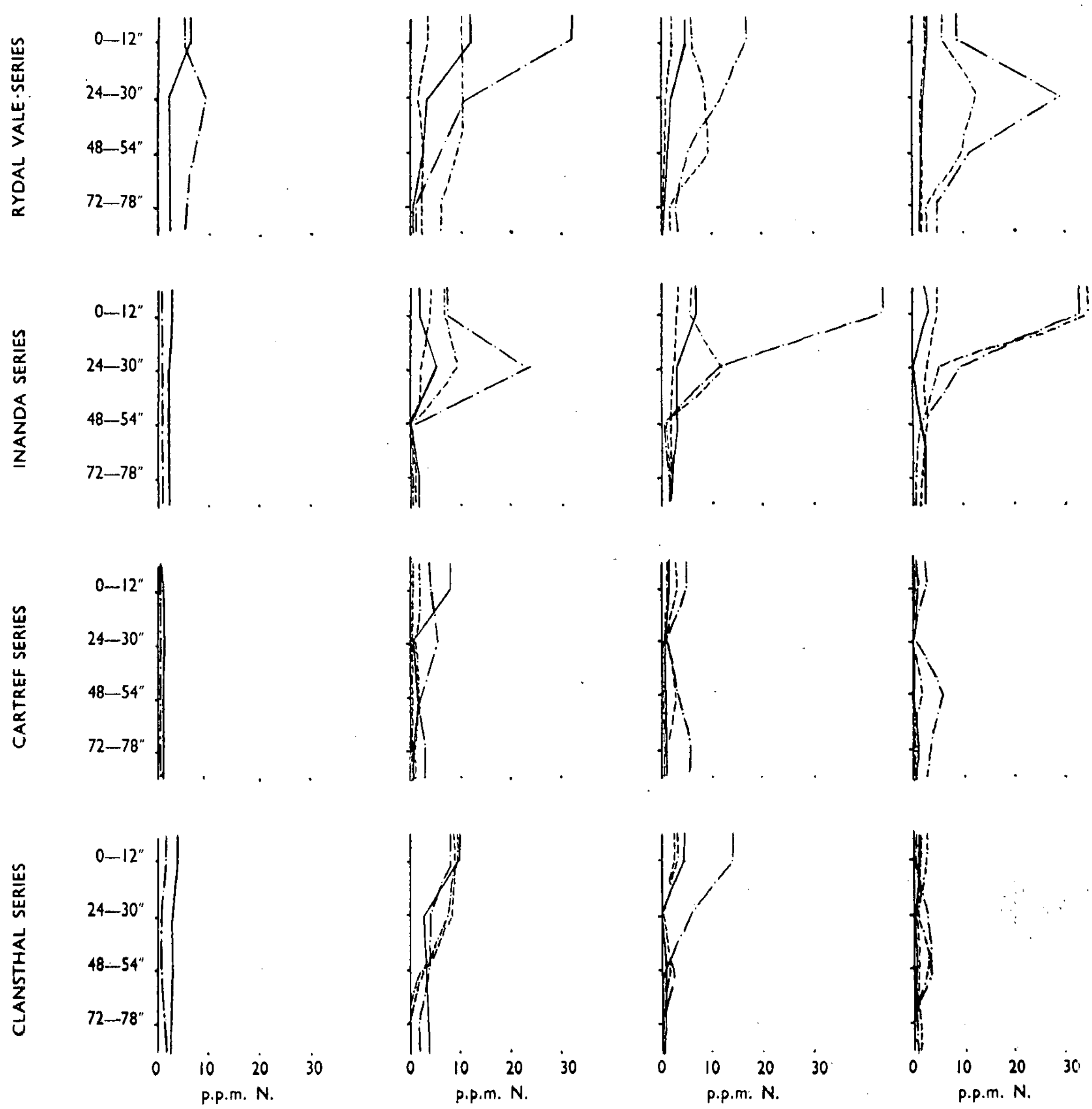

FIG. 4

DISTRIBUTION OF NH_4 & NO_3 IN SOIL 5 MONTHS AFTER FERTILIZER APPLICATION

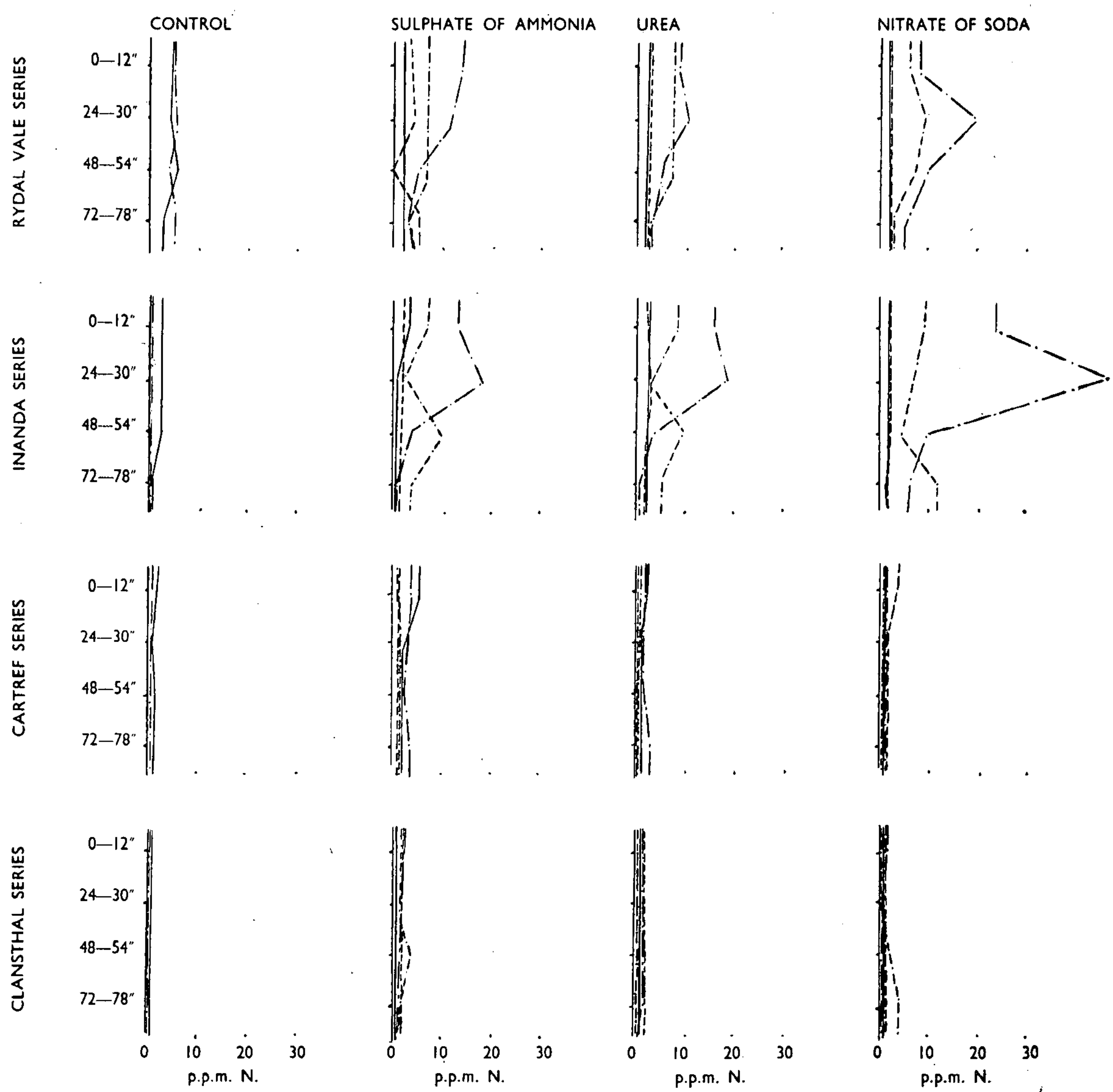

FIG. 5

Mr. Thompson: Regarding the results obtained by Dr. Maud, and his statement that the application of fertilizers to mulched soils is less effective than when applied to bare soils, I would like to place on record that over nine crops, where we have studied yields from trash plots and bare plots, we have had a higher efficiency of nitrogen usage to the extent of about 3 tons of cane per acre per crop. This is quite the reverse to what one would expect from Dr. Maud's results.

Dr. Dick (in the chair): It appears that the optimum conditions for the production of this mineral nitrogen are not exactly the optimum conditions for the actual growth of cane. It is one of those situations where you have two opposing factors.

Mr. Wood: When we watered these soils before incubating them, they were in fact watered to approximately field capacity, and maximum mineralisation occurs at that moisture content. I would have said that field capacity was the ideal moisture content also for the growth of cane, but you do not get large-scale mineralisation occurring unless the soil first dries out considerably. If it is re-wetted to field capacity then you should get maximum mineralisation.

Mr. Glover: How real is the estimate of an acre 6-inch mineralisation in this part of the world? It is certainly very real in Kenya. Is it equivalently so here? You have had experience of both.

Mr. Wood: Yes, I would think so, I would say it is exactly the same here.

Dr. Sumner: I wish to mention some results on work which was done with phosphate at the Soils Science Laboratory, Oxford. This bears out what Mr. Wood has said here about mineralisation of nitrogen as the same basic idea applies to the mineralisation of phosphate. After a considerable flush a lot of soluble phosphate appears in the soil.

Mr. du Toit: Nitrogen is a difficult subject. There are some puzzling features in these two papers. Dr. Sumner referred to the high organic matter in a particular sample and I cannot agree with Mr. Wood's reply that one sample came from soil under cane and the other from bare soil. The samples must have come from entirely different areas to explain such a big difference.

In Table I of Mr. Wood's paper fifteen experiments are referred to. But there were other nitrogen experiments with plant and ratoon cane where the responses were very similar for both, particularly in Table Mountain Sandstone. It has been said that Red Sand does not respond well to nitrogen but the Grey Sand must be considered even worse in this respect. It is low in both carbon and organic matter. However, we have seen that where there is a good layer of trash there is an initial response to nitrogen which then fades — as if there is a supply of nitrogen from elsewhere.

Alluvial soils give a poor response to nitrogen except in the case of old ratoons. Although I must mention that a fairly rich alluvial soil at Tugela gave excellent responses even in plant cane.

Professor Orchard said, when discussing compaction and in referring to moisture and moisture availability "how far is aeration a causative factor". Aeration could have a considerable influence on the nitrogen flush. Some years ago when nitrogen responses were not so common in the sugar industry there was usually inter-row cultivation, causing aeration which seemed to provide for a better state of nitrogen, with perhaps a decrease in organic matter.

Dr. Maud's references to nitrification of ammonia seem to bear out Mr. Wood's observations where he used lime. Dr. Maud's figures show a bigger and quicker accumulation of nitrate in the case of Urea, obviously caused by the formation of ammonium carbonate and an increase in soil pH.

Mr. Hill: Mr. Wood's paper deals with soils, and yet he continues to refer to the geological grouping of our major soil groups. I think it would be an advantage if he came down to the soil series level, which has a unit of classification, and put all these results on an international level.

Mr. Wood: I agree entirely. When I started here last year I was not *au fait* with all the various series. But I did realise that there were these main groups of soils, and I felt that if we could show that there was a variation in potential to mineralise nitrogen in these main groups that we would be getting somewhere. This work could now be broken down very much more in regard to the various soil series.

Mr. Stewart: You express a preference for spring planting in relation to mineralisation of nitrogen. I would say that in autumn planting, where you have turned the soil and aerated it, it passes through winter in rather a friable condition, accompanied by the inevitable harrowing and cultivating at various stages when the soil is dry. Now would you not get a considerable mineralisation of nitrogen which would come into effect in the following spring?

Mr. Wood: Yes. An interesting point is that there is apparently not all that big a difference between the appearance of autumn and spring planted cane a few months after planting. The spring cane appears to very often catch up to quite a large extent. I can only think that the autumn planted cane is not getting the mineral nitrogen that it needs, at the time that it really requires it, to the same extent that spring planted cane is. It needs this nitrogen very early on. It may not be able to use the nitrogen that is being released at the time, because the growth rate is so much slower. I am sure that there must be some sort of release, under autumn planted cane, though it is apparently not anything like as much, because there is not the long dry spell before planting which the spring planted cane gets.

Mr. Gosnell: Can Dr. Beater tell us what happens to the nitrogen in the two sandy series — the Clansthal and the Cartref? We pick up less than 50 per cent as ammonium, very little as nitrate in the plough depth, and at two and a half months there appears to be almost nil down to six feet. What does happen to it?

Mr. Coignet: I have used a lot of nitrates on a two year old crop on the South Coast. At the beginning of spring you can still see the effect of nitrogen, it is like a big flush.

At one time people were keen on a split application of nitrogen. I think some experiments were made at the Experiment Station, and showed that whether it was in one massive application or a split application, the results were the same.

Dr. Beater: We are not sure what happens with a nitrate application except that the effect persists for weeks on the crop. I put urea on my own lawn and even after two months the grass is still very green.

Mr. Wilson: Doesn't Mr. du Toit's work on leaching have some bearing on this?

Mr. du Toit: Dr. Beater went right down and did not find it and if it leached he should have found it. It might possibly have gone into the air as nitrogenous gas, but I think that it more likely has gone down deep. Mr. Coignet's statement that the effects of nitrogen can be observed at the end of a two year crop implies that the nitrogen is still somewhere available for the crop, and this ties up with our results. Dr. Cleasby may remember experiments at Tongaat where huge amounts of molasses were applied in certain areas and after a year or two the soils showed very little potash left in the top soil.

Dr. Cleasby: We did apply very large quantities of molasses, and then twelve or fifteen months later we analysed the control. Molasses contain very high quantities of potash. We analysed the control, where we had not applied it, and the areas we had applied it. We went down to 6 feet, and could not detect any difference between the control, and the ones to which it had been applied. There is no question about it, the potash must have gone even further down.

Dr. Dodds: The mineralisation of nitrogen was very important at the beginning of the Experiment Station's work nearly forty years ago. In those days it was very difficult to get the planters to use much nitrate in their fertilizer. It was expensive and the industry was poor. It is rather surprising that they got as good yield of cane as they did. There must have been much more mineralisation going on than was suspected. One could usually get a response to nitrate in the fertilizer in the control experiments, but it was surprising that the control itself did so much without any activation, merely depending on what you could find in the soil.