FACTORS AFFECTING NITROGEN UTILIZATION BY SUGARCANE IN SOUTH AFRICA

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ABSTRACT

The response of sugarcane to applied N in South Africa varies considerably from one soil to another, particularly in the plant crop. Responses to fertilizer N by ratoon cane are generally much greater than those given by plant cane. Where irrigation is practised yield response per unit of N is significantly higher than that obtained under rain grown conditions.

Response of cane to N can be influenced by various factors, some of which are able to bring about differences in yield as great or greater than those obtained from the N fertilizer itself. These include seasonal effects, time and method of N application, the form of N applied, and the nature of the soil.

The N cycle in relation to sugarcane has been examined, as several factors affecting response of cane to N are concerned with the transformations which N undergoes in the soil - plant system.

The potential of different soil series within the sugar belt to mineralize N, greatly influences the response of plant cane to applied N. The N supplying power of sugar belt soils is also dependent upon how recently they were opened for cultivation, and the length of time they remain dry prior to replanting. However, accurate assessment of soil N available to cane remains difficult, and it is probable that N recommendations will continue to be made largely on an empirical basis of management and yield.

Incorporation of cane trash in the soil, and the C/N ratio of cane roots may affect efficiency of N fertilizer usage by the crop, particularly in the sandier soils of the industry low in N, due to the immobilization of applied N.

Apart from the soil pH effect as such, specific N carriers are able to influence rates of nitrification and thus susceptibility to leaching, especially in the more weakly buffered soils which constitute over 30% of the industry. It appears likely that utilization of N by cane grown in these soils, could be enhanced by the use of the nitrification inhibitor N-Serve.

Application of all the N to the furrow at time of planting can cause severe leaching losses even in heavily textured soils. Top-dressing some weeks after planting, results in more efficient recovery of fertilizer N. Even so, only 25%-30% of N applied in the widely used ammonium form is recovered by the above ground parts of the cane crop.

CHAPTER 1

INTRODUCTION

The South African sugar industry is today the seventh largest sugarcane producer in the world. During the 1969/70 milling season a total of 14,947,850 metric tons of cane was cut to make 1,622,170 metric tons of sugar.

Sugarcane is capable of rapidly depleting the soil of nutrients. It is estimated that every metric ton of millable cane removes approximately 0,6 - 0,7 kg N, 0,15 - 0,25 kg P, and 0,7 kg - 1,0 kg K. Of the major elements nitrogen is probably of greatest importance in the economic production of sugarcane. For the South African industry the total cost of nitrogenous fertilizer equals or is slightly more than that of potassic and phosphatic fertilizers combined, over 31,500 metric tons N being used annually.

There has been a dramatic increase in the use of fertilizer N in many cane producing countries during recent years, as the key role N plays in sugarcane productivity has been recognized. However, this has often been accompanied by greatly reduced fertilizer efficiency, because although cane yields usually increase rapidly when N is first applied, they level off, and sugar content actually tends to decrease after the optimum N level has been reached. In Puerto Rico for example (Samuels, 1965), the amount of N used per hectare increased by 125% between 1944-64, yet cane tonnage increased by only 15%. In South Africa, on the other hand, increase in the use of N fertilizer has shown a somewhat closer relationship with sugar yields largely because past applications of N have often been considerably below those required for optimum growth.

It is nevertheless, important to know how effectively N currently applied is being utilized by cane over the wide range of soils found in the South African sugarbelt. Also the extent to which response to N is influenced by factors such as age and time of harvest, soil moisture conditions, time of application and the nature of the soil etc. This requires an understanding of the transformations which N undergoes in the soil-plant system under sugarcane. Moreover the way in which these transformations may be modified by such factors as mineralization potential of the soil, the presence of plant residues, N carriers, leaching etc. must be considered, as they could well influence the N economy of the crop.

The main object of the work reported in this thesis was to examine the effect of several of the abovementioned factors on the utilization of N by cane, based on laboratory, glasshouse and field studies. Certain of the field data reported have been derived from experiments conducted during the past 20 years by staff of the South African Sugar Association Experiment Station.

^{15}N has proved useful in studying N transformations in soils, and it was used in several of the investigations reported in the present study.

CHAPTER 2

THE SOUTH AFRICAN SUGAR BELT

Situation

The main sugar belt lies along the eastern seaboard of Natal and inland as depicted in Figure 1, and ranges from Margate in the south to the St. Lucia estuary in the north, a distance of 400 kilometres. The irrigated areas around Pongola, in Swaziland and the Eastern Transvaal are also shown.

Sugarcane is grown over a wide range of topographical conditions. These vary from highly fertile alluvial flats with a high water-table, along the Zululand coastal sector to relatively shallow soils on hillsides, at elevations of 600-750 metres or more. Apart from the delta flats around river mouths most of the region is rolling to hilly and intersected with rivers flowing to the sea in deeply eroded valleys. South of Durban many of the hillsides are too steep for mechanical tillage, while northwards though steep, they are generally more suitable for cultivation. The total area under cane as at March 1970 was 338,000 hectares (Beater 1970).

Climate

The data in Table 1 show that the period most favourable for growth occurs between October and March, when the majority of the rainfall is received and temperatures are high. The winter period of drier weather coincides with lower temperatures so that growth is restricted even with supplementary irrigation, particularly between June and August. Frosts occur occasionally in low lying areas near the coast and more frequently inland, retarding growth or in severe cases destroying the cane.

Figure 2 shows that for most of the year evaporation exceeds precipitation indicating the need for irrigation. Currently only 15 per cent of the total acreage of the industry is irrigated.

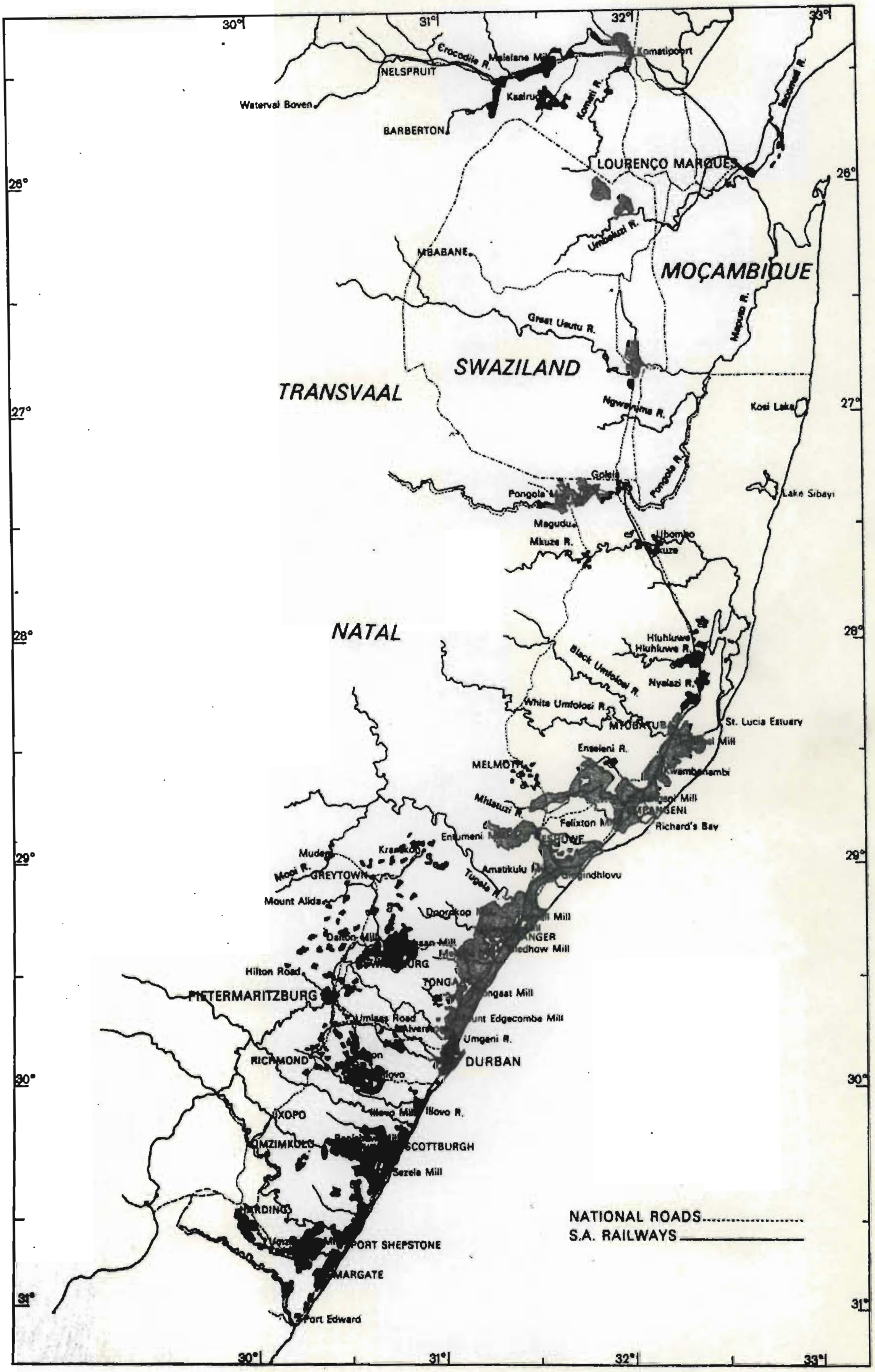


Fig. 1 The sugar industry in South Africa and Swaziland.

Table 1 Meteorological statement

Month	42 year mean Rainfall* mm	30 year mean Pan evaporation mm	38 year mean Temp. (max.) °C.	38 year mean Temp. (min.) °C.
Jan.	113,8	145,0	27,2	19,7
Feb.	116,3	124,5	27,5	19,8
Mar.	127,5	118,4	27,0	19,0
Apr.	72,6	89,2	25,9	16,7
May	50,3	72,6	24,3	13,9
Jun.	40,6	60,7	22,7	11,5
Jul.	30,2	64,3	22,5	11,1
Aug.	36,1	75,7	22,9	12,1
Sep.	63,5	93,2	23,5	16,1
Oct.	92,5	106,9	24,2	16,1
Nov.	109,5	121,2	25,4	17,5
Dec.	118,4	138,9	26,6	18,8
Total	971,3	1210,6		

* computed mean rainfall for 54 centres - remaining data for Sugar Experiment Station only.

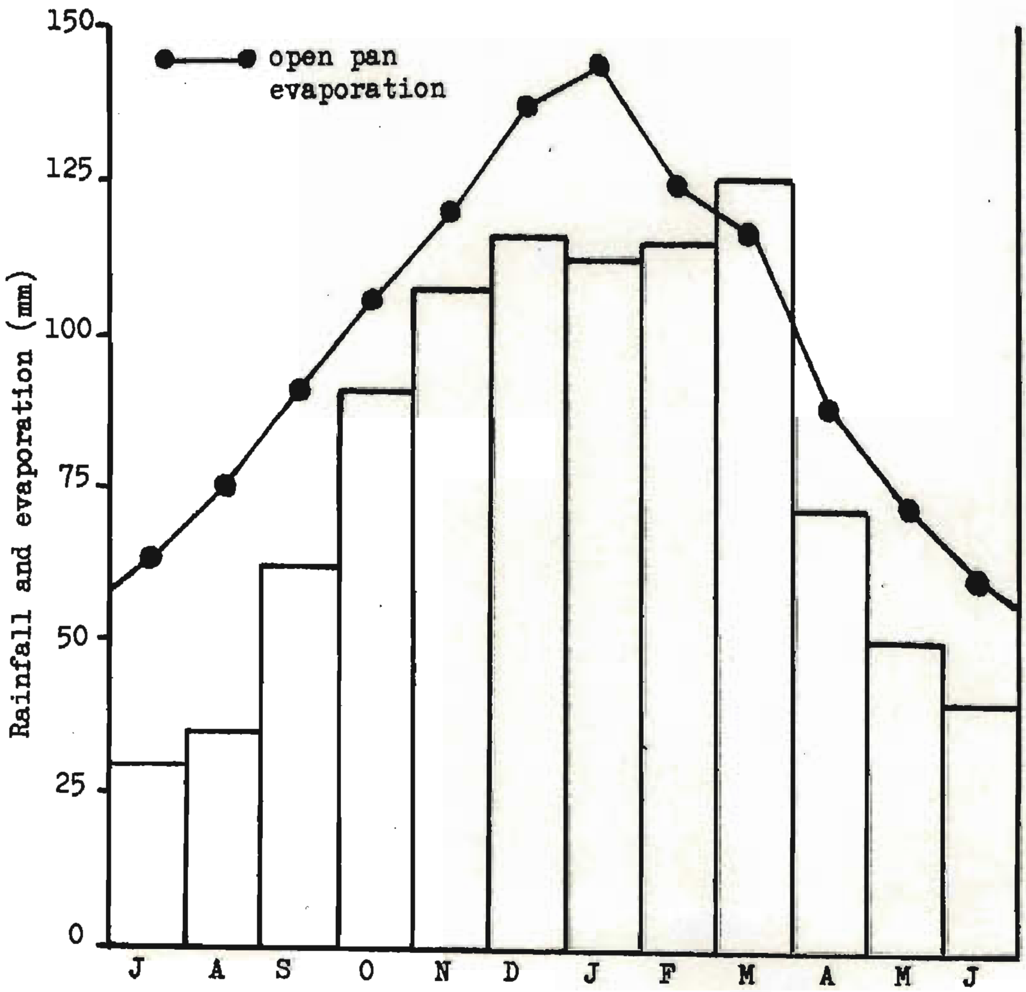


Fig. 2 Comparison of annual rainfall and open pan evaporation.

As rainfall within the cane belt varies annually from 625 - 1375 mm, growth may be adversely affected in those areas where it is low and/or irregularly distributed, unless supplementary irrigation is available.

Soils

A unique field-by-field survey of the soils of the industry has been carried out by the Soil Science Department of the Sugar Experiment Station during the past 16 years, covering approximately 500,000 hectares.

This was deemed necessary because in most cases, with the exception of coastal sands and alluvia, the parent material of the soil profile has been developed in situ from the underlying rock formations. During the evolution of the coastline these were subject to heavy faulting with the result that dissimilar rocks were brought together, and completely different soils developed in adjacent positions. In addition, numerous doleritic intrusions (in the form of dykes and sills) invaded all the earlier rocks, giving a highly fragmented soil pattern.

Geologically the region consists, in decreasing order of age, of granite and associated schists (Archaean), Table Mountain Sandstone (Silurian), numerous shales and sandstones comprising the Karroo system and ranging from the Carboniferous Dwyka tillite through Permian Ecca sediments, Triassic Beaufort sediments and Jurassic lavas.

A brief physical description of soils used from various series during the experimental work to be reported, is presented in Table 2. Parent material is in descending order of age, and an estimate is given of the proportion of the sugar industry occupied by each parent material. (Beater 1970, Macvicar 1970).

ABLE 2 Physical characteristics of soils from the various series studied

arent material	Soil Series	General series description	Parent material % of the industry
ugela schist	Doveton	Reddish-brown clay loam (40-55% clay), moderately acid, with good granular structure - Hutton form	2,2
ranite	Glenrosa	Grey porous loamy sand (6-15% clay), 25-60 cm thick on weathered granite, acid and gritty with weak crumb structure - Glenrosa form	11,1
	Mayo	Black or dark grey, porous sandy clay loam (15-35% clay), 60-90 cm thick, on weathered migmatite. Acid with gritty structure - Mayo form	
.ble Mountain ndstone	Cartref	Grey, porous, deep medium sand to loamy sand (6-15% clay), 60-100 cm thick on rock. Acid throughout - Cartref form	25,0
	Inanda	Dark brown or black, moderately acid humic clay loam, 50-75 cm thick, over a red moderately acid clay loam (35-55% clay). Very porous - Inanda form	3,8
yka tillite	Williamson	Grey, porous fine sandy clay loam (15-35% clay) 15-45 cm thick, slightly to moderately acid - Glenrosa form	10,7
ver Ecca ale	Milkwood	Dark brown or black clay loam. Slowly permeable and often shallow. Moderately acid - Milkwood form	7,6

ABLE 2 (continued)

arent material	Soil Series	General series description	Parent material % of the industry
iddle Ecca hale	Windermere	Black porous fine sandy clay loam (15-35% clay), 15-40 cm thick, on moderately porous black clay 30-60 cm thick, slightly to moderately acid - Swartland form	6,3
eaufort shales nd sandstones	Estcourt	Grey sand to loamy sand (6-15% clay), 15-45 cm thick, over heavy clay which merges to rock at depth. Moderately acid - Estcourt form	1,1
olerite and asalt	Shortlands	Red, slightly acid, moderately porous clay (> 55% clay), usually deep, excellent structure, fertile - Shortlands form	13,5
	Rydalvale	Black, slowly permeable clay, 50-80 cm thick on weathered dolerite, neutral to slightly acid - Arcadia form	
cent sands ed)	Clansthal	Red, porous, deep medium sand to loamy sand (6-15% clay). Moderately acid - Hutton form	4,1
	Shorrocks (sand)	Red, porous, sandy loam to sandy clay (15-35% clay), with a sand topsoil strongly acid - Hutton form	
cent sands rey)	Fernwood	Grey, deep medium sand, moderately acid throughout, structureless, infertile - Fernwood form	4,2
uvium	Dundee (clay loam)	Dark brown clay loam to clay, deep and moderately acid to neutral - Dundee form	8,0

Sugarcane husbandry

Though land is prepared for planting throughout the year, the winter months are preferable as loss of growing time is at a minimum and rainfall is sparse. After ploughing, the land is left fallow until the onset of spring rains is imminent, generally in September, when the cane-setts are planted. Temperatures begin to rise and the plant is usually assured of the maximum period of uninterrupted growth. Phosphatic fertilizer is drilled in the furrow at planting, while nitrogenous and potassic fertilizers are normally top-dressed in a single application 8 - 10 weeks afterwards. In some cases applications of fertilizer N are split between furrow and top-dressing.

Age of rain grown cane at harvest varies depending on environment, being 14-20 months at the coast, and 24 months or more in the cooler, higher altitude areas inland. At harvest, dead leaves and sheaths adhering to the plant are removed, either physically when cutting or by burning. The leaves plus green tops are collectively termed 'trash', and under dryland conditions at low elevations are left in the field between the rows of cane to act as a mulch. Burning usually occurs only in colder areas or where waterlogging may be encountered.

After cutting, the cane which develops by regeneration from the first or 'plant crop' is termed the 'first ratoon' crop, and arises from buds on the underground stems of the harvested cane. The ratoon cane is top-dressed with nitrogenous and potassic fertilizers broadcast or banded over the trash soon after harvest. Generally three or four ratoons are grown before the final crop is burnt, ploughed out and fresh material is planted. On average a hectare of rain grown cane yields 75-80 metric tons every 18-24 months

CHAPTER 3

THE RESPONSE OF SUGARCANE TO NITROGEN

Carey and Robinson (1953), and Hodnett (1956) reviewed the response of sugarcane to fertilizers from some 2,000 experiments carried out between 1900 and 1955 in various parts of the British Commonwealth. They showed that the response to a standard amount of fertilizer N varied considerably from one country to another, being largely influenced by water supply and whether the crop was plant or ratoon cane.

Responses by first ratoon crops were usually much greater than those by the preceding plant cane and the increased responses were usually maintained in the later ratoon crops. Where irrigation was practised, responses were significantly higher than where the cane was rain grown. Even where rainfall was relatively high, irrigation was found to be beneficial by ensuring an increased response to fertilizer N.

Results from South African field experiments

Rain grown cane

Since 1950 a large number of field experiments have been undertaken by the Sugar Experiment Station, with a view to determining optimum rates of use of single nutrient carriers for rain grown cane in the varied range of soils and climate experienced in the sugar belt.

In 1950, a series of 3 x 3 x 3 NPK exploratory experiments commenced, in which N was applied as sulphate of ammonia at levels of 0, 110 and 220 kg N per hectare to all crops. The results from 28 of these were reported by du Toit (1957). They were followed in 1956 by a more comprehensive series of 4 x 2 x 3 NPK experiments in which the N carrier was again sulphate of ammonia applied at the following rates:

Plant cane: 0, 55, 110, 220 kg N per hectare

Ratoon cane: 0, 110, 220, 330 kg N per hectare

Based on the results of the 3 x 3 x 3 experiments, unfertilized controls were eliminated from those soil series on which marked responses to applied N had occurred in the plant crop. The N levels used in these experiments were as follows:

Plant cane: 66, 132, 198, 264 kg N per hectare

Ratoon cane: 110, 220, 330, 440 kg N per hectare

In addition, during the past decade a variety of experiments in which levels of N were incorporated have been carried out both by the Experiment Station and agronomists on various estates throughout the cane belt. The writer examined results from all the abovementioned experiments in order to obtain an overall picture of response to various amounts of applied N.

If mean responses to levels of N over control (no N) are considered, then the picture that emerges for plant cane and the subsequent ratoon crops is that presented in Table 3.

TABLE 3. Mean responses to levels of N over control receiving no nitrogen (rain grown cane)

kg N per hectare	Plant cane		All ratoon crops	
	tc/ha*	t suc/ha*	tc/ha*	t suc/ha*
55	6,0 (41)	1,46 (40)		
110	8,7 (82)	1,14 (81)	14,8 (116)	2,22 (113)
165	11,6 (51)	1,19 (51)		
220	7,4 (39)	0,94 (38)	17,7 (112)	2,42 (109)
330			21,7 (30)	2,53 (30)
440			18,8 (11)	2,62 (10)

Figures in brackets indicate number of experiments reported.
* Throughout tc/ha ...

For the same amount of N the greater response of the ratoon crops is seen when compared with that of plant cane. The data for plant cane indicate that there would be little to gain from applying more than 55 kg N per hectare to this crop, because while it may increase the yield of cane it does not provide an economic increase in the amount of sugar produced. This is true for many soils, but if the data from the 4 x 2 x 3 experiments on those soils in which the zero N treatment was deleted, is now included, the overall response to an additional 55-66 kg N per hectare is seen to become economic in terms of tons sucrose per hectare as shown in Table 4.

TABLE 4. Mean additional response to levels above 55 - 66 kg N per hectare

kg N	Plant cane	
per hectare	tc/ha	t suc/ha
55 - 66		
to	3,4 (61)	0,54 (61)
110 - 132		
to	1,1 (59)	- 0,09 (58)
198 - 220		
to	2,0 (23)	0,20 (23)
264 - 275		

Figures in brackets indicate number of experiments reported

At the current fertilizer price (1971) of R74,50 per metric ton it is estimated that an additional 100 kg N as urea will be economic only if an increased yield of 0,45 tons sucrose per hectare is obtained.

For rain grown ratoon cane, the data in Table 3 indicate that amounts of N much in excess of 110 kg N per hectare are hectare, despite noticeable increases in cane yield at the higher N levels. This is substantiated by the figures presented in Table 5, where results from the 4 x 2 x 3 ratoon crops in which the N control treatment was excluded, have been incorporated with those in Table 3.

TABLE 5. Mean additional response to levels above 110 kg N per hectare (4 x 2 x 3 experiments incorporated)

kg N	Ratoon cane (all crops)	
per hectare	tc/ha	t suc/ha
110 - 220	3,1 (154)	0,20 (151)
220 - 330	0,7 (52)	-0,13 (50)
330 - 440	0,4 (34)	0,11 (33)

figures in brackets indicate number of experiments reported

Irrigated cane

As only 15% of the cane grown in South Africa is irrigated, relatively few experimental results are available. These are summarised in Table 6. Despite the small number of experiments, the figures reflect the much larger responses obtained to a given amount of N under irrigated conditions in both plant and ratoon cane, when compared to a similar amount applied to rain grown cane.

TABLE 6. Mean responses to levels of N over control (no N) - irrigated cane

kg N	Plant cane		All ratoon crops	
per hectare	tc/ha	t suc/ha	tc/ha	t suc/ha
83	26,7 (6)	2,46 (6)		
110	23,5 (9)	2,13 (9)	40,8 (8)	5,60 (8)
165	27,5 (9)	2,58 (9)	36,1 (9)	4,72 (9)
220	31,8 (5)	1,97 (5)	45,9 (8)	5,64 (8)

For plant cane it appears that there would be little advantage in applying more than 83 kg N per hectare to this crop. As with rain grown ratoons, the data in Table 6 imply that amounts of N in excess of 110 kg N per hectare are unlikely to be economic in terms of sugar produced by irrigated ratoon crops. Nonetheless the information available is somewhat conflicting.

In a 4 x 2 x 3 NPK experiment at Pongola, harvested at 12 month intervals and irrigated to potential, results for a plant crop and three ratoons indicated that 120 kg N per hectare was the optimum N level. However yields of over 100 tons per hectare were obtained throughout in the absence of applied N.

On the other hand amounts of N required by rain grown and irrigated cane, as determined in another experiment, suggested that irrigated ratoons could effectively utilize levels of N in excess of 165 kg N per hectare as shown in Table 7.

TABLE 7. Response of cane to levels of N - rain grown (R) vs. irrigated (I)

kg N	Second ratoon*				Third ratoon*			
	tc/ha		t suc/ha		tc/ha		t suc/ha	
per hectare	R	I	R	I	R	I	R	I
0	67,4	75,7	10,62	11,58	38,3	55,1	5,44	8,22
165	102,6	115,1	16,24	17,14	51,7	87,8	6,85	13,10
330	108,4	131,0	16,57	18,12	51,1	103,7	6,18	14,29

* Second and third ratoons harvested at 13 and 12 months respectively

<u>Optimum amounts of N in South Africa and elsewhere</u>

This review of field experiments has revealed that the optimum application of N for both rain grown and irrigated plant cane in South Africa generally lies between 55 - 85 kg N per hectare. The actual amount however depends to a considerable extent on the in some cases applications of 110 kg N have been shown to be economic.

* For both rain grown and irrigated ratoon crops amounts much in excess of 110 - 130 kg N per hectare are usually uneconomic.* In some irrigated ratoons, economic responses have been obtained from 165 kg N and above, though age of the crop at harvest may partly account for this.

Amounts of N required for optimum yields under South African conditions compare favourably with those applied in other sugar producing countries as indicated in Table 8.

TABLE 8. Approximate amounts of N required for optimum cane yields in various countries

Country	kg N per hectare	
Brazil	132	
Caribbean area	105	(rain grown plant and ratoons)
Egypt	55	(plant cane)
	100-110	(ratoon cane)
Hawaii	220	(irrigated cane)
India	110	(all crops)
Indonesia	120	(plant cane)
	145	(ratoons)
Mauritius	100-110	(all crops)
Phillipines	110	
Puerto Rico	132	(per 12 month crop)
Queensland	105	(plant cane)
	130	(ratoons)
South Africa	55-110	(rain grown and irrigated plant cane)
	110-130	(rain grown and irrigated ratoons)

This table was compiled from data reported by Chapman (1968), De Geus (1967), Little (1963), Parish (1962), Prasad et al. (1967), Samuels (1965), and Stanford (1963). The somewhat higher amount of N used in Hawaii is explained by the fact that crops are generally more than 24 months old at harvest, and yields often over 225 tons per hectare.

A reasonable standard of efficiency has apparently been achieved in South Africa with regard to amounts of N fertilizer applied to sugarcane.

CHAPTER 4

FACTORS INFLUENCING THE RESPONSE OF SUGARCANE TO APPLIED NITROGEN

Although optimum amounts of fertilizer N required by sugarcane can be determined from responses to levels of N as reported in Chapter 3, the somewhat limited value of averaged data of this type must be emphasised. This is because of variations in response due to factors some of which are able to bring about differences in yield as great or greater in magnitude, than those obtained from the N fertilizer itself. Several of these factors will now be examined, particularly with regard to their pertinence to sugarcane production under South African conditions.

Season

Age and time of harvest

Aughtry (1958) reported an experiment in Jamaica in which he measured the comparative performance of irrigated ratoon cane grown to $12\frac{1}{2}$ months with and without 100 lb N per acre. The treatments were started at five different dates between January and July. He found that growth rate was governed primarily by climatic factors, and while the age of cane affected growth to a limited extent, this was negligible when compared to the seasonal response. Seasonal differences exerted their greatest effect on yield of cane and were largely responsible for the variable effect obtained with applied N, as shown in Figure 3.

Shaw and Innes (1965) in an experiment designed to determine the effect of season, irrigation and N fertili

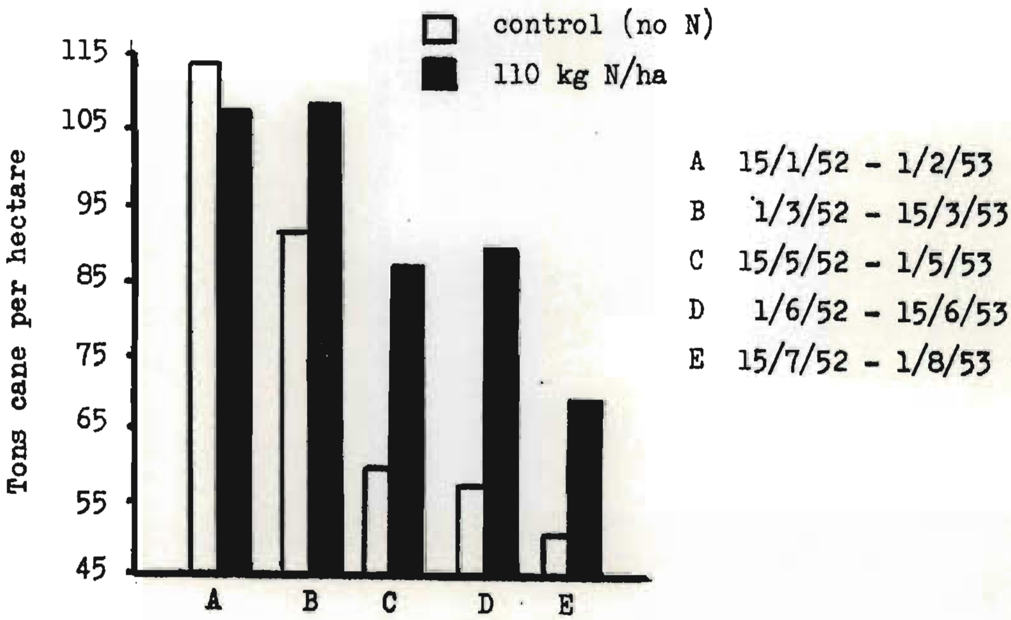


Fig. 3 The effect of season on cane yield, in the presence or absence of applied N - Jamaica.

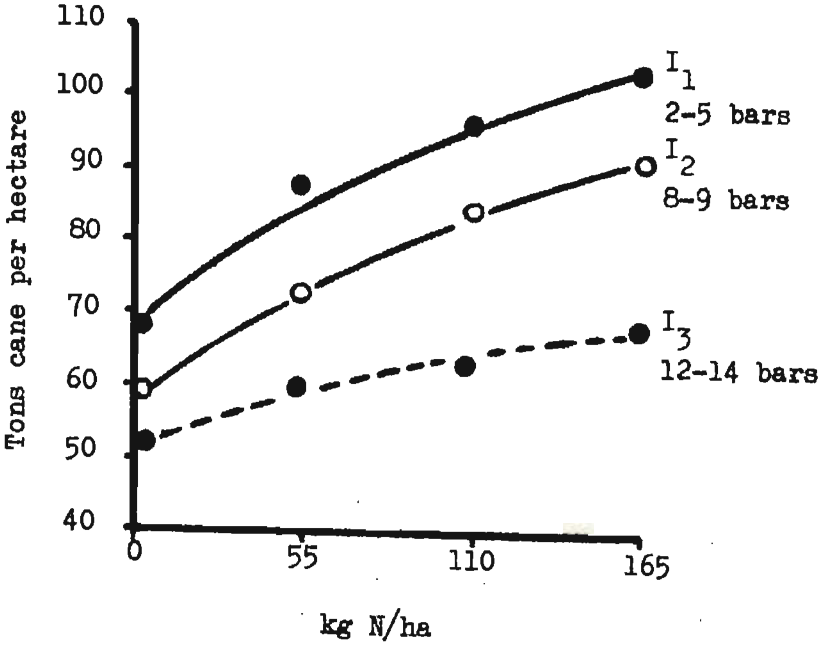


Fig. 4 Reduction of N response due to moisture stress - Jamaica.

on the growth pattern and yield of an annual plant cane crop, showed that both yield and the manner in which it accumulated were primarily influenced by seasonal conditions, especially those prevailing during the first 30 weeks after planting. Subsequently this was found to apply equally to the first ratoon crop as shown in Table 9. It is of interest to note that time of harvest was found to be of great importance in realising the benefits of optimum fertilization.

TABLE 9. The influence of season on cane yield - Jamaica

Month	tc/ha (plant cane)		tc/ha (first ratoon)	
planted	30 weeks	52 weeks	30 weeks	52 weeks
January	38	85	47	87
April	67	105	67	94
July	36	83	43	74

In South Africa the effects of climatic cycle on yield have also been studied. Rostron (1971) has compared yields of cane and recoverable sugar of 52 week-old irrigated first ratoon crops, which were started at eight different times through the ensuing year as shown in Table 10.

TABLE 10. Harvest data for 52 week-old crops started at eight different times - South Africa

Yield	Date previous crop was cut							
	18/12/68	12/2/69	9/4/69	4/6/69	30/7/69	24/9/69	19/11/69	14/1/70
tc/ha	137	146	150	166	166	162	148	146
tons *ers/ha	13,8	12,6	11,4	15,8	17,2	17,1	15,6	14,3

*ers = estimated recoverable sugar.

From these results it is apparent that cane harvested at the peak of the season from July - September produced maximum yields of recoverable sugar per hectare. Cane harvested from February - May produced the lowest yields.

Moberly (1971) reported differential response to high levels of N from irrigated 12 month-old cane cut at different times of year in South Africa. He showed that the depressive effects of excessive N on estimated recoverable sugar (ers) were more extreme when the cane was cut at an unfavourable (May) compared with a favourable (November) time of year (see Table 11). In contrast the time of cutting was relatively unimportant even at high levels of N when the cane was harvested at 18 months of age.

The uptake of N was shown to be more efficient in crops grown during a favourable climatic cycle i.e. Nov. - Nov. (12 months) or Nov. - Nov. - May (18 months) compared to a less favourable cycle May - May (12 months) or May - May - Nov. (18 months). He states that it would therefore be possible to use lower levels of N for crops grown during a favourable climatic cycle.

Rainfall and soil moisture conditions

With rain grown cane seasonal effects are likely to be even more pronounced than with an irrigated crop. This was illustrated by Takahashi (1967a) in an experiment in which the recovery of labelled fertilizer N by a summer plant crop harvested at 13,5 months, was only 21,3% compared to 35,3% for a fall plant crop harvested at 12 months. Seasonal effects, as in this instance, are very often closely linked with adverse or favourable soil moisture conditions.

*

TABLE 11. The effect of increasing amounts of N on mean yield of 12 month-old cane cut at different times of year, compared with cane cut at 18 months old - South Africa

kg N/ha	3 x 12 month crops Nov. - Nov. (favourable)			3 x 12 month crops May - May (unfavourable)		
	tc/ha/ month	ers	ers/ha/ month	tc/ha/ month	ers	ers/ha/ month
0	3,6	13,9	0,50	3,9	12,4	0,47
112	6,2	13,8	0,86	4,5	12,5	0,56
336	7,4	13,9	1,04	5,9	11,8	0,68
672	7,2	13,5	0,98	6,4	11,3	0,71

kg N/ha	2 x 18 month crops Nov. - Nov. - May			2 x 18 month crops May - May - Nov.		
	tc/ha/ month	ers	ers/ha/ month	tc/ha/ month	ers	ers/ha/ month
0	4,5	14,3	0,65	3,1	14,7	0,45
112	6,0	14,4	0,86	4,5	14,9	0,66
336	7,5	15,1	1,13	5,6	14,7	0,82
672	7,9	14,4	1,14	6,4	14,3	0,91

The summer plant crop was subject to early drought conditions, which prevented lateral movement of N through the roots. This was not the case with the fall plant crop grown under a more favourable moisture regime.

Work in Jamaica (Anon 1964) with irrigated cane has shown that the response to applied N can be very seriously reduced where soil moisture is inadequate (see Figure 4).

Hodnett (1956) stressed the fact that moisture distribution was almost as important as the total quantity received. This has been confirmed in South Africa by Thompson and Wood (1967). In two successive 12-month seasons the mean experimental yields from fertilized plots were 99 and 41 tons cane per hectare. Total rainfall for these two 12-month periods was 825 mm and 708 mm, for which no clear distinction existed between the two seasons. The reduction in yield in the second season was shown to be the result of a severe moisture shortage, caused mainly by poor rainfall distribution as illustrated by gypsum block data for the soil to a depth of 105 cm (see Figure 5).

Also in South Africa, response to different amounts of N under various soil moisture conditions has been studied. Yields from rain grown cane were compared with those from cane receiving two different supplementary irrigation treatments, at four different N levels, for both a plant crop and a first ratoon. Table 12 shows that the amount of water received markedly influenced yield in the plant crop but no response to N was obtained in this instance.

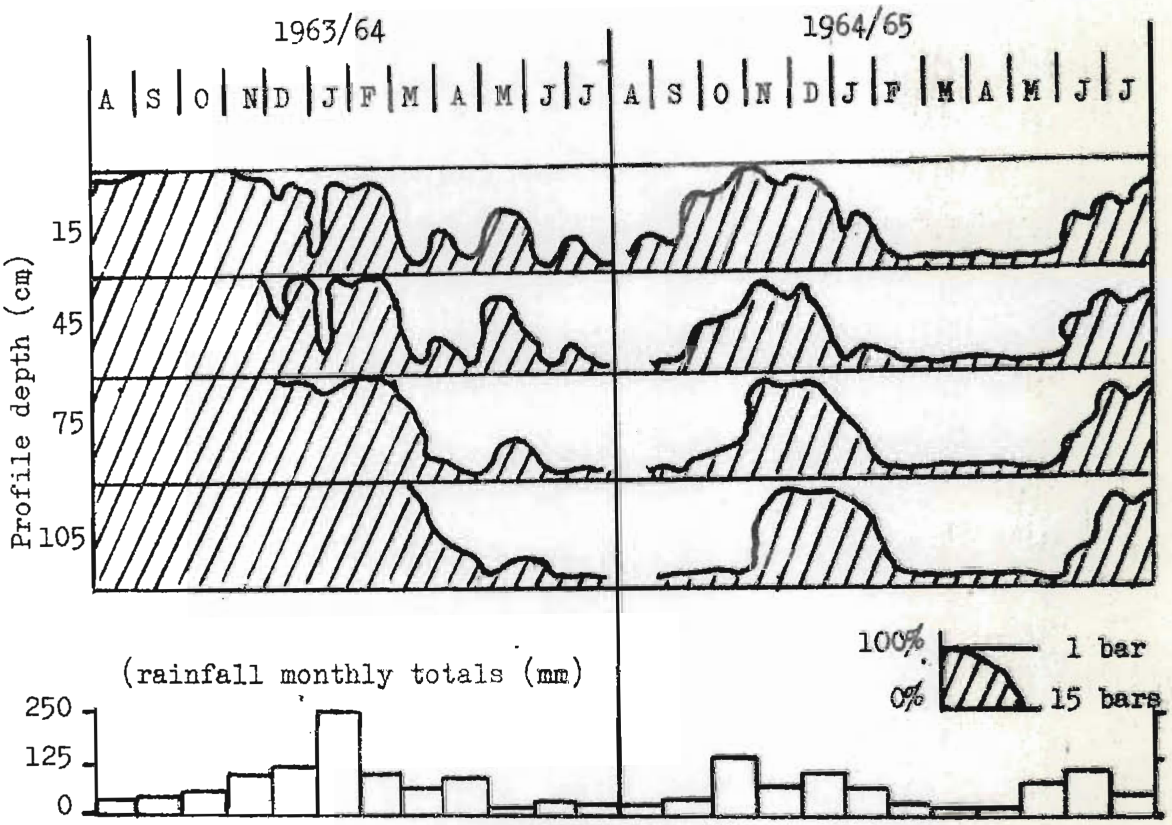


Fig. 5 Changes in available soil moisture occurring under sugarcane in relation to rainfall distribution during two successive 12 month periods. (Shaded areas represent moisture available between 1 and 15 bars)

TABLE 12. The influence of various moisture and N levels on cane yield - South Africa

Water received		760 mm		1167 mm		1497 mm	
Crop	kg N/ha	Rain grown only		Rain + irrig. every 17 days		Rain + irrig. every 5 days	
		tc/ha	t suc/ha	tc/ha	t suc/ha	tc/ha	t suc/ha
	Nil	58,5	8,65	100,6	14,78	111,1	16,64
Plant	50	56,7	8,24	97,9	14,04	116,7	17,47
Cane	100	54,2	7,80	100,8	14,60	110,9	16,13
(12 months)	200	56,4	8,00	85,8	12,19	121,6	17,92
	Mean	56,4	8,18	96,3	13,91	115,1	17,05
Water received		1003 mm		1308 mm		1638 mm	
	Nil	97,7	17,18	92,7	13,37	95,0	14,11
First	50	119,8	17,32	111,8	15,97	126,6	17,25
ratoon	100	117,2	16,35	125,7	18,52	126,1	16,96
(12 months)	200	128,6	16,87	125,7	17,92	152,3	19,42
	Mean	115,8	16,60	114,0	16,44	125,0	16,93

In the first ratoon crop response to 55 kg N per hectare was much the same at all moisture levels. No statistically significant interactions were observed between N and moisture, suggesting that rainfall was adequate and sufficiently well distributed to eliminate large differences in response except perhaps at the highest level of N and moisture.

Time of application of nitrogen

A survey of the literature shows that in many sugar producing countries, particularly where cane is grown for periods of up to

24 months before cutting, it was customary until relatively recently to split applications of fertilizer N so that as many as four or five dressings were given. Much of the experimental work carried out in the last decade or so, however, has yielded very little evidence supporting this practice. In fact the effects have very often been deleterious causing significant decreases in yield and sucrose content. All indications suggest that a single application of an adequate amount of N should be applied within the first two or three months of growth. It would appear that the cane plant has the ability to store considerable quantities of N absorbed in the early stages of growth, and is able to utilize this for subsequent development.

Baver (1963) summarising work on the timing of N applications over the 50 years from 1911 - 1960, reports that practically all data showed that adequate early fertilization is one of the keys to good yields. The work of Takahashi (1966) in Hawaii using ^{15}N labelled fertilizers has made it possible to obtain a much clearer understanding of the effects of splitting applications of N, and why this is very often not as effective as a single application. He reports that:

(i) an early single application of N results in larger yields of dry matter than the same amount of N divided into several smaller amounts and applied over a longer period of time.

(ii) the timing of the N application affects overall recovery of fertilizer N in the plant tissues, larger recoveries coming from an early single dose.

(iii) efficiency of N uptake is greatest when a maximum dosage of N fertilizer is applied early.

(iv) larger amounts of residual fertilizer N are found in the soil when the N application is split.

In South Africa du Toit (1959b) was able to show that even for a two year crop, early top-dressing was very important. On a Inanda series soil, 55 kg N per hectare was applied as a top-dressing either three or twelve months after planting. Table 13 shows that the late top-dressing increased yield over control far less than the early one and considerably reduced the sucrose per cent cane. The early dressing actually improved the sugar content, showing the superiority of this treatment.

TABLE 13. Effect of time of N application on yield and sucrose content over control - South Africa.

kg N/ha	tc/ha	suc % cane	t suc/ha
Control	122,1	16,72	20,4
55 kg N (t.d. at 3 months)	+33,3	+0,34	+5,98
55 kg N (t.d. at 12 months)	+15,7	+0,96	+1,08

In an irrigated experiment 110 kg N per hectare was applied (a) all in furrow at planting; (b) half in furrow and half top-dressed at 11 weeks old; (c) all top-dressed 11 weeks after planting. Half the experiment was harvested at 13,5 months and the remainder at 20 months. The results from both harvests are given in Table 14.

TABLE 14. Cane yields at two ages following application of N in three different ways - South Africa

N treatment	tc/ha	t suc/ha	age
Control (no N)	55,8	8,06	
All N in furrow	84,7	12,07	13,5
N split ($\frac{1}{2}$ f-$\frac{1}{2}$t.d.)	80,2	11,63	months
All N top-dressed	84,0	12,14	
Control (no N)	121,9	17,56	
All N in furrow	151,4	22,15	20
N split ($\frac{1}{2}$ f-$\frac{1}{2}$t.d.)	139,1	20,56	months

No difference in the yield of sucrose between the single application of N in the furrow or that top-dressed was apparent either at 13,5 or 20 months. There was however, a trend albeit it not statistically significant for the split application to be less efficient at both dates of harvest.

Time of application of N and the effects of splitting dressings will be considered further in Chapter 11.

Form of nitrogen

In a review du Toit (1967) discussed the relative merits of the most commonly used N fertilizers in the South African Sugar industry since 1957. His paper also included a review of experimental results from overseas cane growing countries. In Mauritius, British Guiana and Jamaica it was shown conclusively that ammonium sulphate outyielded equal applications of N in the form of urea. In Louisiana, Hawaii and Queensland however no real difference between yields from the two fertilizers was obtained.

In South Africa also, the average results obtained when equal quantities of N are applied in the form of urea and sulphate of ammonia are practically identical as indicated in Table 15.

TABLE 15. Results of 13 experiments (23 crops) comparing urea and ammonium sulphate in South Africa

Treatment	tc/ha	t suc/ha
No nitrogen	91,8	14,22
Urea 110 kg N/ha	111,8	17,34
220 kg N/ha	113,6	17,23
S/A 110 kg N/ha	112,7	17,27
220 kg N/ha	114,2	16,91

Limestone ammonium nitrate has on average given somewhat poorer yields than those obtained from comparable amounts of urea and ammonium sulphate, and in one trial on an acid sand of the Cartref series, the differences in yield were appreciable and significant. Possible reasons for this will be discussed in Chapter 10.

Yields obtained with aqua ammonia or anhydrous ammonia have been reassuring, and they are already being used extensively in the newly developed sugarcane areas of the Eastern Transvaal.

Therefore, although conditions do occur where one form of N fertilizer appears to be significantly superior to another, to date these have not been sufficiently well defined for recommendations regarding N carriers to be based on anything more than the cost per unit of N applied.

The soil

The greater and more frequent responses to N fertilizer by ratoon crops when compared to those in plant cane, have been reported by numerous workers, among them Samuels (1956), du Toit (1959), Innes (1960) and Parish (1962). They have ascribed various reasons for the more efficient use of applied N by the ratoons.

At one time in South Africa it was generally believed that the practices of ploughing in a green manure crop or leaving the land fallow for long periods were mainly responsible for reducing the response of plant cane to applied N. However when indifferent responses persisted on many soils after green manuring and fallowing had been discontinued, it became obvious that some other factor was responsible.

When the responses from the rain grown N fertilizer experiments conducted in South Africa, and reported in Chapter 3, are related to the soils on which they were obtained, some interesting features emerge. Large responses from N applied to plant cane are confined primarily to soils derived from Table Mountain Sandstone (Cartref series) and Dwyka tillite (Williamson series) as shown in Figure 6A.* *Moderate responses are often obtained on Recent sands (Clansthal and Fernwood series), granites (Glenrosa series) and Table Mountain Sandstone (Inanda series). *Plant cane grown on many of the remaining soils derived from dolerites, schists, shales and alluvia, often shows little or no response to applied N.* With ratoon cane however large responses are obtained on a much wider range of soils, though not on all, as depicted in Figure 6B. Table 16 also shows the influence of the soil on responses to fertilizer N in a number of repeated experiments.

*NB. TABLE 16. Influence of soil derived from various parent materials on response to applied N (rain grown cane) - South Africa

Soil derived from	kg N/ha	plant cane		first ratoon		second ratoon	
		tc/ha	t suc/ha	tc/ha	t suc/ha	tc/ha	t suc/ha
Table Mountain	110	9,0	1,41	21,7	3,63	11,9	1,79
Sandstone (8)	220	15,9	2,20	28,9	4,52	13,9	1,90
Recent sands (15)	110	6,0	0,99	17,0	2,46	19,7	2,62
	220	6,0	0,96	15,0	2,02	13,7	1,55
Shales (6)	110	2,9	0,43	11,0	1,93	5,8	1,05
	220	2,5	0,34	13,4	1,95	9,2	1,30
Dolerite (3)	110	0,5	-0,36	3,1	0,20	17,2	2,46
	220	2,0	-0,02	14,6	1,41	21,1	2,53
Others (4)	110	0,0	-1,18	8,3	1,37	5,4	0,78
	220	0,0	-3,09	13,9	1,88	10,1	1,43
Mean (26)	110	4,3	0,65	14,1	2,22	16,1	1,70
	220	5,8	0,81	18,6	2,62	17,5	1,68

Average age of cane at harvest was 21 months
Figures in brackets indicate number of experiments reported.

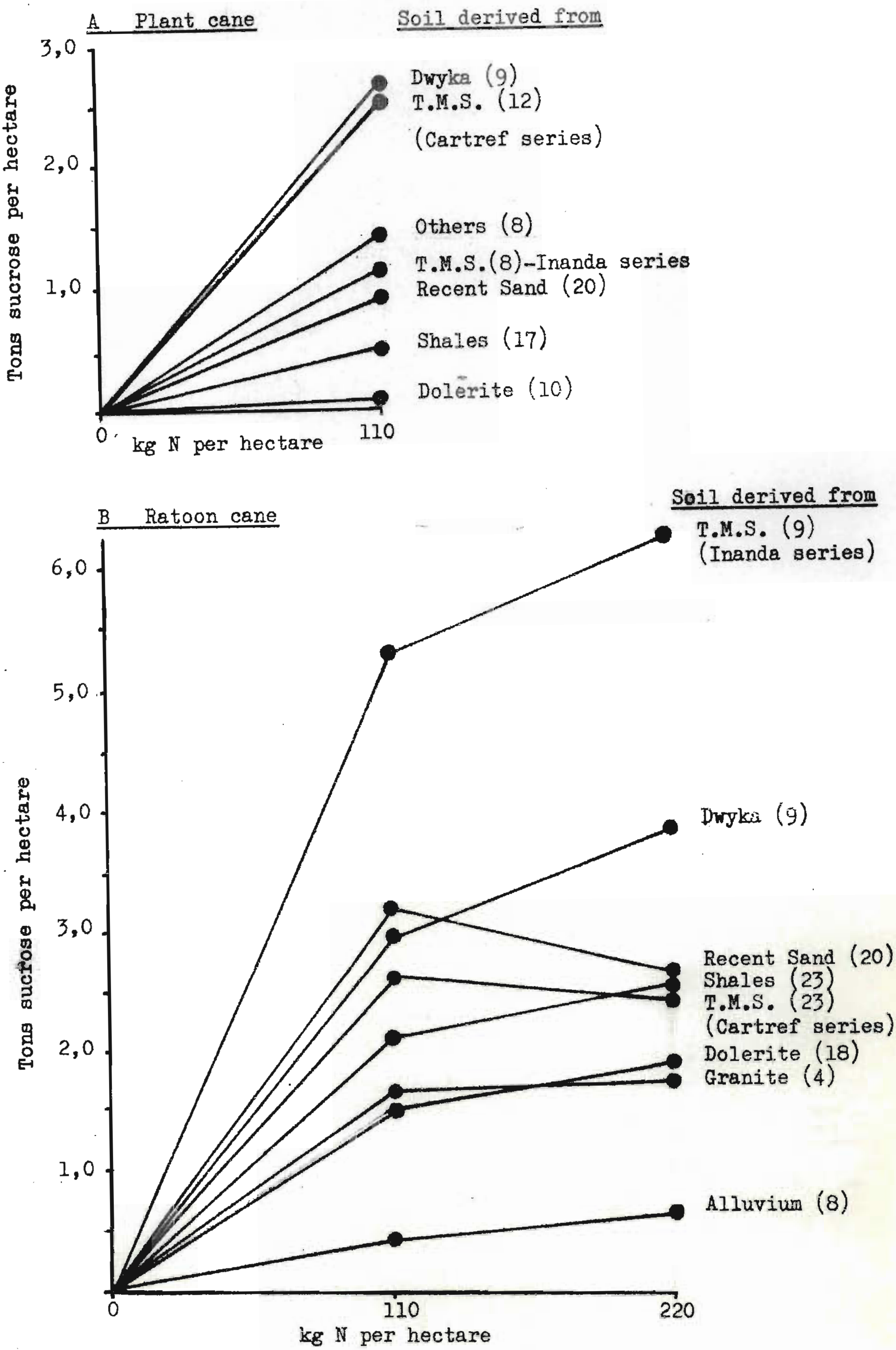


Fig. 6 Response of plant and ratoon cane (tons sucrose per hectare) to applied N, over a range of sugar belt soils. (Figures in brackets indicate number of experi-

These data indicate that in many cases plant cane is able to obtain much, if not all, of its N requirement directly from the soil. Ratoon crops on the other hand generally appear unable to obtain sufficient amounts of N from this source for optimum growth. Examination of N yields from the unfertilized plant cane crops of 60 South African fertilizer experiments, conducted over a wide range of soils, appear to confirm these observations. Yields ranged from 19 to > 140 kg N per hectare per annum, assuming that one ton of unfertilized cane removes approximately 1 kg N divided equally between the millable stalk and trash. Moreover the amount of soil N released annually was shown to diminish with each successive crop. For a series of 11 repeated experiments (plant crop to third ratoon), average N release (kg N/ha/annum) declined as follows: 81,3 plant crop; 69,0 first ratoon; 66,9 second ratoon; 60,6 third ratoon. This suggests a fairly rapid fall off in rate of N release between plant crop and first ratoon, followed by a more gradual decline in later ratoons.

Theron (1954) hinted at the importance of soil N release to sugarcane nutrition in South Africa, in the following statement:- "To all appearance this crop reacts in every way analogous to the ordinary grass leys. Thus the marked response I have seen of plant cane to applications of phosphate is similar to the reaction obtained with newly established pastures, and is a clear indication of nitrogen liberation and humus loss during the period of establishment. The response to nitrogen of the ratoon cane shows that nitrification and humus mineralization is effectively inhibited, and thus humus regeneration can take place under the ratoon crop". Theron (1963) has since withdrawn his hypothesis that living plant roots inhibit nitrification which he previously put forward. (Theron, 1951).

The writer thinks that the analogous behaviour of grass leys and sugarcane referred to by Theron, is of extreme importance in helping to explain many of the responses by cane to applied N. Theron and Haylett (1953) obtained a response pattern following N application to a grass ley, similar to that observed with sugarcane. Figure 7, demonstrates this similarity by comparing the effects of N on yields of grass and sugarcane over several seasons. They attributed the poor response of grass to applied N in the first season, to the considerable amount of N mineralized in newly ploughed land prior to replanting, which on some soils is sufficient to meet crop needs. Similarly N mineralized by soils under plant cane must often influence significantly the crop fertilizer N requirement. This will be considered further in Chapter 7.

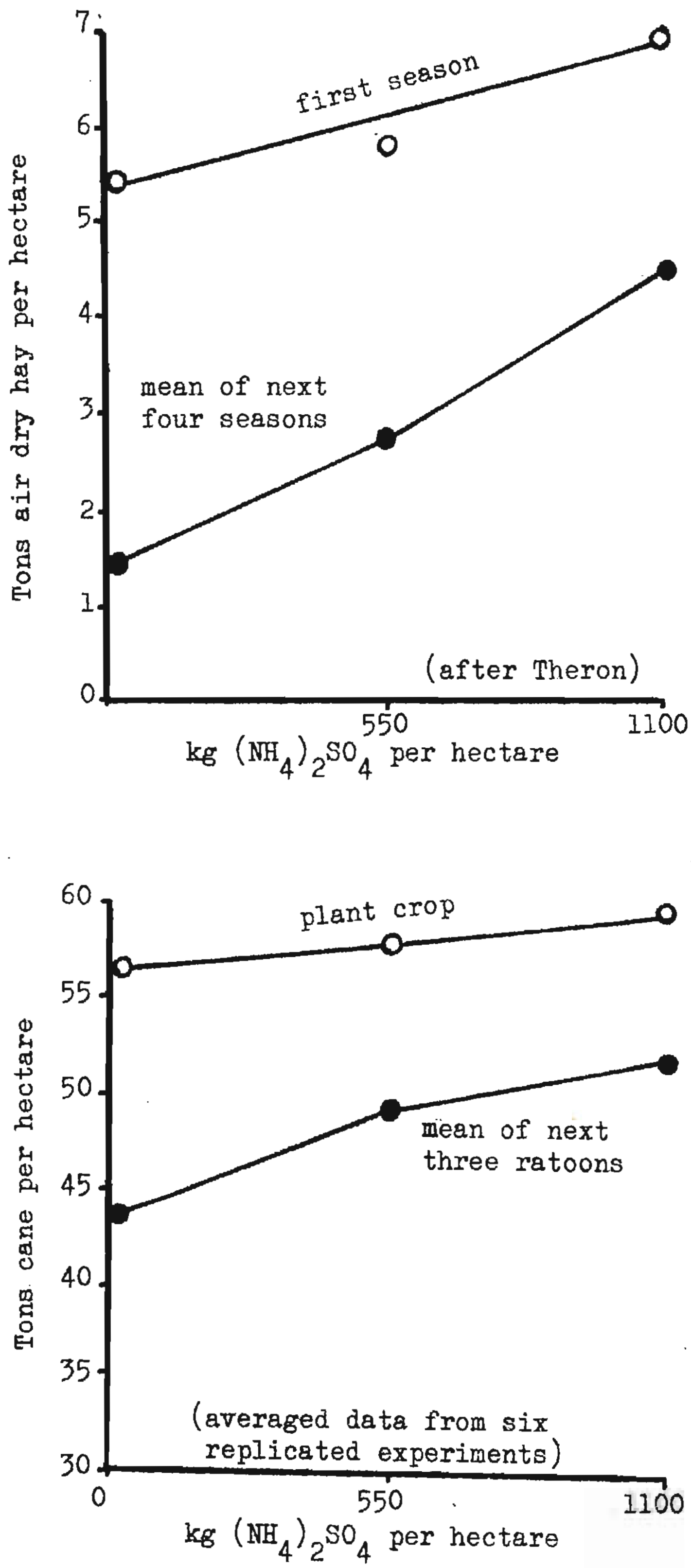


Fig. 7 Patterns of response to applied N shown by grass and sugarcane

CHAPTER 5

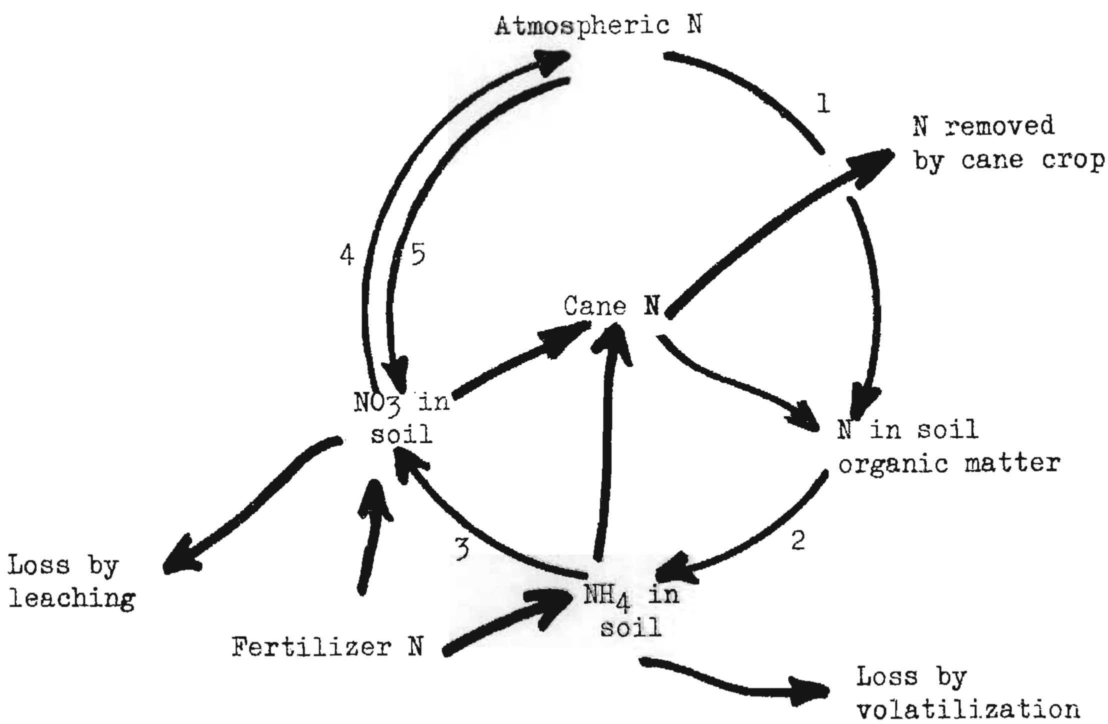
THE NITROGEN CYCLE IN RELATION TO SUGARCANE

Nitrogen transformations

It would be appropriate at this stage to consider the systems governing the availability of both natural and commercial sources of N to the sugarcane crop. Effective utilization of N depends on an understanding of the transformations which N undergoes in the soil. Many of the transformations proceed simultaneously and may compete with one another for particular forms of N as indicated in Figure 8. Martin (1966) has pointed out that for a particular ecosystem the N cycle is best regarded as a flow sheet of possibilities, rather than a closed system involving quantitative circulation of N indefinitely.

The transfer of N from the atmosphere to the soil other than in rainfall is primarily by microbiological fixation of molecular N_2. Amounts of N produced by non-symbiotic fixation generally appear to be small and are almost impossible to assess accurately under field conditions (Martin et al. 1962; Moore 1966). Anderson (1962), in a survey of N fixing bacteria in South African sugarcane soils noted an interesting feature concerning the incidence of Azotobacter in Table Mountain Sandstone soils (Cartref series). As reported in Chapter 4 large responses to applied N are usually obtained on soils of this series, and all samples examined consistently showed a very low incidence of Azotobacter. On the other hand a high incidence of Azotobacter (indicative of a large population) was always found in Recent red sands (Clansthal series). Anderson suggested that this could partially explain the lack of large responses to applied N often noted on these sands.

In an intensive production system such as sugarcane growing, in which the plant is regularly cut and removed from the field, the most important transformation in the N cycle is that concerned with



1 Non-symbiotic N fixation

2 Ammonification

3 Nitrification

4 Denitrification

5 N from rainfall etc.

* Fig. 8 N transformations in a sugarcane crop receiving fertilizer N.

uptake of fertilizer N by the crop. Other transformations are important primarily because they may result in permanent or temporary losses of fertilizer N to the crop.

* The soil-nitrogen-fertilizer system

Widely accepted present day views of the soil-nitrogen-fertilizer system are summarised diagrammatically in Figure 9, which has been adapted from the work of Jansson (1958).

When fertilizer nitrate nitrogen (NO_3-N) is added to the soil it becomes part of a soluble NO_3-N pool available for plant uptake. Some may be lost due to leaching and where oxygen supply is limited denitrification of NO_3-N by soil micro-organisms can occur leading to gaseous N losses. Jansson et al. (1955) have shown that in the presence of ammonium nitrogen (NH_4-N) only a small fraction of the NO_3-N participates in the internal N cycle of the soil ie. those transformations concerned with mineralization and immobilization.

When NH_4-N is added to the soil it generally enters actively into the internal N cycle. Exchangeable NH_4-N, which is that adsorbed on readily accessible sites of the soil colloid, is immediately available for (a) plant uptake; (b) nitrification by autotrophic micro-organisms (Nitrosomonas and Nitrobacter) or (c) immobilization into organic N forms by heterotrophic micro-organisms. These three processes may proceed simultaneously until the surplus NH_4-N pool is exhausted. Additional NH_4-N may be produced by mineralization of soil organic matter. Some of the NH_4^+ ions may be held in the interlayer positions of the clay minerals present in the soil and are rendered non-exchangeable (fixed NH_4^+ pool).

Freshly immobilized N present in the microbial tissues is initially readily mineralizable and at this stage forms the active organic N pool (Jansson, 1958). However this represents only a small

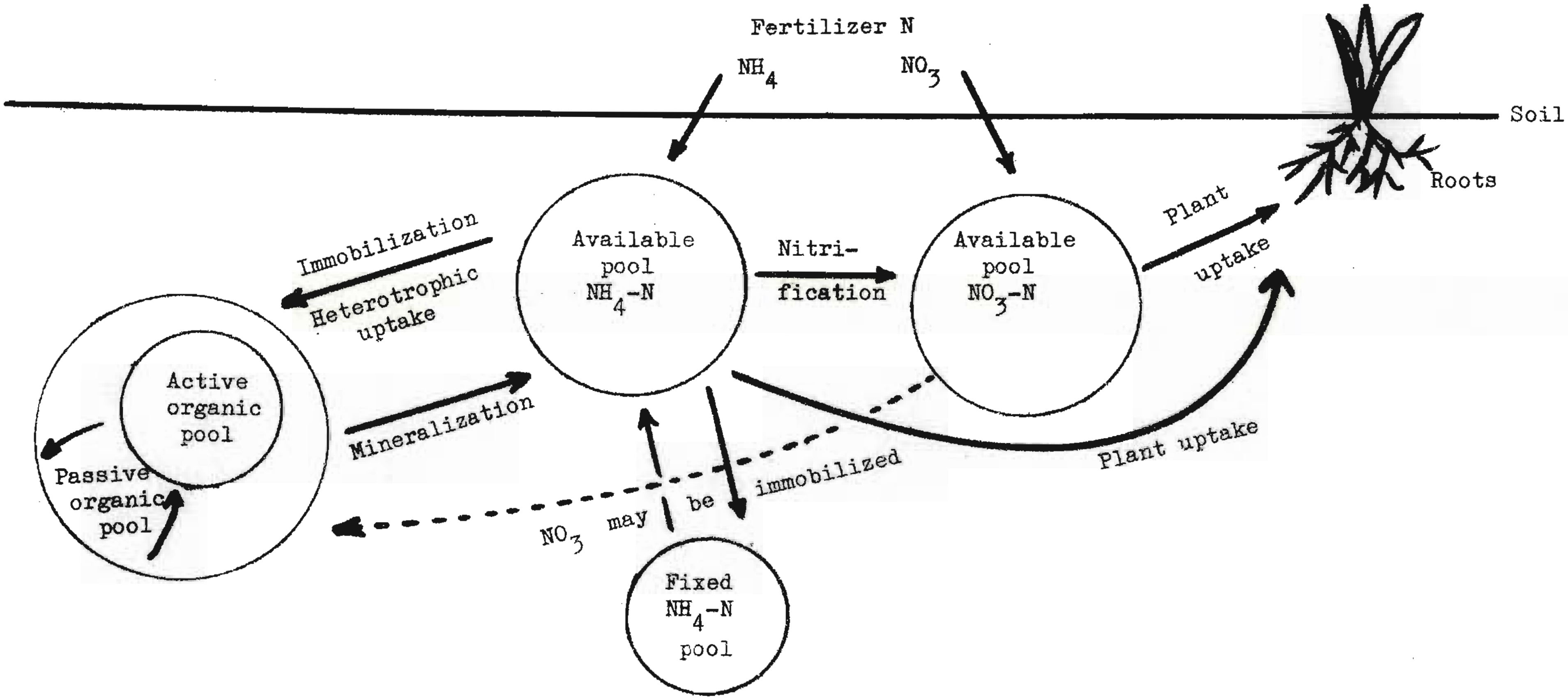


Fig. 9 The soil-nitrogen-fertilizer system (after Jansson)

fraction of the total soil organic N pool, referred to as the 'passive pool', as it does not actively participate in the rapid cycling of soil N because of its resistance to biological attack. It is however slowly mineralized releasing N which is utilized in the NH_4-N and NO_3-N pools.

Competition for nitrogen

From the foregoing it is apparent that competition exists between N immobilizing micro-organisms, the nitrifiers and the plant roots for fertilizer ammonium. The heterotrophic micro-organisms must therefore exert their greatest influence on plant uptake of N when the NH_4-N level in the soil is low. This is likely to occur frequently under sugarcane, as it does under many grasses, due to the high root density encountered. The writer has found the equivalent of 50 metric tons of roots per hectare on a fresh weight basis. The roots often have a wide C/N ratio ($>$ 40) unless high rates of fertilizer N have recently been applied. This means that in many soils there must frequently be insufficient N to meet the total requirement for microbial decomposition, so that the heterotrophs make up the deficit by using much or all of the available soil and fertilizer N. Immobilization of N is likely to occur when the C/N ratio of the material undergoing decomposition is higher than 30 : 1 (Gasser 1969). Mineralization of N can generally be detected when the ratio is less than 20 or 25 : 1 (Harmsen and Kolenbrander 1965).

Roots and root hairs of living plants are known to support a vast microbial population that feeds upon root cells and organic compounds secreted or excreted via the roots (Starkey 1958 : Subba - Rao et al. 1962). These rhizosphere micro-organisms are also able to immobilize a variable quantity of N depending on the amount of readily oxidizable C released by the roots. If necessary they too will utilize any available N to the detriment of the plant.

Though the decomposition of organic materials eventually results in the release of mineral N from the soil, the rate of release as indicated above depends largely on the C/N ratio of the organic matter, as discussed further in section B of Chapter 9.

Nitrogen losses from the system

Leaching As on most soils under grass, losses due to leaching under cane are generally considered to be small, mainly because of the marked capacity of both grass and cane to absorb N soon after application (Bishop 1965, Yuen and Borden 1937). Accurate data showing magnitude of losses under different soil conditions are not easily obtainable and results show wide variation. Losses can be expected to be most serious on light sandy soils, where fertilizer N is applied in the nitrate form, though they are probably appreciable on other soils if fertilizer application is immediately followed by heavy rain. Leaching losses will be considered further in Chapters 10 and 11.

Denitrification It is probable that gaseous losses of N as N_2 or N_2O due to microbiological reduction of nitrate must occur under sugarcane, though this would be difficult to assess quantitatively under field conditions. The main evidence for the occurrence of denitrification under cane is from experiments in which recoveries of labelled fertilizer N from the soil-plant system have been far below 100%, and cannot be attributed entirely to leaching. (Takahashi 1970 a and b).

Although dentrification usually occurs in conditions of low oxygen partial pressure, which in soils is generally associated with high moisture content, gaseous losses can apparently be obtained under relatively well aerated conditions. Ekpete and Cornfield (1964) indicated that when organic matter was applied to a soil together with nitrate, large denitrification losses could occur even at low soil moisture levels. Woldendorp (1963) using labelled N demonstrated significant denitrification losses of N from grasses during periods of intense root activity, which might well apply to sugarcane. In these instances respiration by living roots plus the associated rhizosphere microflora, is responsible for lowering the soil oxygen level faster than it can be replaced by diffusion from the atmosphere. Oxygen is then obtained from oxidised forms of N such as NO_3 present in the soil, the oxygen serving as a hydrogen acceptor.

Woldendorp was largely able to correct N balance sheets in grassland when these losses were taken into account. Where the plant is rapidly absorbing applied N in the field, as usually occurs under newly developing ratoon cane, it seems unlikely that substantial losses due to denitrification will take place, unless annerobic conditions develop shortly after fertilizer application. Nonetheless Woldendorp et al. (1965) maintain that conditions are often very favourable for denitrification where root density is high, as it is under cane. Also the number of denitrifying organisms in the rhizosphere is much higher than in non-rhizosphere soil, and in many cases after application of fertilizer N there is a considerable flow of nitrate through the rhizosphere zone.

In addition to microbiological denitrification, it is possible for loss of N to occur through chemical reactions in the soil. The chief reaction is thought to be the formation of ammonium nitrite from ammonia and nitrous acid, and its decomposition into gaseous N and water. (Martin and Skyring 1962). Little is known about the practical importance of these reactions, but Martin and Skyring say that losses of N under grass (and probably cane), where soil nitrate content is usually very small, are difficult to explain on any other hypothesis than through ammonia removal.

In the remaining chapters, ways in which transformations in sugar belt soils are able to influence N utilization by cane are examined, together with various factors that modify N transformations in the sugarcane ecosystem.

CHAPTER 6

MATERIALS AND METHODS

General information is now presented about the soils used, and materials (if any) added to them, together with brief details of experimental procedures and analytical methods. Additional information with regard to individual experiments will be given in the chapters concerned.

Soils

These were selected to cover the widest possible range. The marked differences in texture, organic matter content, soil reaction and nutrient status occurring between soils from various series, are shown in Table 17.

The methods of analysis used were as follows:

(a) Mechanical composition - Bouyoucos (1951), hydrometer method.

(b) Soil pH - 1 : 2,5 soil-water suspension measured with a glass electrode.

(c) Organic carbon - Walkley and Black (1934) volumetric method.

(d) Total N - semi-micro Kjeldahl procedure (Bremner, 1960a).

(e) Available phosphate - adaptation of Truog's method (1930), using a soil : solution ratio of 1 : 50 and shaking for 15 minutes.

(f) Cation exchange capacity (C.E.C.) - following saturation of the soil with N ammonium acetate at pH 7,0.

(g) Exchangeable bases - K, Na, Ca flame photometrically on aliquots of the ammonium acetate leachate; Mg by atomic absorption.

Organic materials

In certain experiments plant residues were added. The materials used were either cane trash (a finely ground composite sample of dead basal leaves and sheaths of sugarcane), or cane roots of different C/N ratios. Analytical data are given in Table 18.

ABLE 17. Some physical and chemical properties of the soils investigated

Soil series	Mech. comp. %				Textural	pH	%	%	C/N	ppm	Exchangeable bases me %				me %
	CS	FS	S	C	Group*		org. C	N	ratio	P	K	Ca	Mg	Na	CEC
Doveton	17	23	10	49	c	5,8	2,82	0,14	20,1	49	0,46	5,2	1,9	0,19	12,5
Glenrosa	54	22	9	15	sl	5,3	1,02	0,05	20,2	9	0,37	0,5	0,8	0,08	3,9
Mayo	35	34	7	21	scl	5,1	2,27	0,10	22,7	3	0,32	4,4	1,2	0,10	8,7
Cartref	56	30	5	9	s	4,9	1,07	0,05	21,4	29	0,23	0,6	0,5	0,08	2,9
Inanda	20	26	13	42	sc	5,1	5,94	0,15	39,6	57	0,24	1,1	0,9	0,17	11,9
Williamson	15	40	14	32	scl	5,4	2,07	0,12	17,3	27	1,17	2,4	1,6	0,11	12,8
Milkwood	11	17	25	44	cl - c	5,8	3,78	0,16	23,6	16	0,23	4,9	4,8	0,21	23,2
Windermere	14	36	16	33	scl	5,2	2,11	0,12	17,6	16	0,71	1,9	1,6	0,15	10,7
Estcourt	14	59	7	18	sl	6,2	1,32	0,08	16,5	4	0,22	2,8	2,8	0,36	10,1
Shortlands	8	18	11	59	c	6,2	3,63	0,16	22,7	2	0,61	5,2	4,0	0,23	18,7
Rydalvale	4	16	17	60	c	5,9	5,53	0.26	21,3	7	1,94	2,0	8,4	0,37	32,0
Clansthal	63	25	3	9	s	6,2	0,74	0,05	14,8	40	0,20	1,2	0,7	0,07	3,6
Shorrocks	21	60	5	14	ls	4,6	0,96	0,05	19,2	34	0,15	0,7	0,7	0,07	4,3
Fernwood	50	41	2	6	s	5,5	0,70	0,04	17,5	7	0,07	0,7	0,6	0,08	2,9
Dundee	13	10	24	54	cl	5,5	3,11	0,18	17,3	19	1,81	4,9	4,3	0,25	20,1

= sand ls = loamy sand sl = sandy loam scl = sandy clay loam sc = sandy clay c = clay cl = clay loam

TABLE 18. Analysis of organic residues used

Material	% C	% N	C/N ratio	% P	% K	% Ca	% Mg	% Na
Cane trash	42,6	0,280	152,0	0,03	0,09	0,33	0,19	0,03
Roots - high C/N ratio	44,0	0,438	100,5	0,11	0,86	0,16	0,06	0,09
Roots - low C/N ratio	40,0	0,785	50,9	0,16	0,86	0,22	0,08	0,16

The methods of analysis used were as follows:

(a) Organic carbon - a modification of Tinsley's method (1950), for determining total C by wet combustion.

(b) Total N - semi-micro Kjeldahl procedure (Bremner and Shaw, 1958).

(c) All other nutrient determinations were carried out on aliquots of digestate from (b) above, using a colorimetric or flame photometric procedure.

Procedure for incubation experiments

Nitrogen transformations To work at the standard moisture conditions required in incubation studies, the water holding capacity (WHC) of both soils and organic materials added was required. The method used was that of Jansson (1958), and the results obtained are given in Table 19.

Initially soils were moistened to between 50 and 60% WHC, this being close to field capacity and considered optimal for aeration and microbiological activity. (Stevenson 1956; Saunder 1959). However, following experiments in which N was applied, it was evident that considerable N losses, probably due to denitrification were occurring, particularly on sandy soils. To minimise such losses which had also been noted by Jansson and Clark (1952), the moisture level was reduced to 30% WHC, and this did not appear to affect the rate of mineralization. Organic materials were moistened to 50% WHC throughout.

At first small samples of soil were incubated in separate flasks, but this procedure became impractical in later studies where large amounts of soil were required and space was limited. Bulk samples of various treatments were therefore incubated in large sealed preserving jars which were regularly aerated, and sub-samples were removed for N analysis as required.

TABLE 19. Water holding capacity (WHC) of the soils and organic residues

Soil series	Textural group	Water as per cent of air dry soil at saturation
Cartref	sand	34
Fernwood	sand	38
Clansthal	sand	42
Shorrocks	loamy sand	42
Glenrosa	sandy loam	44
Inanda	sandy clay	46
Mayo	sandy clay loam	47
Williamson	sandy clay loam	47
Windermere	sandy clay loam	48
Estcourt	sandy loam	50
Rydalvale	clay	51
Milkwood	clay loam	52
Doveton	clay	54
Dundee	clay loam	56
Shortlands	clay	62
Organic material		
sugarcane trash		600
sugarcane roots		700

Carbon mineralization Measurements of C mineralized were made in conjunction with N mineralization studies in several incubation experiments, so that microbial activity under various treatments could be determined. The samples used were generally taken from the bulk samples mentioned above, just prior to incubation. The modified respirometer technique of Birch and Friend (1956), was used throughout for measuring C mineralized, using a thermostatically controlled water bath as shown in Plate 1.

Procedure for pot experiments

The polystyrene pots used each held 1,5 kg of air dried soil (2 mm sieved). Where organic materials were incorporated these were mixed with the soils beforehand. Soils were watered only to 50% WHC, and first watering was with a nutrient solution supplying 100 ppm K and 80 ppm P, and where appropriate varying levels of fertilizer N. To facilitate even distribution of water and nutrients throughout the soil, all solutions were applied down a perforated nylon tube situated in each pot. All pots were sealed at the base to prevent leaching.

Pots to be cropped were planted just prior to first watering, and were kept together with any uncropped treatments in a glasshouse throughout each experiment. Pots were watered daily and where cropped amounts added were adjusted to allow for increase in plant weight with time.

At harvest the plant top was removed, and after rapidly air drying the soil the roots were generally separated from it and washed. All plant parts were dried at 65°C in a forced draught oven for 24 hours, after which they were ground in a Wiley mill and stored prior to N analysis. A sub-sample of air dry soil was also set aside for N analysis from all cropped and uncropped pots.

The determination of soil and plant nitrogen

Inorganic nitrogen   Initially in soil incubation studies the extractant solution used was N KCl in 0,1 N HCl, but this was replaced by N K_2SO_4 in 0,1 N H_2SO_4 when the [illegible]

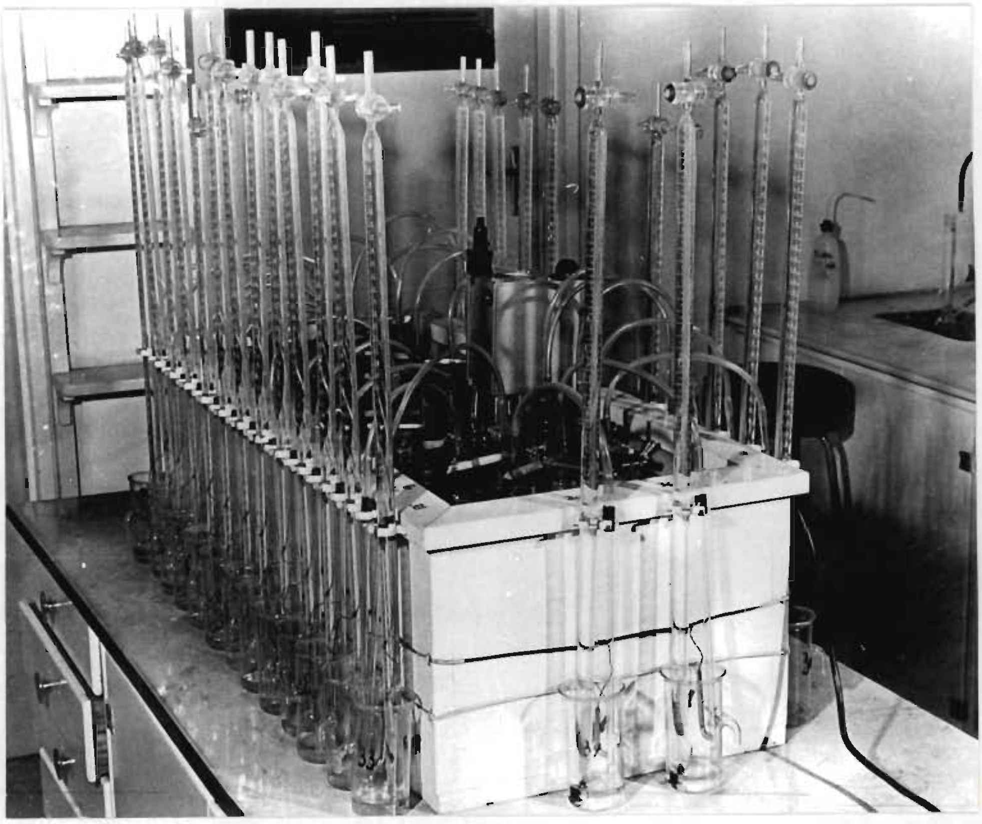


Plate 1 The equipment used for measuring carbon mineralization by the respirometer technique

tion of N by Nesslerization was discontinued.

A solution : soil ratio of 2 : 1 was used throughout, samples being shaken for 15 minutes prior to filtration. No quantitative recovery of extracts was made and aliquots of the filtrate were taken for NH_4-N and NO_3-N determinations. The procedure of Saunder et al. (1957), was soon replaced by Bremner's method (1960b), which uses MgO and titanous sulphate for the release of the NH_4-N and NO_3-N fractions extracted. This proved to be simple, rapid and accurate, and allowed for the handling of large numbers of samples. Furthermore it readily permitted preparation of samples for isotope-ratio analysis of N.

Total nitrogen In both soils and plant material a semi-micro Kjeldahl procedure based on the method of Bremner and Shaw (1958) and designed to include NO_3-N was used. Ammonia was steam distilled from the diluted digests made alkaline with NaOH collected in boric acid and titrated with standard H_2SO_4.

Organic nitrogen Where a balance sheet of total soil N was required, organic N was determined in soils from which mineral N had previously been extracted. The residue left after filtering was leached with distilled water until all inorganic N had been removed. It was then dried to constant weight at $35^{\circ}C$ and after grinding, organic N determined by the standards Kjeldahl procedure.

Tracer nitrogen Where fertilizers with labelled N were used the content of excess ^{15}N ranged from 2,5 to 5,0 atom %, calculated on the basis of the total N of the fertilizer.

Ammonia liberated by steam distillation from samples containing ^{15}N was collected in dilute HCl. The equipment used was subjected to the ethanol distillation technique (Bremner and Edwards 1965) between steam distillations in order to eliminate any memory effects due to the retention of labelled ammonia.

The NH_4Cl solutions containing up to 5 mg N were each concentrated to a volume of 1 - 2 ml at 100^oC. The concentrated samples were treated in a vacuum with alkaline sodium hypobromite - iodide solution according to the method of Sprinson and Rittenburg (1949), as modified by Bremner (1965). The N_2 gas liberated from each sample was measured in an Atlas M 86 mass spectrometer.

The equations used for the calculation of results are given in Appendix 1.

CHAPTER 7

ASSESSING THE POTENTIAL OF SUGAR BELT SOILS TO SUPPLY NITROGEN TO SUGARCANE

Various workers including Birch 1958, 1960; Saunder et al. 1957; Stevenson 1956; Winsor and Pollard 1956, have shown that air dried soils on subsequent rewetting are able to release considerable quantities of N by mineralization. Such rewetted soils generally produce larger amounts of mineral N than the corresponding field moist soils (Cooke and Cunningham 1958, Harpstead and Brage 1958; Munro and Mackay 1964). To some extent this effect depends on the nature and content of soil organic matter, often being more pronounced, the larger the amount of humus present in the soil (van Schreven 1956).

When ratoon cane is ploughed out and replanted, the soil is often exposed to air drying for several weeks. At the onset of the next rains accelerated mineralization of N must frequently occur as described above. As the amount of N released was seen to influence plant crop response to applied N as discussed in Chapter 5, laboratory and glasshouse experiments were carried out to measure the relative capacities of a wide range of soils to supply plant available N.

A Pot experiment to determine N potential of different soil series

PROCEDURE

Trudan (Sorghum sudanense) was grown in pots containing 1,5 kg soil, taken from 12 different soil series. The soils were treated with $(NH_4)_2SO_4$ at four levels of application equivalent to

0, 55, 110 and 220 kg N per hectare. Standard P and K dressings were applied to all pots of both the plant and first ratoon crops. The soils were taken from the 0-15 cm layer under third ratoon cane, air dried and sieved (2 mm).

For each soil series, three replicates of the four N levels were cropped for either five weeks (plant crop) or seven weeks (first ratoon crop). The trudan tops were then harvested, oven dried, weighed and analysed for N content. Pre-treatment of the first ratoon crop prior to application of N fertilizer treatments, was the production and removal of a plant crop after five weeks, to which N had been applied at the rate of 110 kg per hectare.

The relative amounts of N mineralized by soils from the various series used, were measured after they had been moistened and incubated at 30°C for two weeks.

RESULTS

Responses to applied N in the plant crop were linear and similar for all soils over the range of N levels tested as shown in Table 20. However, the results averaged over all N fertilizer treatments indicate that highly significant differences existed between the amounts of N taken up from soils of the different series. These differences were apparent in the growth of the control treatments at time of harvest as shown in Plates 2A and B. Differences in mean uptake of N between soil series in the ratoon crop though significant were much smaller, and N uptake greatly reduced at all fertilizer levels on all soils (see Table 21). At harvest few differences in growth were observed between the various control treatments of the ratoon crop.

TABLE 20. Uptake of N (mg N per pot) by trudan (plant crop) (N applied at four levels to twelve soils)

Soil series	Level of N applied				Mean
	0 kg N	55 kg N	110 kg N	220 kg N	uptake
Cartref	16,4	38,7	63,8	112,6	57,9
Fernwood	17,2	47,5	69,7	125,9	65,1
Windermere	25,8	53,2	75,4	139,1	73,4
Milkwood	25,9	53,2	86,8	146,1	78,0
Doveton	26,0	52,0	84,7	129,5	73,1
Williamson	30,1	57,0	88,8	161,4	84,3
Clansthal	35,5	61,6	91,7	152,3	85,3
Inanda	36,5	61,6	89,7	145,5	83,3
Mayo	45,0	68,0	95,7	159,1	92,0
Rydalvale	46,8	60,8	82,1	140,3	82,5
Dundee	52,6	75,0	106,0	176,9	102,6
Shortlands	60,1	89,1	108,0	174,1	107,8
Mean	34,8	59,8	86,9	146,9	82,1
S.E. of treatment mean			± 4,0		± 2,0
LSD p = (0,05)			11,2		2,8
(0,01)			14,9		5,6
C.V.%			8,4		

A

B

Plate 2 Differences in N uptake from soils of eight different series, as reflected in growth of trudan control treatments (no N) at time of harvest of the plant crop.

TABLE 21. Uptake of N (mg N per pot) by trudan (ratoon crop) (N applied at four levels to twelve soils)

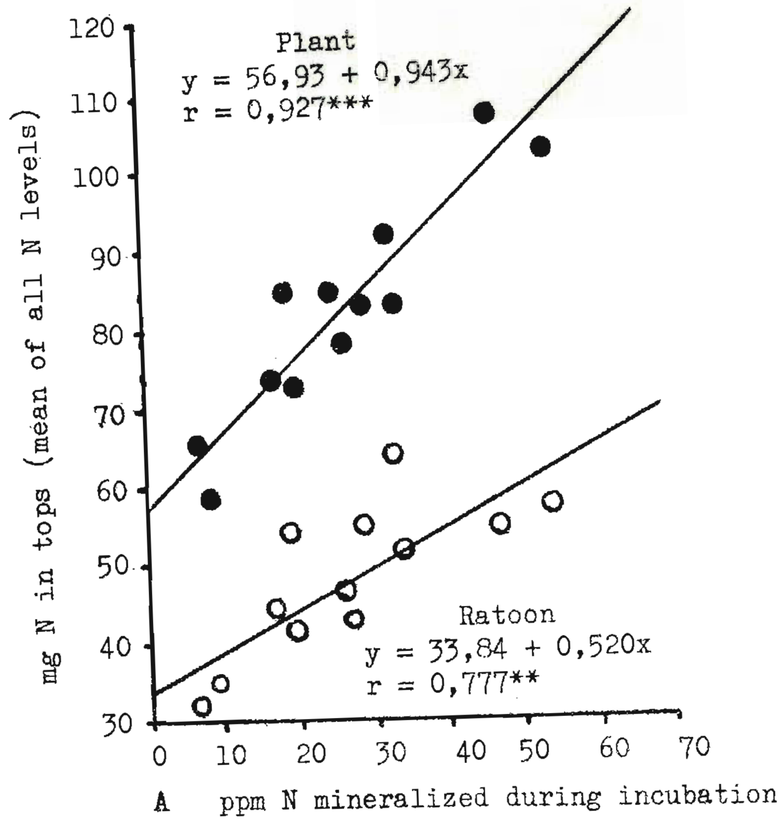
Soil series	Level of N applied				Mean
	0 kg N	55 kg N	110 kg N	220 kg N	uptake
Cartref	13,8	37,0	41,2	44,3	34,1
Fernwood	13,4	33,0	55,1	25,8	31,8
Windermere	14,9	25,0	43,3	90,4	43,4
Milkwood	13,7	24,0	42,6	89,3	42,4
Doveton	10,9	24,7	44,1	86,9	41,7
Williamson	13,4	28,1	48,5	95,3	46,3
Clansthal	16,9	35,7	57,7	104,6	53,7
Inanda	14,1	33,2	59,0	108,4	53,7
Mayo	28,7	46,3	65,3	111,2	62,9
Rydalvale	11,0	34,1	53,0	105,2	50,8
Dundee	20,6	34,2	61,8	111,4	57,0
Shortlands	23,0	35,3	57,1	103,4	54,7
Mean	16,2	32,6	52,4	89,7	47,7
S.E. of treatment mean			± 2,8		± 1,4
L.S.D. (0,05)			7,7		3,9
(0,01)			10,3		5,1
C.V.%			10,0		

Total mineral N in the soils after two weeks incubation, and N mineralized during this period are shown in Table 22.

TABLE 22. Release of mineral N during a two week incubation period by soils from twelve different soil series

Soil series	Total N %	Total mineral N ppm before incubation	Total mineral N ppm after incubation	ppm N mineralized
	S.E.	± 1,5	± 1,7	± 2,3
Fernwood	0,037	7,0	14,0	7,0
Cartref	0,035	6,5	15,0	8,5
Doveton	0,135	5,0	24,5	19,5
Windermere	0,168	11,0	28,5	17,5
Milkwood	0,253	5,0	31,5	26,5
Clansthal	0,053	13,0	32,0	19,0
Williamson	0,140	9,5	35,0	25,5
Mayo	0,124	7,5	40,5	33,0
Inanda	0,219	13,0	42,0	29,0
Rydalvale	0,220	9,0	42,5	33,5
Shortlands	0,247	9,5	56,5	47,0
Dundee	0,207	10,0	64,0	54,0
Mean		8,8	35,5	26,7

Both were highly correlated with N removed by the plant crop when averaged over all fertilizer treatments (see Figure 10,A and B). The same data showed a poorer, but still significant correlation with N taken up by the ratoon crop. N removal by the plant crop control treatments (no N) also correlated closely with N mineralized



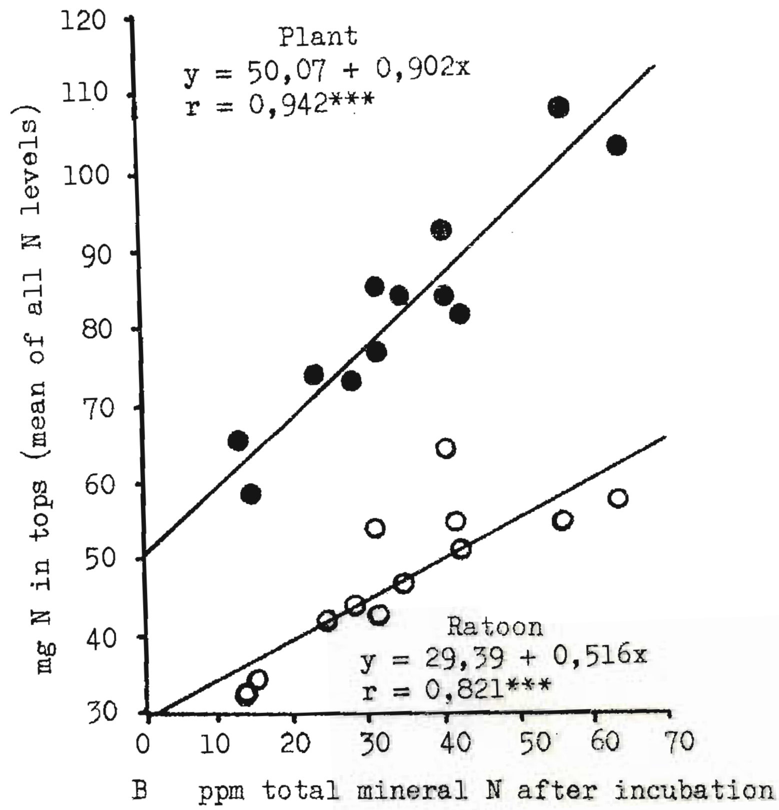


Fig. 10 Relationship between A (N mineralized), B (total mineral N), and N uptake by plant and ratoon crops of trudan.

during incubation (r = 0,924 ***). Correlation with N removed by the ratoon crop controls was poor, though just significant (r = 0,541*).

Soils low in total N (see Table 22) tended to yield less N to the plant crop than soils with higher N contents. However the correlation between total N and N uptake in the control treatments shown in Figure 11, though significant (r = 0,602*), is not thought to be sufficiently good to provide more than a rough estimate of available soil N. No correlation was found between total N and N removed by the ratoon crop control treatments.

More detailed results of this experiment are presented in Appendix 2.

B Pot experiment to measure variability in N potential between sites within a soil series

To be meaningful the N potential determined for a soil of a particular series must be generally applicable to all soils of that series. To measure variability in potential from site to site the following glasshouse experiment was run concurrently with that just described.

PROCEDURE

Trudan was grown in pots containing soils taken from six widely scattered sites, for each of three soil series. Analysis of soils and location of sites are given in Appendix 3. The pots received either no nitrogen or an application equivalent to 55 kg N per hectare as $(NH_4)_2SO_4$. For each soil, three replicates of the two N levels, were cropped for six weeks, after which the trudan tops were harvested, oven dried, weighed and analysed for N content. Amounts of N mineralized by all soils used, were measured following incubation at $30^{o}C$ for two weeks.

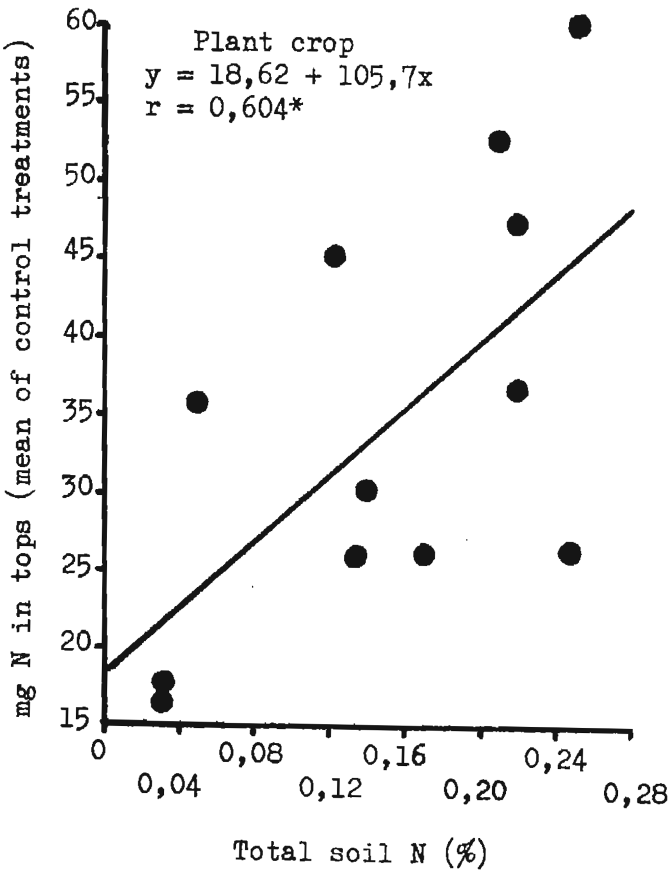


Fig. 11 The relationship between total soil N and N uptake by trudan. (Plant crop control treatments).

RESULTS

Table 23 shows that the average amount of N taken up by plants grown in soil from different sites of the Cartref and Mayo series was fairly consistent within series.

TABLE 23. Mean uptake of N (mg N per pot*) by trudan (N applied at two levels to soils from six sites and three soil series)

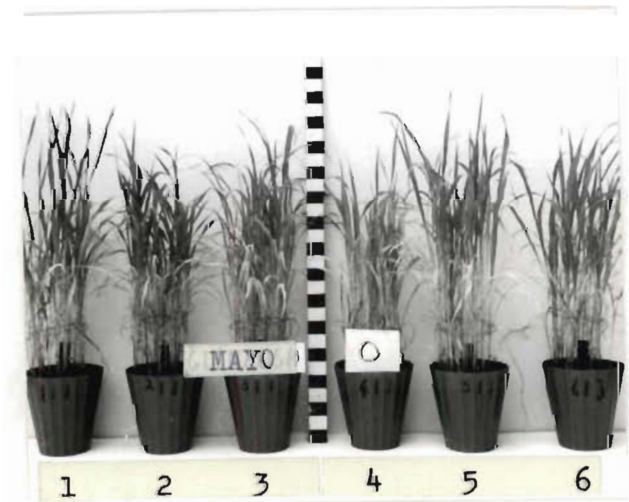
Soil number	Cartref	Mayo	Shortlands
S.E.	± 1,2	± 0,9	± 1,6
1	34,4	52,4	82,8
2	33,3	45,0	45,4
3	40,3	42,1	98,9
4	33,2	35,8	50,1
5	34,0	47,4	71,8
6	44,8	49,1	88,8
Mean	36,6	45,3	73,0

* mean of six pots

The amount of N removed from soil of the Shortlands series was however, uncharacteristically low in two instances (soils 2 and 4). This was subsequently associated with heavy dressings of filter press mud previously applied to these soils, which adversely affected N mineralization (see Table 24). The data nevertheless indicate that each soil series appears to have a reasonably well defined N potential which differs from series to series. This is clearly reflected in the growth differences between series shown by the control treatments at time of harvest (See Plate 3).

Cartref

Mayo



Shortlands

Plate 3 Variation in N potential between soils of three different series as reflected in the growth of trudan control treatments (no N) at time of harvest. The similarity in N potential between soils of the same series but taken from six different sites is clearly seen. (Site number is given in each photograph)

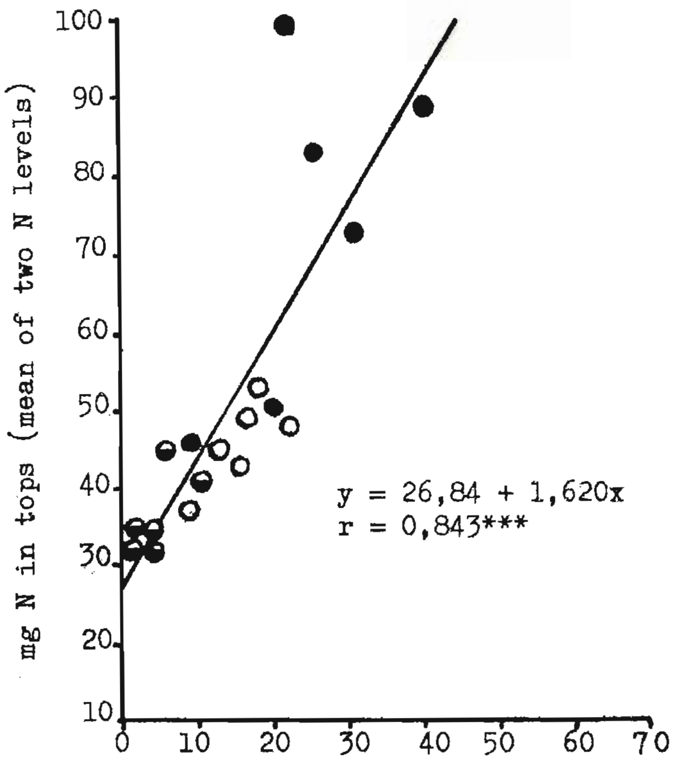
TABLE 24. Total mineral N present after two weeks incubation (means of six sites and three soil series)

Soil No.	ppm total mineral N		
	Cartref	Mayo	Shortlands
S.E.	± 2,3	± 1,4	± 3,4
1	13,5	28,5	52,4
2	14,0	26,5	21,5
3	18,0	24,0	59,5
4	7,5	17,0	29,0
5	8,5	25,5	41,5
6	14,5	26,0	51,0
Mean	12,7	24,6	42,5

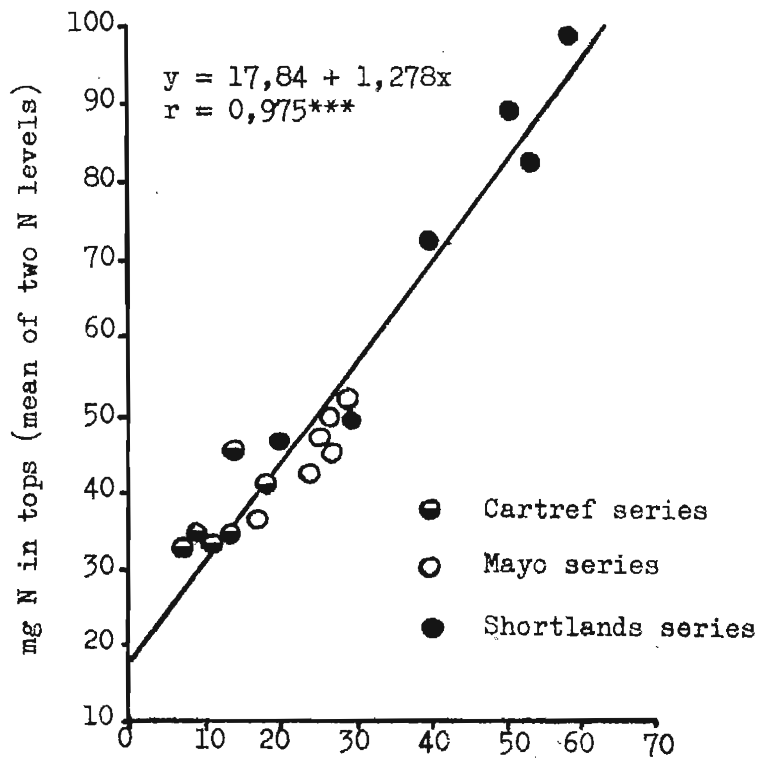
As in pot experiment A, both total mineral N in the soil after two weeks incubation and N mineralized during this period, were closely correlated with plant uptake of N as shown in Figure 12A and B. Detailed results of this experiment are presented in Appendix 3.

C The effect of period of soil drying on subsequent N release.

In 1960, Birch using a series of laboratory composited soils, showed that the amount of N mineralized by a soil depends on the period of time it is allowed to remain dry before being rewetted. As the magnitude of N release following length of drying could well influence cane response to applied N, it was decided to determine how closely Birch's findings applied to a range of sugar belt soils.



A ppm N mineralized during incubation



B ppm total mineral N after incubation

Fig. 12 Relationship between A (N mineralized), B (total mineral N), and N uptake by trudan grown on soils from various sites representing three different soil series.

PROCEDURE

Bulk samples of soil representing 13 different series were moistened to 50% WHC and incubated at 30°C for 14 days. Subsequently six equal amounts of each bulk sample (i - vi) were removed from the incubator and treated as follows:

(i) was extracted immediately for total mineral N

(ii) was returned immediately to the incubator for a further 19 days after which additional N mineralized was determined.

(iii-vi) were allowed to air dry at room temperature and left exposed for periods of 3, 6, 9 and 12 weeks respectively. They were then re-wetted to 50% WHC and returned to the incubator for a further 19 days, following which the additional N mineralized was determined. Simultaneously further samples were set aside and left exposed for similar periods so that any changes in moisture content could be checked.

RESULTS

Table 25 shows amounts of N mineralized by soils of the different series during 19 days incubation, following the various periods of drying, compared with no drying. The data confirm that the magnitude of N release increased in all soils with period of drying prior to incubation.

For example in the Dundee series soil, drying for 12 weeks led to the production on rewetting the soil (compared with no drying) of 179 kg N per hectare equivalent*, which is considerably more than the amount required to produce the normal rain grown cane crop.

* Equivalent amount in a [illegible]

TABLE 25. The effect of period of air drying on N mineralized (kg N per hectare equivalent) during incubation for 19 days

Soil series	Period of drying (wks) prior to rewetting				
	0	3	6	9	12
Dundee	58	137	179	217	237
	-	(4,1)	(3,6)	(4,5)	(4,7)
Rydalvale	69	105	141	168	199
	-	(9,8)	(7,8)	(8,7)	(4,7)
Milkwood	20	101	lost	139	166
	-	(3,9)	(3,3)	(2,7)	(3,2)
Shortlands	29	76	78	134	159
	-	(4,7)	(4,3)	(5,3)	(3,6)
Inanda	31	85	108	132	152
	-	(6,1)	(5,4)	(4,5)	(5,4)
Williamson	22	92	96	132	150
	-	(1,7)	(1,5)	(1,3)	(1,6)
Doveton	36	72	99	114	134
	-	(3,8)	(2,4)	(2,5)	(1,6)
Windermere	43	45	65	85	123
	-	(1,3)	(1,6)	(1,9)	(1,4)
Glenrosa	38	52	69	87	121
	-	(1,6)	(1,3)	(1,5)	(1,5)
Shorrocks	16	54	69	92	116
	-	(0,3)	(0,9)	(0,5)	(1,3)
Estcourt	9	43	69	85	108
	-	(2,4)	(1,5)	(2,3)	(1,0)
Cartref	11	40	43	83	99
	-	(0,7)	(0,3)	(0,5)	(0,7)
Fernwood	18	36	58	74	85
	-	(0,5)	(0,4)	(0,4)	(0,8)

Even for soils with relatively poor N potential such as those of the Cartref series, an amount of 88 kg N per hectare equivalent was produced. It is apparent from Table 25 however, that drying even for much shorter periods results in the subsequent release of substantial amounts of N from all soils.

The lack of any marked change in moisture content of most of the soils drying for between 3 and 12 weeks (see Table 25), suggests that it is the duration of the dry state that is in some way associated with the increased N mineralization that occurs. Birch attributes the possible mechanism involved to an enlargement of the organic surfaces exposed, either by fragmentation or increased porosity of the organic gels on drying, both leading to an increased surface area.

DISCUSSION

The results of experiments A, B and C confirm previous conclusions, namely that the type of soil greatly influences response to fertilizer N in the plant crop, and to a much lesser degree in the succeeding crops. They also provide a basis for predicting somewhat more accurately N fertilizer requirements for plant cane in the various soil series.

In pot experiment A, uptake of N by the plant crop where no N was applied, increased with increasing rates of N release from the different soils, as measured by N mineralized during a two week incubation period. Rate of N release from these soils is seen to correspond quite well with level of response to applied N obtained from the plant cane fertilizer experiments reported in Chapter 4. (Table 16 refers).

Thus the biggest responses in the field were usually found on soils which mineralized small amounts of N, namely those derived from Table Mountain Sandstone and Recent sands (Cartref and Fernwood series). The smallest responses on the other hand, came from soils derived from dolerite and alluvia (Rydalvale, Shortlands, and Dundee series), which as Table 22 shows mineralized large amounts of N. On the basis of the results from pot experiments A and B it should theoretically be possible to predict more accurately N fertilizer requirements for plant cane on many soils mineralizing intermediate amounts of N. In practice however this is far from straightforward.

Current N fertilizer recommendations for plant cane now take cognizance of the fact that some sugar belt soils mineralize less N than others, but even so a precise measurement of N available to the plant crop is not easily obtained. Much depends on when the ratoon crop is ploughed out, and for how long the soil remains dry before replanting, as this affects the magnitude of mineral N release on rewetting.

Under South African conditions, greatest benefit would probably be derived from ploughing out the old cane stools early in winter, especially on those soils with a relatively low capacity to mineralize N. Planting the new crop in spring would be advantageous as it normally follows a dry winter period. However a considerable amount of cane is autumn planted during the rains, at which time the soil is seldom exposed long enough after removal of the previous crop to permit prolonged drying to occur. Under these conditions reductions in the amounts of soil N mineralized could be expected. In addition seasonal effects as discussed in Chapter 4, could also be expected to influence soil N release in any particular crop cycle.

There appears to be even less likelihood of assessing reliably the amount of soil N released to ratoon cane crops. As shown in Chapter 4, the N supplying power of all but a few soils under cane (eg. alluvia) declines with time. This is confirmed by the fact that ratoon cane yields are usually only maintained by increasing the level of applied N. Examination of soils under established cane generally reveals only insignificant quantities of mineral N. This suggests that any soil N mineralized must be immediately reabsorbed by the plant or soil micro-organisms. Under these circumstances, laboratory mineralization data obtained, following removal of the soil from the field and the influence of the growing plant, is unlikely to bear much relation to N available for plant use.

In the foreseeable future therefore it is likely that application rates of N to ratoon cane will continue to be decided largely on an empirical basis of management and expected yield.

CHAPTER 8

CHANGES IN NITROGEN SUPPLYING POWER AND OTHER SOIL PROPERTIES UPON CULTIVATION

Various workers (Goring and Clark 1948; Harmsen and van Schreven 1955; Mortensen 1963; Thompson and Black 1949) have shown that when soils are first brought into cultivation rapid decomposition of organic matter occurs, resulting in the release of large quantities of mineral N. On certain soils the rate of N mineralization may be so high initially that for some time no significant response is obtained from the application of N. Simultaneously soil organic carbon is also rapidly mineralized to CO_2. Under cultivation this accelerated breakdown continues until much of the easily decomposed material has disappeared, that which remains being more resistant to attack. In consequence the rate of mineralization is in due course considerably reduced.

As the sugar belt contains a wide range of soils, it was decided to see what changes had occurred in their N supplying power and other properties after being brought into cultivation under cane.

PROCEDURE

Pairs of composite samples representing 13 different soil series, were taken to a depth of 15 cm under third ratoon cane and closely adjacent virgin veld. After air drying, they were passed through a 2 mm sieve.

Three aspects of the effects of cultivation were studied in the laboratory.

1) The relative amounts of C and N mineralized by the virgin and corresponding cultivated soils.
2) Relative patterns of decomposition with time.
3) Differences in N immobilization in the presence of added organic material.

For 1, 50g samples representing 10 different series of virgin and cultivated soils were moistened to 60% WHC and placed in respirometer vessels at 35°C for two weeks, after which amounts of C and N mineralized during this period were determined for each soil.

In 2, 10g samples representing virgin and cultivated soils of four series were moistened to 60% WHC and incubated at 35°C. After periods of 1, 2, 3, 4, 7, 11 and 14 days, samples from each series were extracted in order to obtain the pattern of N mineralized with time. C mineralized was obtained for the soils from daily measurements of CO_2 evolved in the respirometer vessels used in 1 above.

In 3, 30g samples of the soil pairs representing six different series were moistened as above, with or without 400 ppm C added as glucose. The samples were placed in the respirometer vessels for 6 days at 30°C, when amounts of C mineralized and total mineral N present were determined.

RESULTS

Amount of C and N mineralized The data in Table 26 show the much larger amounts of C and N mineralized in all virgin soils

TABLE 26. C and N mineralized during two weeks incubation

Soil series	Cultivated soils					Virgin soils				
	C mineralized		N mineralized		% colour *	C mineralized		N mineralized		% colour *
	ppm	kg/ha+	ppm	kg/ha+	adsorption	ppm	kg/ha+	ppm	kg/ha+	adsorption
Cartref	210	470	23	52	-	500	1120	37	83	-
Fernwood	245	549	25	56	67	495	1109	81	181	63
Windermere	520	1165	33	74	11	1285	2878	146	327	63
Williamson	430	963	34	76	50	655	1467	54	121	81
Inanda	400	896	35	78	38	1120	2509	138	309	77
Milkwood	465	1042	37	83	22	1830	4100	161	361	88
Shorrocks	375	840	48	108	29	415	930	52	116	86
Mayo	415	930	50	112	47	700	1568	78	175	62
Doveton	530	1187	57	128	74	610	1366	65	146	71
Shortlands	530	1187	63	141	47	720	1613	77	172	53

* Percentage adsorption in CCl_4 when soils exposed to triphenyl tetrazolium chloride (Roth 1965)

\+ Equivalent amount in a hectare to a depth of 15 cm when compared with their cultivated counterparts, while the potential to mineralize N varied from one soil to another as noted in earlier work. However, for the cultivated soils the amount mineralized in two weeks varied from 52 to 141 kg N (per hectare 15 cm equivalent), while for the virgin soils the range was far wider, being from 83 to 361 kg N per hectare. Losses of soil carbon were correspondingly higher in the virgin soils when compared with those from the cultivated soils.

The data in Table 26 revealed that a highly significant correlation ($r = 0{,}937^{***}$) existed between the amounts of C and N mineralized in both virgin and cultivated soils, as shown in Figure 13.

Patterns of decomposition with time The patterns of C and N mineralization occurring during the 14-day incubation of the four series of soil pairs, are shown graphically in Figures 14 and 15. The marked flush of mineralization following rewetting of the air dry soils can be observed in both virgin and cultivated soils, being more pronounced in the former. Both C and N mineralization declined rapidly after the second day, presumably as readily decomposable substrate was used up. After approximately one week, slow but steady rates of mineralization were attained, being consistently higher in the virgin soils.

N immobilization effects The data in Table 27 suggests that immobilization effects due to the presence of residues in the soil high in carbon, are likely to be more severe in cultivated, than in virgin soils. The increased C mineralization due to the added glucose, resulting in assimilation of part of the soil mineral N, is apparent in all soils. However sufficient N was mineralized in all but the Cartref series sand, to appreciably exceed that immobilized.

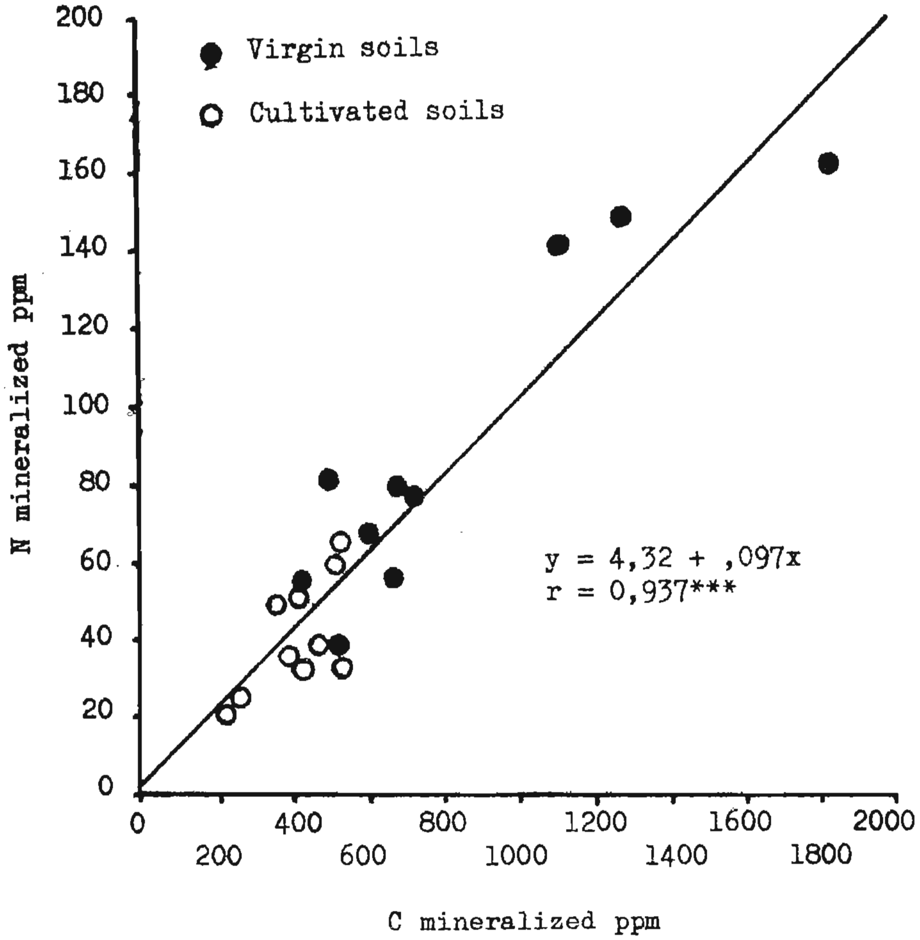


Fig. 13 Relationship between C and N mineralized by virgin and cultivated soils during two weeks incubation.

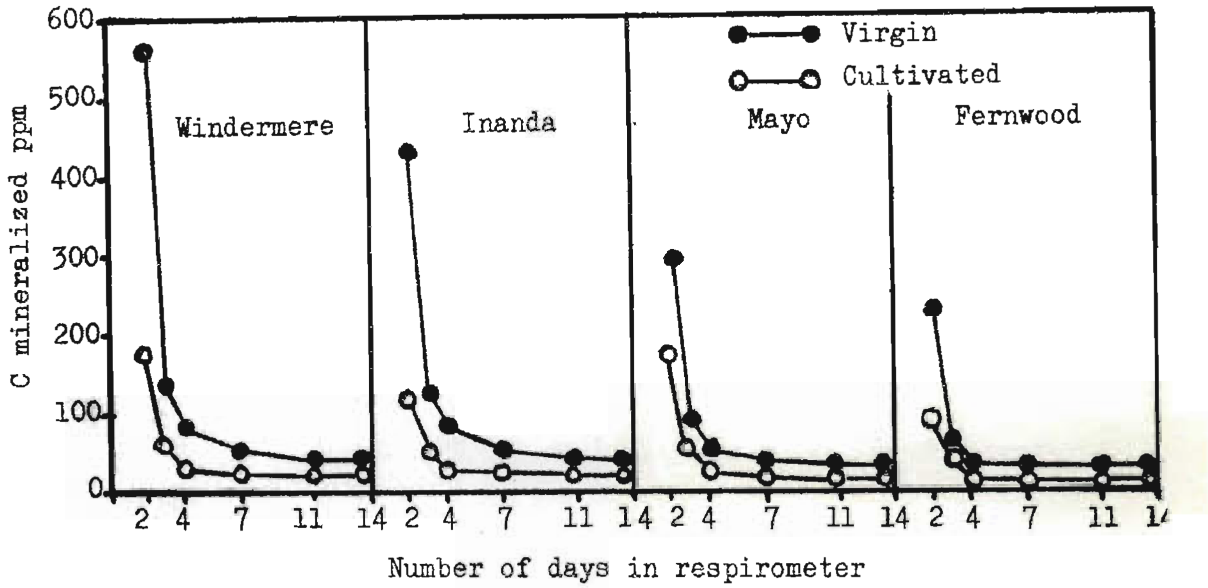


Fig. 14 Patterns of carbon mineralization with time in virgin and cultivated soils from four different series.

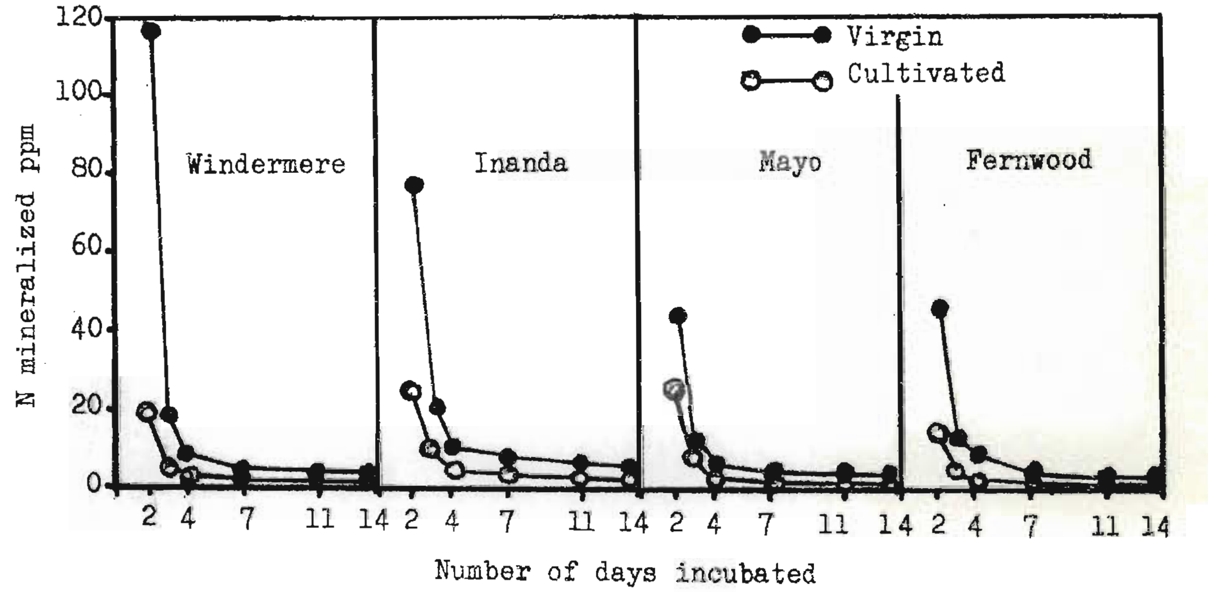


Fig. 15 Patterns of nitrogen mineralization with time in virgin and cultivated soils from four different series.

TABLE 27. Immobilization effects following addition of carbon as glucose to various soils, and incubating for six days (all results expressed in ppm)

Soil series	Cultivated				Virgin			
	No C added		400 ppm C		No C added		400 ppm C	
	C min	Total min N	C min	Total min N	C min	Total min N	C min	Total min N
Cartref	129	23	350	3	265	30	542	10
Fernwood	145	33	382	14	282	59	617	39
Windermere	281	38	538	26	686	118	985	102
Inanda	228	59	493	29	694	120	967	101
Mayo	244	55	516	35	358	60	687	47
Rydalvale	464	77	698	49	670	97	910	69

Effects of cultivation on other soil properties

Reduction in organic matter following the cultivation of virgin soils is reflected in Table 28, by the lower C and N contents of most of the cultivated soils. Despite this C/N ratios remain at a level considerably higher than those normally encountered in cultivated soil. There is some evidence (Clement and Williams 1964, 1967) that C/N ratios under permanent grass, and short-term leys are higher than under arable soils. This is probably due to the large amounts of undecomposed root material in grassland soils which provide a surplus of C-rich material (Woldendorp *et al*. 1965). The same situation may well apply to many soils under sugarcane particularly in the high altitude areas (eg. Inanda series) where build-up of carbonaceous residues far exceeds decomposition of organic matter.

A considerable increase in soil acidity is apparent in most soils following cultivation. This is associated with utilization and leaching of exchangeable cations, especially calcium and magnesium both of which have been reduced in the majority of cultivated soils (see Table 28).

TABLE 28. Analytical data - virgin and cultivated soils

Soil series		pH	% org.C	% N	C/N ratio	ppm P	Exchangeable bases me% K	Ca	Mg	Na
Doveton	(V)	6,1	2,63	0,15	17,5	6	0,64	3,8	3,1	0,30
	(C)	5,8	2,82	0,14	20,1	49	0,46	5,2	1,9	0,19
Mayo	(V)	6,0	2,99	0,12	24,9	5	0,37	2,3	1,6	0,18
	(C)	5,1	2,27	0,10	22,7	3	0,32	4,4	1,2	0,10
Cartref	(V)	5,2	1,15	0,06	19,2	8	0,26	0,6	0,7	0,07
	(C)	4,9	1,07	0,05	21,4	29	0,23	0,6	0,5	0,08
Inanda	(V)	5,9	7,24	0,26	27,8	2	0,27	2,4	3,3	0,24
	(C)	5,1	5,94	0,15	39,6	57	0,24	1,1	0,9	0,17
Williamson	(V)	6,6	2,75	0,16	17,2	62	1,07	6,0	2,6	0,27
	(C)	5,4	2,07	0,12	17,3	27	1,17	2,4	1,6	0,11
Milkwood	(V)	6,1	4,10	0,30	13,7	3	1,48	7,5	4,0	0,26
	(C)	5,8	3,78	0,16	23,6	16	0,23	4,9	4,8	0,21
Windermere	(V)	6,1	3,86	0,25	15,4	4	0,48	3,6	5,3	0,40
	(C)	5,2	2,11	0,12	17,6	16	0,71	1,9	1,6	0,15
Estcourt	(V)	6,8	1,11	0,08	13,9	2	0,32	4,1	3,8	0,33
	(C)	6,2	1,32	0,08	16,5	4	0,22	2,8	2,8	0,36
Shortlands	(V)	6,4	4,42	0,20	22,1	3	1,02	9,5	7,7	0,43
	(C)	6,2	3,63	0,16	22,7	2	0,61	5,2	4,0	0,23
Rydalvale	(V)	6,2	6,52	0,31	21,0	4	1,58	12,0	9,8	1,20
	(C)	5,7	5,53	0,26	21,3	7	1,94	12,0	8,4	0,37
Shorrocks	(V)	5,8	1,00	0,09	11,1	4	0,26	1,7	0,8	0,09
	(C)	4,6	0,96	0,05	19,2	34	0,15	0,7	0,7	0,07
Fernwood	(V)	5,6	1,44	0,08	18,0	2	0,10	1,3	1,4	0,18
	(C)	5,5	0,70	0,04	17,5	7	0,07	0,7	0,6	0,08
Dundee	(V)	5,6	3,02	0,20	15,1	16	1,30	5,2	4,1	0,30
	(C)	5,5	3,11	0,18	17,3	19	1,81	4,9	4,3	0,25

V = virgin soil C = cultivated soil

These losses may have been accelerated following the application of ammonium fertilizers. NH_4^+ replaces Ca^{++}, Mg^{++} and other bases, by cation exchange on the soil colloid, and is in turn replaced by H ions following nitrification, as discussed further in Chapter 10. In most virgin soils available phosphorus supplies were very low.

DISCUSSION

Using the triphenyl tetrazolium chloride (TTC) technique, Roth (1965), working with soils supplied by the writer, was able to demonstrate that the enhanced decomposition noted in the virgin soils, could in most cases be associated with a much higher level of bacterial activity in these soils. This is indicated by the increased percentage colour absorption capacity when compared to their cultivated counterparts (see Table 26). It applies especially to soils of the Inanda, Milkwood and Windermere series, in which the greatest differences in levels of decomposition were noted.

From the data in Table 28, the average percentage of C and N mineralized in the virgin soils was 2,6 and 5,3 respectively. For the cultivated soils it was only 1,6 and 3,7. This confirms that the resistance of soil organic matter to mineralization increases as decomposition proceeds.

Porter _et al_. (1964) examined the nature of the organic N fraction most susceptible to decomposition under cultivation. They found that the amino acid form of N (which represents about half of the total N in virgin soils) accounted for 61% of the N decrease. The organic N substances comprising the other half of the total N, contributed only 33% of the N decrease.

Following decomposition of ryegrass labelled with ^{14}C over a four year period, Jenkinson (1964) found that after a year, a fraction of the soil organic matter (the soil biomass) had a specific activity ten times that of the soil organic matter as a whole. He suggested the existence of 'labile", and 'stable' organic matter fractions, the size of the former in a soil providing an excellent measure of its 'mineralization potential' ie. percentage of the total C and N that is easily mineralized. These fractions would appear to correspond to the 'active' and 'passive' organic N pools suggested by Jansson (1958).

The work reported in this chapter supports Jenkinson's hypothesis. The virgin soils were shown to possess a much greater mineralization potential than their cultivated counterparts, from which it could be concluded that they contain a much larger pool of labile organic material or easily decomposed biomass. Thus the N supplying power of sugar belt soils is partly determined by the length of time they have been under cultivation, and this factor can be expected to influence crop response to applied N.

CHAPTER 9

UTILIZATION OF FERTILIZER NITROGEN AS INFLUENCED BY CROP RESIDUES

An important factor affecting the utilization of N by plants is the presence in the soil of crop residues low in N. Many workers (Allison and Cover 1960, Allison and Klein 1962, Chandra and Bollen 1959, Munson and Pesek 1958, Parker et al. 1957, Stojanovic and Broadbent 1956, etc.) have shown that initially the effect of adding a variety of carbonaceous residues to a soil is to lower its N content. This is due to increased assimilation of inorganic N by micro-organisms.

A Trash incorporation and its effect on the uptake of fertilizer and soil nitrogen by sugarcane

Incorporation of a certain amount of cane trash and other plant residues, inevitably occurs under field conditions following harvesting, subsequent replanting and cultivation treatments. In some areas of the sugar belt trash is actually ploughed into the soil before planting. It seemed possible that competition between soil micro-organisms and the developing cane plant for applied N, could depress plant uptake of N sufficiently to influence yield, especially on soils of low N supplying power.

In order to examine this and other factors related to the utilization and recovery of fertilizer N applied to cane, a glasshouse experiment was designed incorporating the use of ^{15}N labelled $(NH_4)_2SO_4$, to provide information on the following points:

(a) the efficiency of use of fertilizer N applied at different rates to cane grown in various soils, in relation to the amount of fertilizer immobilized in the presence or absence of added trash;

(b) the distribution of applied N between plant and soil under the conditions stated in (a);

(c) the influence of fertilizer N on the release and uptake of soil N.

PROCEDURE

Pots containing 1,5 kg air dry topsoil representing three different series (Clansthal sand, Glenrosa sandy loam and Shortlands clay) were treated as follows:

1) Control
2) 0,5% trash (equivalent to 11 tons/ha)
3) 45 mg N as $^{15}(NH_4)_2SO_4$ (equivalent to 66 kg N/ha)
4) 45 mg N plus 0,5% trash
5) 112,5 mg N as $^{15}(NH_4)_2SO_4$ (equivalent to 165 kg N/ha)
6) 112,5 mg N plus 0,5% trash

The soils and ground trash were carefully mixed beforehand. All pots received a standard nutrient solution supplying 100 ppm K and 80 ppm P. Where labelled $(NH_4)_2SO_4$ solution was added, the content of excess ^{15}N was 4,33 atom % on the basis of total N in the fertilizer.

For each soil series used several replicates of each treatment were planted with previously germinated single budded cane setts of uniform weight (10g), while additional replicates were left unplanted. All soils were maintained at 50% of field capacity by weighing and watering daily.

After 12 weeks, two replicates of each treatment were harvested, the whole plant consisting of top, sett and roots being weighed after separation from the soil, and subsequent washing. The plant material was prepared for N analysis, while the soils from both the cropped and corresponding uncropped treatments were air dried prior to analysis. Tops, setts and roots were analysed for total N and the degree of enrichment with ^{15}N determined. Soils also, were analysed for total, inorganic and labelled N.

RESULTS AND DISCUSSION

Plant uptake and recovery of N

The mean total N, fertilizer N, and soil N present in the whole plant (tops, roots and setts) from two replicates of all treatments, is shown for the soils of each series in Figures 16, 17 and 18. The percentage of total N in the plants derived from the fertilizer, and percentage recovery of fertilizer N by the whole plant is presented in Figures 19 and 20.

Trends in the results from all three soils used were sufficiently similar for them to be pooled for analysis. LSD values at 5% and 1% for the pooled data are shown as vertical lines in Figures 16-20.

(i) Total N and fertilizer N uptake by the whole plant

Uptake of total and fertilizer N increased significantly in all soils with increasing amounts of applied N, whether trash was absent or present. Addition of trash however very significantly depressed uptake of N at all fertilizer levels in all soils.

In the absence of trash, total N in the plant showed an almost linear relationship with the amount of N applied (see Figure 16). When trash was present, the higher rate of applied N (112,5 mg N per pot) apparently

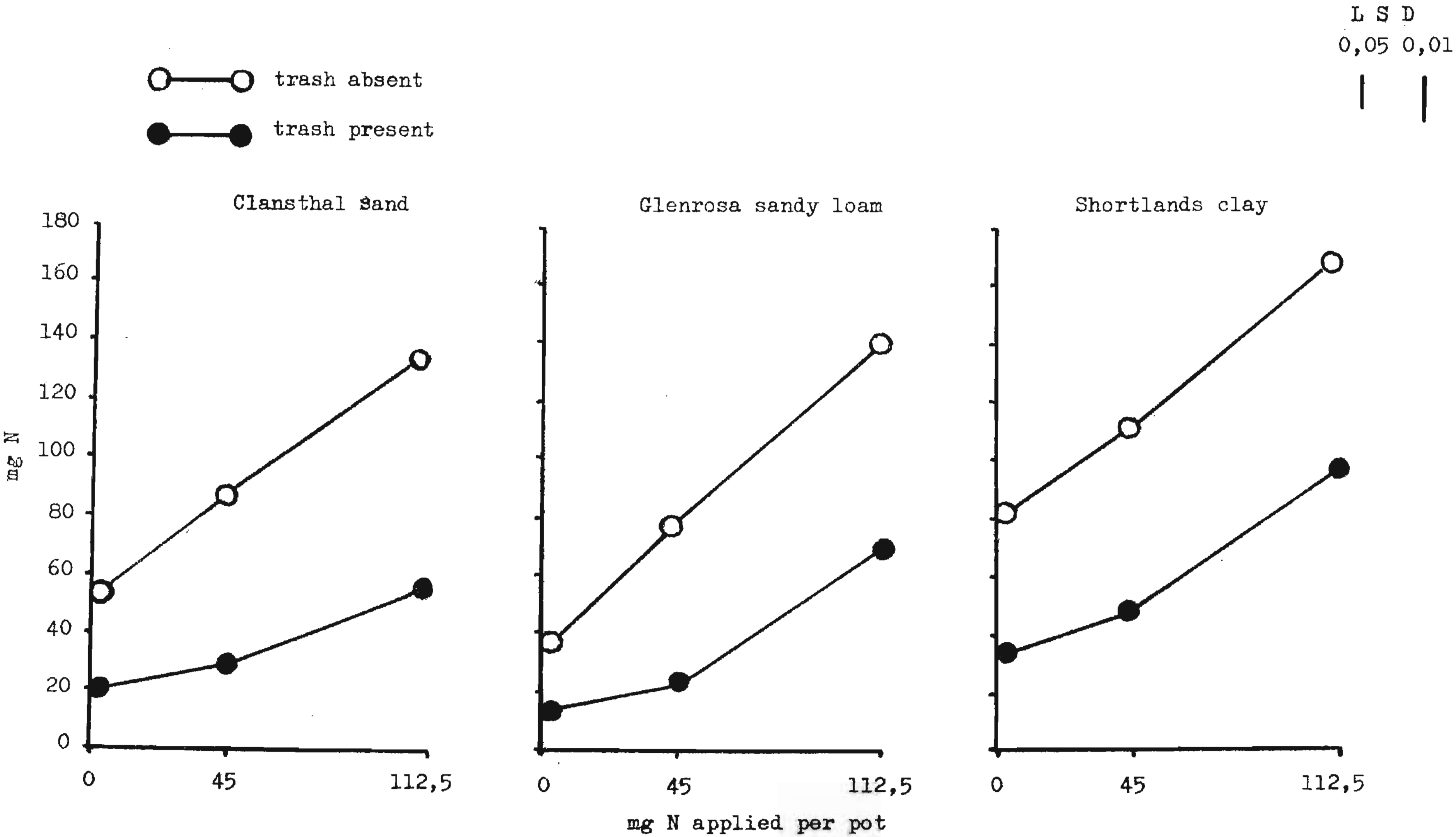


Fig. 16 Total N present in whole plant (top + roots + sett) in the absence or presence of trash

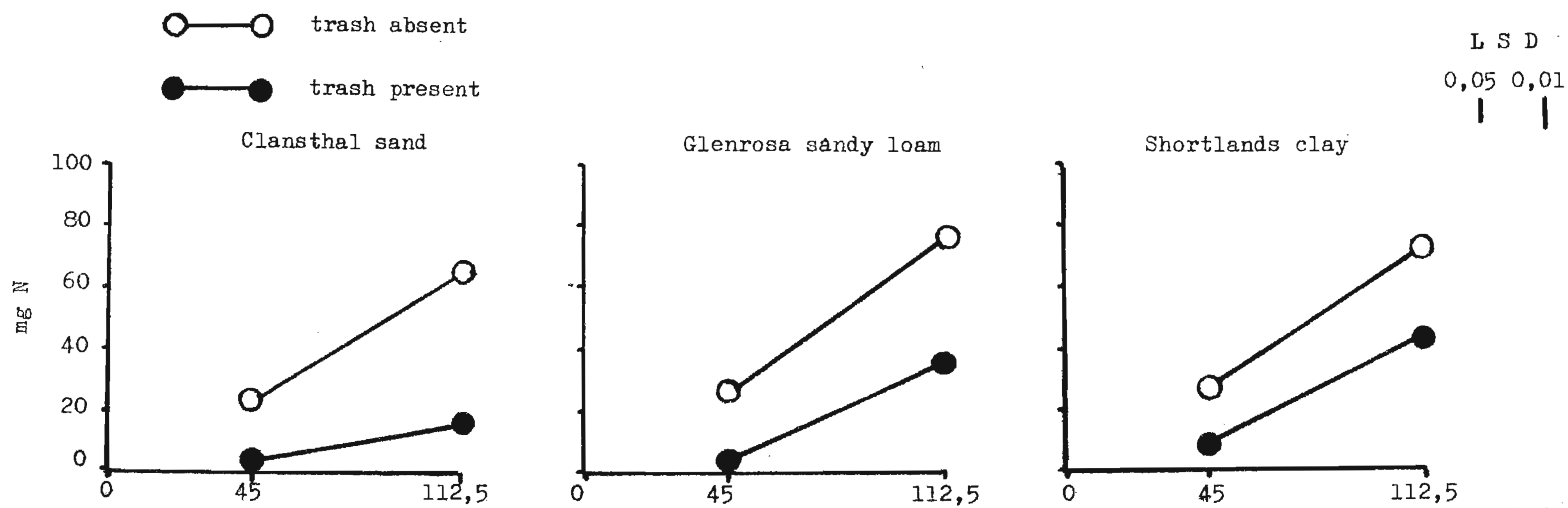


Fig. 17 Fertilizer N present in the whole plant

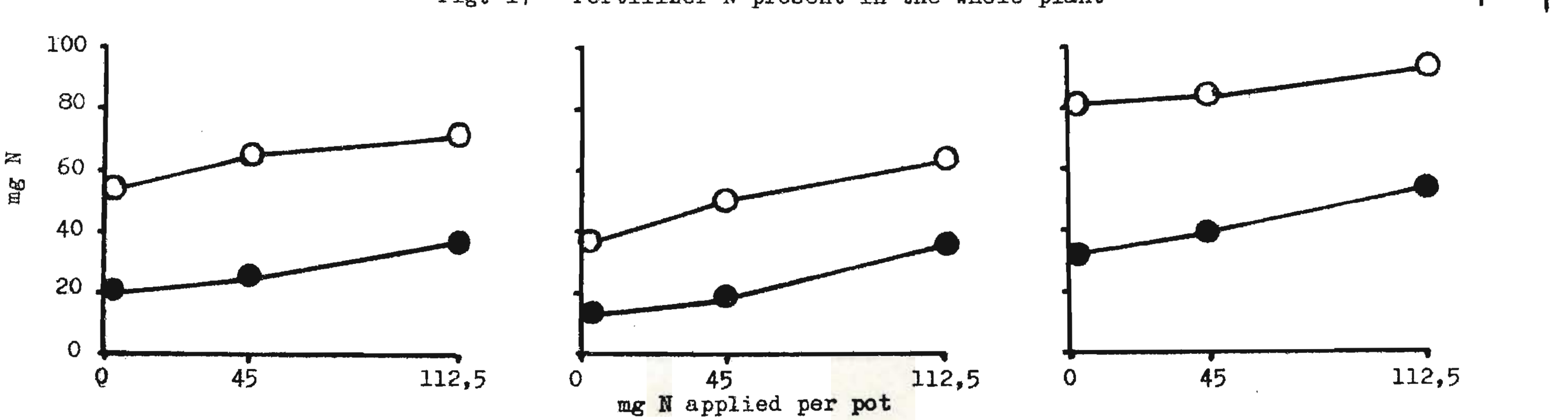


Fig. 18 Soil N present in the whole plant

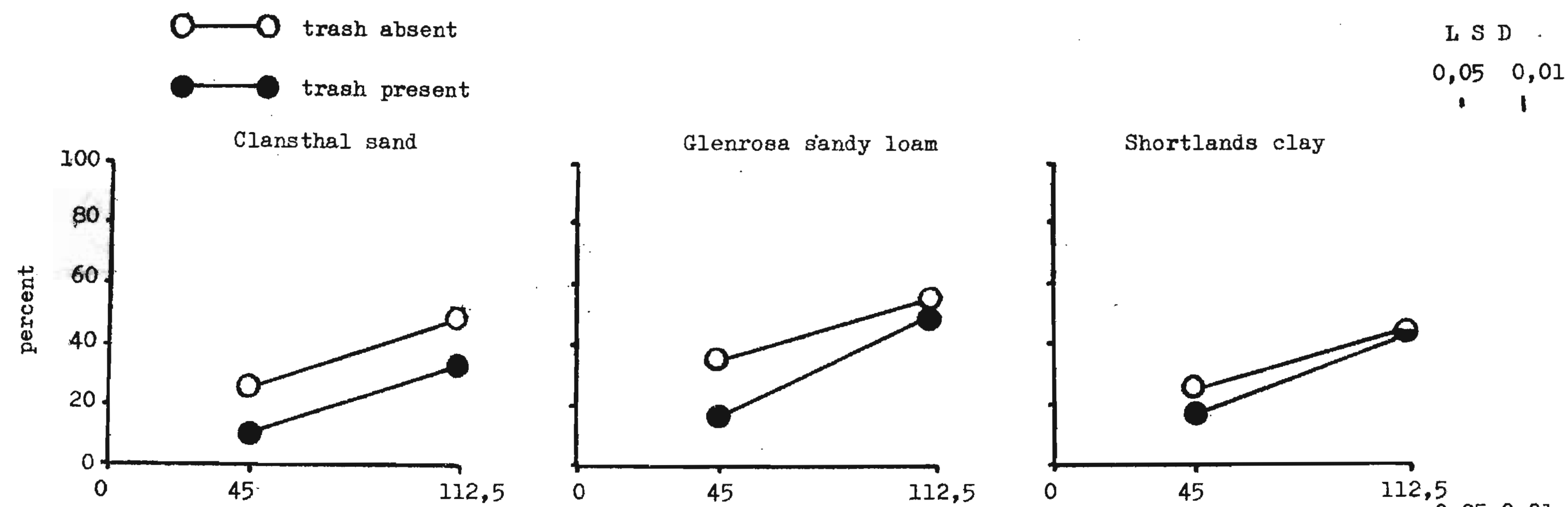


Fig. 19 Percentage total N derived from fertilizer N (whole plant)

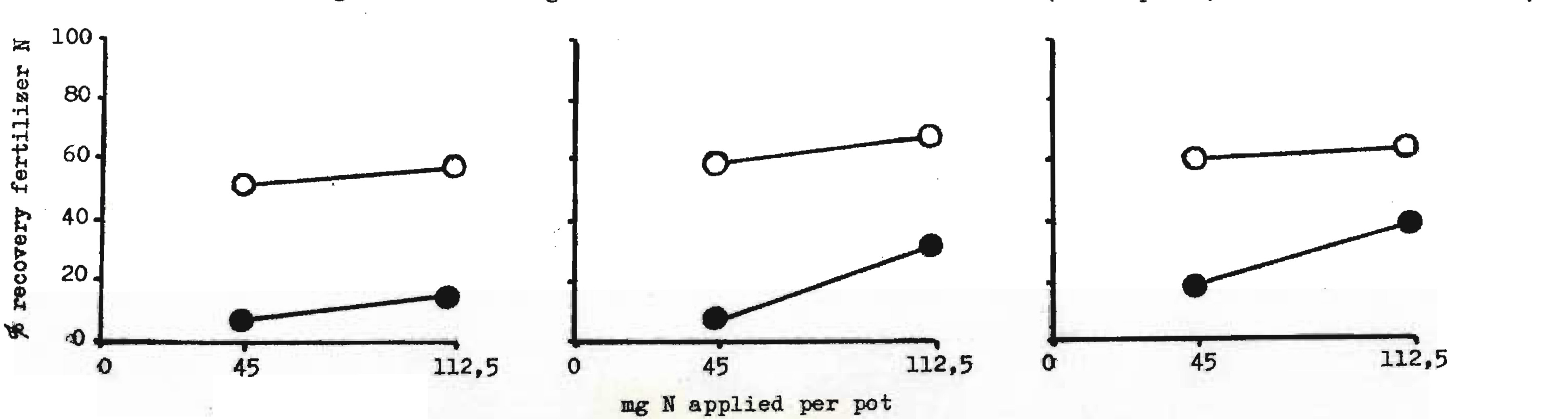


Fig. 20 Percentage recovery of fertilizer N in the whole plant

overcame immobilization effects to a proportionately greater extent than the lower rate (45 mg N per pot). This resulted in a non-linear increase in N uptake as reflected in the curves in Figure 16. This effect was also observed in crop growth as shown in Plate 4.

(ii) Soil N uptake by the plant (including N from the sett)

Figure 18 shows that the higher level of applied N significantly increased uptake of soil N in all soils whether in the absence or presence of trash, while a similar trend existed at the lower rate of application. Trash significantly reduced the uptake of soil N at all N levels.

(iii) Percentage of total N derived from fertilizer N

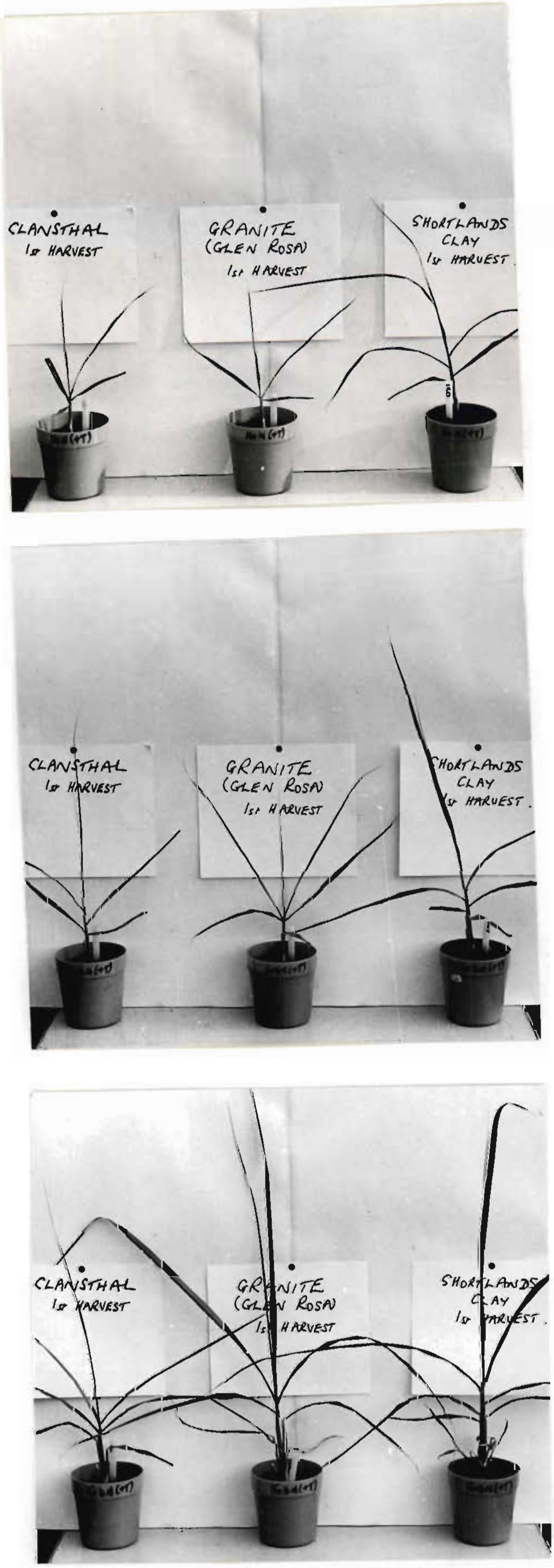
This increased significantly with increase in rate of N application with or without added trash. Trash significantly lowered the percentage of total N derived from the fertilizer except where the higher rate of N was applied to the Shortlands clay where it appeared to have no effect.

(iv) Percentage recovery of fertilizer N by the plant

A significant increase in percentage recovery of fertilizer N was obtained throughout at the higher rate of applied N when trash was present. A similar trend was apparent in the absence of trash but the increase was significant only in the Glenrosa sandy loam. Trash significantly lowered percentage recovery at both levels of applied N in all soils.

Recovery of fertilizer N varied much less between soils in the absence of trash than when it was present.

Clansthal Glenrosa Shortlands



No N applied

45 mg N applied

112,5 mg N applied

Plate 4 The effect of trash addition on cane growth in soils from three different series, receiving three levels of applied N (0,5% trash present in all pots).

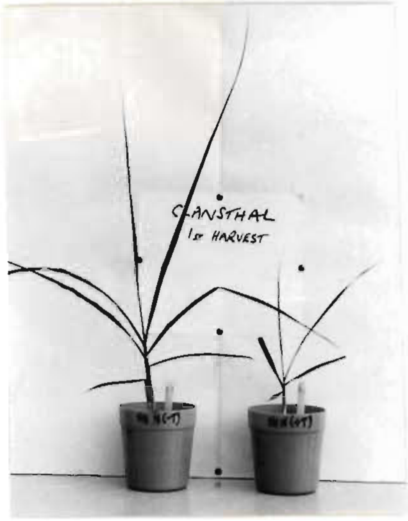
Mean recoveries for both levels of applied N in the absence of trash were 53,7%, 63,0% and 61,6% respectively for the Clansthal, Glenrosa and Shortlands soils, but were 11,1%, 19,0% and 27,4% respectively where trash was present. These latter recoveries imply that plants growing in the Shortlands clay were better able to compete with N immobilization effects due to added trash, than those growing on the sandier Glenrosa and Clansthal soils. The greater uptake of soil N from the Shortlands clay in both the presence or absence of trash when compared with that from the other soils confirms this (see figure 18). This was further illustrated by the better growth observed in the control pots of the Shortlands clay compared with the other controls as shown in Plate 5.

Further details of these results are presented in Appendix 4.

Balance sheet of fertilizer N recovered (crop plus soil)

Substantial amounts of applied N were immobilized in the organic form in the cropped soils under all treatments. This is apparent from the balance sheet showing overall recovery of fertilizer N presented in Table 29. As a comparison fertilizer N recovered from the uncropped soils is also given.

Though much larger amounts of applied N were immobilized where trash was present, the considerable quantities found in both cropped and uncropped soils in the absence of trash, indicate that immobilization was occurring continuously in all soils, due to microbial action. When trash was absent, the presence of growing cane apparently caused greater amounts of fertilizer N to be immobilized than when no crop was grown. This was not always the

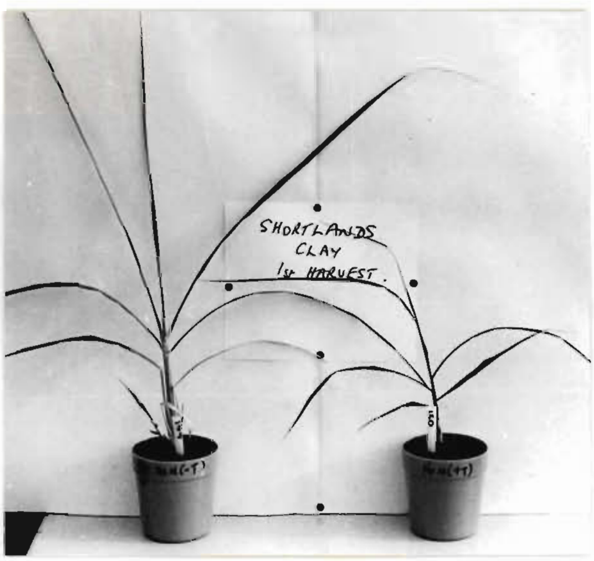


Clansthal

(-T) (+T)

Glenrosa

(-T) (+T)



Shortlands

(-T) (+T)

Plate 5 Cane growth in control treatments (no N) on soils from three different series, in the absence or presence of trash. (-T) trash absent, (+T) trash present.

TABLE 29. Balance sheet of fertilizer N recovered in cropped (whole plant) and uncropped pots. (Means of two completely harvested replicates)

N recovery	Clansthal sand				Glenrosa sandy loam				Shortlands clay			
	45 mg N*		112,5 mg N*		45 mg N*		112,5 mg N*		45 mg N*		112,5 mg N*	
	**(-T)	(+T)	(-T)	(+T)	(-T)	(+T)	(-T)	(+T)	(-T)	(+T)	(-T)	(+T)
Cropped pots												
Total soil N mg	789	914	870	975	803	903	809	882	2802	2856	2760	2847
Fert. N in SOM + mg	15,3	32,0	34,2	59,7	14,5	35,4	20,8	62,9	16,3	36,2	37,2	61,1
Fert. N in plant mg	22,8	3,0	64,0	17,6	26,3	3,3	76,0	34,6	27,0	8,0	71,2	41,8
Total fert. N recovered mg	38,1	35,0	98,2	77,3	40,8	38,7	96,8	97,5	43,3	44,2	108,4	102,9
Total recovery of fert. N, % of that added	84,7	77,8	87,3	68,7	90,7	86,0	86,0	86,7	96,2	98,2	96,4	91,5
Uncropped pots												
Total soil N mg	797	851	840	860	828	864	893	914	2777	2936	2928	2907
Fertilizer N in soil mg												
(a) Inorg. N	20,3	1,0	68,9	5,4	20,3	0,4	71,3	23,4	27,2	8,3	64,4	43,1
(b) Org. N	10,3	29,9	21,0	60,9	11,8	31,0	12,2	52,5	12,3	31,1	28,3	61,2
otal fert. N recovered mg	30,6	30,9	89,9	66,3	32,1	31,4	83,5	75,9	39,5	39,4	92,7	104,3
otal recovery of fert. , % of that added	68,0	68,7	79,9	58,9	71,3	69,8	74,2	67,5	87,8	87,6	82,4	92,7
ean % recovery of pplied N calculated) — Cropped	79,6				87,4				95,6			
Uncropped	68,9				70,7				87,6			
ean, % loss of pplied N (by ifference) — Cropped	21,4				12,6				4,4			
Uncropped	31,1				29,3				12,4			

**(-T) = trash absent (+T) = trash present * amount of N applied per pot + SOM = Soil organic matter case however with plants grown in the presence of trash.

With one exception, total recovery of applied N from the uncropped soil treatments, never equalled that obtained from the corresponding cropped soils, though it came closest to doing so in the Shortlands clay. Average total recovery from the three soils for all treatments was 87,5% and 75,7% for the cropped and uncropped soils respectively.

Mean total recovery of N for the cropped fertilizer treatments, was highest in the Shortlands clay (95,6%) and lowest in the Clansthal sand (79,6%). A similar pattern of recovery was obtained from the uncropped fertilizer treatments, though total recoveries were considerably lower especially in the sandy soils. This is probably explained by the fact that a substantial portion of the applied N remained in the inorganic form at time of harvest in the uncropped soils (see Table 29), particularly where no trash was added. They were therefore more prone to losses from denitrification, volatilization etc. than the cropped soils.

The somewhat high N losses from the cropped sandy soils could have been caused by daily watering down a perforated tube. In these soils of low water holding capacity this may have allowed anaerobic conditions to develop locally within the pots, thus causing dentrification. Soils low in organic matter such as those of the Clansthal and Glenrosa series have been shown to be more susceptible to dentrification losses (Broadbent 1951, MacVicar _et al_. 1950) and greater recovery of N applied as $(NH_4)_2SO_4$ has been noted in more finely textured soils (Nash and Johnson, 1967) such as the Shortlands clay.

Recovery of fertilizer N from succeeding crops.

Other replicates from the pot experiment just described were used to determine the amount of fertilizer N removed by three successive crops, grown in the presence or absence of trash on the three soils. After the first 12 weeks, tops and setts only, were harvested and the pots replanted with a fresh pregerminated sett. At this stage half the pots were given additional amounts of unlabelled N equal to the previous applications of labelled fertilizer, while the remaining pots received no further N. All pots received the PK nutrient solution however.

Following removal of the tops and setts after a second period of 12 weeks, the pots were again replanted, unlabelled N being applied or omitted as before. After a further 12 weeks growth, tops and setts were again removed.

In view of the large number of samples it was not possible to analyse the replicates individually for ^{15}N, and only composite samples of tops and setts were examined from each treatment.

Table 30 shows that in the absence of trash the second and third crops accounted for a relatively small increase in the amount of original fertilizer N recovered. Mean recovery of fertilizer N from the three soils between the first and third crop at both levels of applied N only rose by 5,2% from 50,6% to 55,8%, where no additional N was supplied. This rapid decrease in availability of the original fertilizer indicates that it is only released slowly once it becomes immobilized in the soil organic phase. In fact, much of the residual fertilizer N recovered by tops and setts in the later crops may have come from the decomposing root material remaining in the cropped pots (Viets 1960).

In the trash treated soils shown in Table 31 there was no evidence of an accelerated release of previously immobilized N, an additional mean recovery of 6,9% fertilizer N being obtained from all soils between the first and third crops where no additional N was supplied. However the depressing effect of trash on N fertilizer uptake noted in the first crop was not apparent in the two subsequent crops grown on any of the soils, indicating that net mineralization had been achieved.

No mineral N could be detected in any of the cropped soils following harvest of the first crop. It was therefore assumed that where no additional fertilizer N was applied, the later crops were virtually dependent on N derived by mineralization from organic sources, though a small quantity was supplied by each sett initially, throughout all treatments.

The application of additional amounts of unlabelled N to the second and third crops had a stimulatory effect upon the release of previously immobilized fertilizer N in the presence or absence of trash as shown in Tables 30 and 31. The effect was small in both the Clansthal and Shortlands soils, an average of 2% more fertilizer N being recovered over the second and third crops where extra N was supplied when compared to those treatments in which it was omitted. In the Glenrosa soil treatments however, an average of 7% more fertilizer N was recovered over the two crops, the reason for which is not clear. In general though, the release of residual N was not greatly affected by the additional N. Jansson (1963) estimated that plant availability of true residual N (i.e. organically bound and chemically fixed) is only about 1% per year of the original fertilizer addition. Release of immobilized fertilizer N is further considered in section B of this chapter. Further details of the above results are given in Appendix 4.

TABLE 30. Recovery of fertilizer N from three successive crops grown on three soils in the absence of added trash (composite sample data)

Crop	Plant part harvested	Clansthal				Glenrosa				Shortlands			
		Fertilizer originally applied - mg N per pot											
		45		112,5		45		112,5		45		112,5	
First	Tops (mg fert. N)	14,7		47,2		19,4		53,3		21,1		58,9	
	Setts (mg fert. N)	3,0		10,5		2,0		5,3		3,0		8,0	
% orig. fert. N recovered		39,3		51,3		47,6		52,1		53,6		59,5	
		* + N	– N	+ N	– N	+ N	– N	+ N	– N	+ N	– N	+ N	– N
Second	Tops (mg fert. N)	1,9	1,7	5,9	3,9	1,8	0,9	7,5	1,8	1,6	1,1	7,7	6,5
	Setts (mg fert. N)	0,3	0,2	0,7	0,6	0,5	0,5	1,3	0,5	0,2	0,1	0,9	0,8
% orig. fert. N recovered		4,9	4,2	5,9	4,0	5,1	3,1	7,8	2,0	4,0	2,7	7,6	6,5
Third	Tops (mg fert. N)	0,6	0,8	2,4	1,8	1,2	0,5	5,8	1,0	0,8	0,4	1,7	1,3
	Setts (mg fert. N)	0,4	0,2	0,6	0,5	0,3	0,1	0,9	0,4	0,1	0,1	0,2	0,2
% orig. fert. N recovered		2,2	2,2	2,7	2,0	3,3	1,3	6,0	1,2	2,0	1,1	1,7	1,3
Total % original fertilizer N recovered		46,4	45,7	59,9	57,3	56,0	52,0	65,9	55,3	59,6	57,4	68,8	67,3

* + N indicates that additional unlabelled N was applied to 2nd and 3rd crops

– N indicates that no further N was applied

TABLE 31. Recovery of fertilizer N from three successive crops grown on three soils in the presence of added trash (composite sample data)

Crop	Plant part harvested	Clansthal				Glenrosa				Shortlands			
		Fertilizer originally applied - mg N per pot											
		45		112,5		45		112,5		45		112,5	
First	Tops (mg fert. N)	2,2		10,9		2,3		25,1		6,7		37,2	
	Setts (mg fert. N)	0,8		3,5		0,8		3,6		1,3		4,7	
% orig. fert. N recovered		6,7		12,8		6,9		25,5		17,8		37,2	
		* + N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N	+ N	- N
Second	Tops (mg fert. N)	2,9	2,6	5,8	5,5	1,9	1,1	8,1	2,9	2,5	2,2	6,6	4,5
	Setts (mg fert. N)	0,3	0,3	0,9	0,7	0,3	0,3	1,3	0,7	0,2	0,2	0,5	0,6
% orig. fert N recovered		7,1	6,4	6,0	5,5	4,9	3,1	8,4	3,2	6,0	5,3	6,3	4,5
Third	Tops (mg fert. N)	1,5	1,1	2,3	1,7	2,2	0,9	3,1	1,2	1,6	1,1	4,5	1,6
	Setts (mg fert. N)	0,3	0,2	0,8	0,3	0,4	0,2	1,6	0,7	0,2	0,1	0,3	0,2
% orig. fert. N recovered		4,0	2,9	2,8	1,8	5,8	2,4	4,2	1,7	4,0	2,7	4,3	1,6
Total	% original fertilizer N recovered	17,8	16,0	21,6	20,1	17,6	12,4	38,1	30,4	27,8	25,8	47,8	43,3

* + N indicates that additional unlabelled N was applied to 2nd and 3rd crops

− N indicates that no further N was applied

Crop use of applied nitrogen

It is interesting to note from Table 30, that average recovery of N by the tops alone from the first crop over all soils in the absence of trash was only 44%. This was under controlled conditions designed to ensure maximum utilization of fertilizer N. It is therefore extremely unlikely that recovery of applied N by harvested cane in the field where control is much poorer, would approach this figure. The reduction in efficiency of N use due to the presence of trash is evident from Table 31, where average recovery of N by tops in the first crop was only 15%. However being a pot experiment this low recovery undoubtedly exaggerates considerably field effects. Nonetheless reductions in fertilizer efficiency may often occur in the sandier soils of the sugar belt low in N (eg. Cartref series), and additional N will then be required to compensate for that immobilized by crop residues.

B. The influence of C/N ratios of roots on nitrogen availability

Legg and Allison (1960) demonstrated that the percentage N in roots of plants grown at different levels of applied N, indicates the wide range of root C/N ratios obtained under such conditions. Their findings are substantiated by the data given in Table 32. This shows the marked lowering in C/N ratios of sugarcane roots that occurred in the pot experiment described in section A of this chapter, when amounts of applied N were increased in three different soils.

Thus, plants grown at low soil N levels may continuously add substantial quantities of root material of high C/N ratio to the soil. Through microbial action this may immobilize much mineral N required by the crop, as shown already, It is suggested that this situation could readily be found under grass leys or sugarcane. Both crops develop a dense root mat capable of providing between 10-15 tons of roots per hectare (dry weight basis), as reported by the writer in Chapter 11 and Henzell _et al_. (1964). The work now reported was conducted primarily to examine the effect on N availability of adding various amounts of root material of differing C/N ratio to three sugar belt soils.

PROCEDURE

Nitrogen immobilization and mineralization rates were determined in the Clansthal sand, Glenrosa sandy loam and Shortlands clay soils. To these, sugarcane root material of two different C/N ratios (approximately 50 and 100) had been added at two levels, namely 0,5% and 1,0% (see Table 33).

TABLE 32. Changes in C/N ratio of sugarcane roots with increasing amounts of fertilizer N

	N applied mg per pot								
	Nil			45			112,5		
Soil series	% C	% N	C/N ratio	% C	% N	C/N ratio	% C	% N	C/N ratio
Clansthal	40,1	0,48	83,5	40,6	0,60	67,7	40,7	0,88	46,3
Glenrosa	44,9	0,30	149,7	44,8	0,45	99,6	42,8	0,54	79,3
Shortlands	44,1	0,53	83,2	43,4	0,64	67,8	43,0	0,92	46,7

TABLE 33. Soils and root material - analytical data

Soil series	pH	% C	% N	C/N ratio
Clansthal	7,2	0,58	0,052	11,2
Glenrosa	5,3	1,02	0,054	18,9
Shortlands	6,2	2,52	0,186	13,5
Roots - low C/N ratio		40,0	0,785	50,9
Roots - high C/N ratio		44,0	0,438	100,5

The bulk soil samples were moistened to 30% water holding capacity, either with water or a solution of ^{15}N labelled $(NH_4)_2SO_4$ (4,51 atom % excess), equivalent to 50 ppm N on an air dry soil basis.

All treatments were incubated at 30° C for 112 days, samples being withdrawn periodically to determine changes in mineral and organic N under various treatments, in the presence or absence of applied N. Carbon mineralization was measured throughout the experiment in all treatments, using the respirometer vessels as before. Samples were extracted with acidified N K_2SO_4 and analysed for mineral N. Organic N in the extracted soil was determined by the Kjeldahl method, while ^{15}N was obtained by mass spectrometer analysis.

RESULTS

<u>Changes in mineral N</u>

(i) In all three soils whether fertilizer N was present or not the time required to attain maximum N immobilization increased as the C/N ratio and/or rate of application of root material increased. This is shown by the differences in total amounts of mineral N present in the various fertilized treatments after 112 days incubation, as depicted in Figure 21.

(ii) For the same treatment amounts of N remineralized differed considerably between one soil and another, but were always higher at the lower C/N ratio and/or level of root application, even in the absence of added fertilizer N as shown in Table 34.

(iii) At either rate of root addition a C/N ratio of 50 was accompanied by greater release of unlabelled N from soil

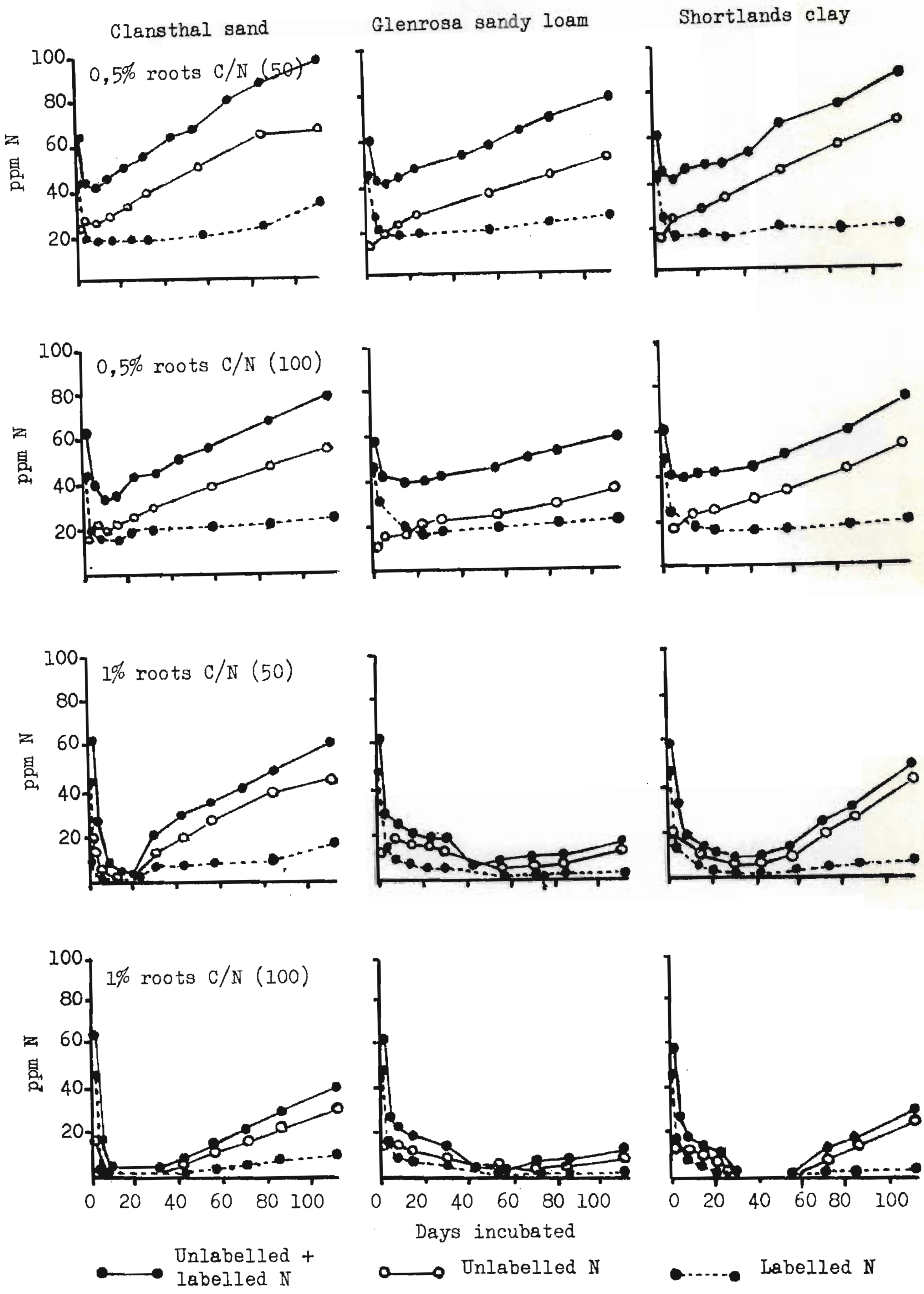


Fig. 21 Changes in mineral N (NH_4-N + NO_3-N) in three soils receiving labelled fertilizer N and root material of different C/N ratios.

reserves over the same period, than the higher C/N ratio of 100.

TABLE 34. Remineralization of N under various treatments (fertilizer N absent)

Root C/N ratio	Root material added (%)	ppm mineral N present after 112 days		
		Clansthal	Glenrosa	Shortlands
50	0,5	59	29	50
100	0,5	45	9	38
50	1,0	53	12	30
100	1,0	22	trace	6

(iv) Where inorganic fertilizer N was immobilized, most of the subsequently remineralized N came from unlabelled organic reserves in all soils.

(v) The fertilized controls shown graphically in Figure 22, confirm that small but varying amounts of the applied fertilizer were immobilized and remineralized by all soils, this being most pronounced in the Shortlands clay.

Changes in organic N

Figure 23 shows for each soil the changes in amounts of fertilizer N immobilized as organic N by the different treatments. All curves reflect the rapid immobilization of fertilizer N which occurred during the early part of the incubation period, the extent of which was dependent on root C/N ratio and rate of application. Remineralization of organic fertilizer N eventually followed under all treatments, generally being most rapid in the Clansthal sand. The relatively slow rate of remineralization, particularly in the Shortlands clay, suggests that fertilizer N may remain in the organic form for a long period in many soils, as indicated by the results of

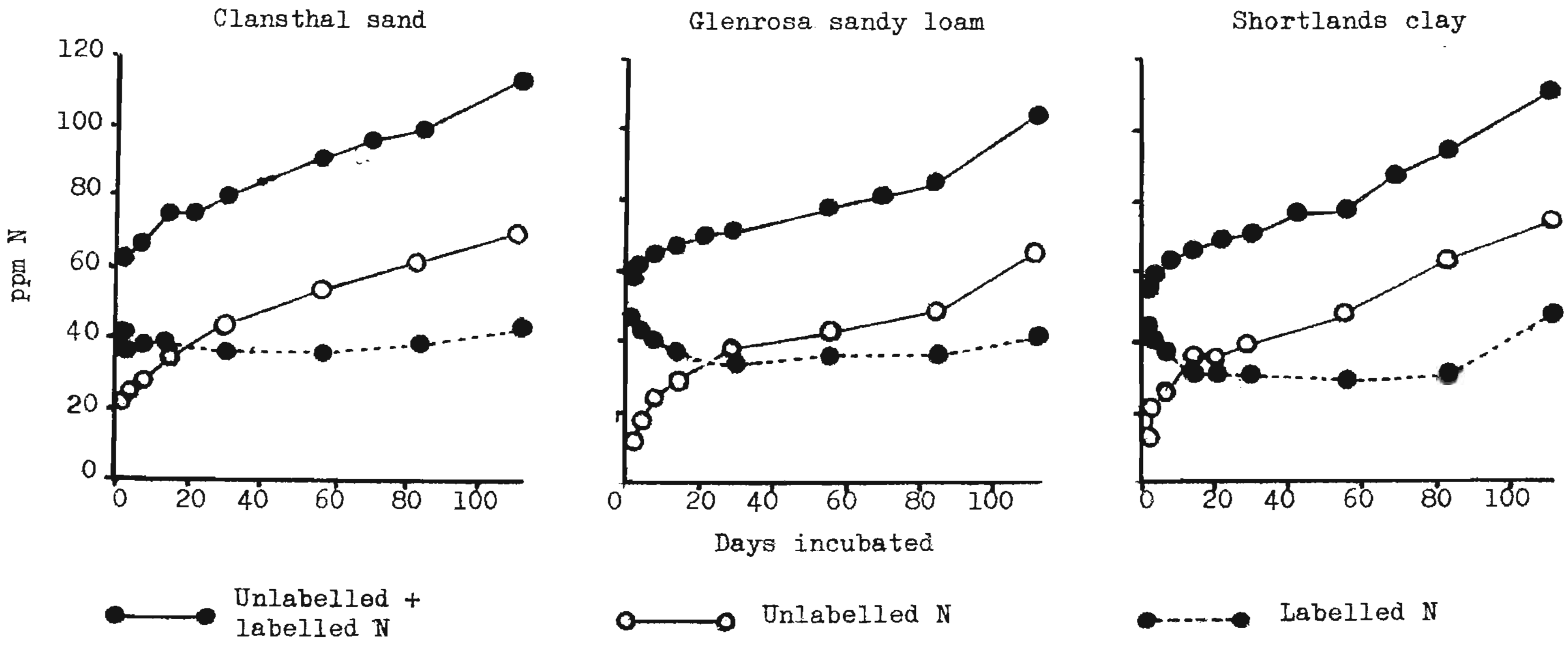


Fig. 22 Changes in mineral N (NH_4-N + NO_3-N) in the control soils receiving fertilizer N.

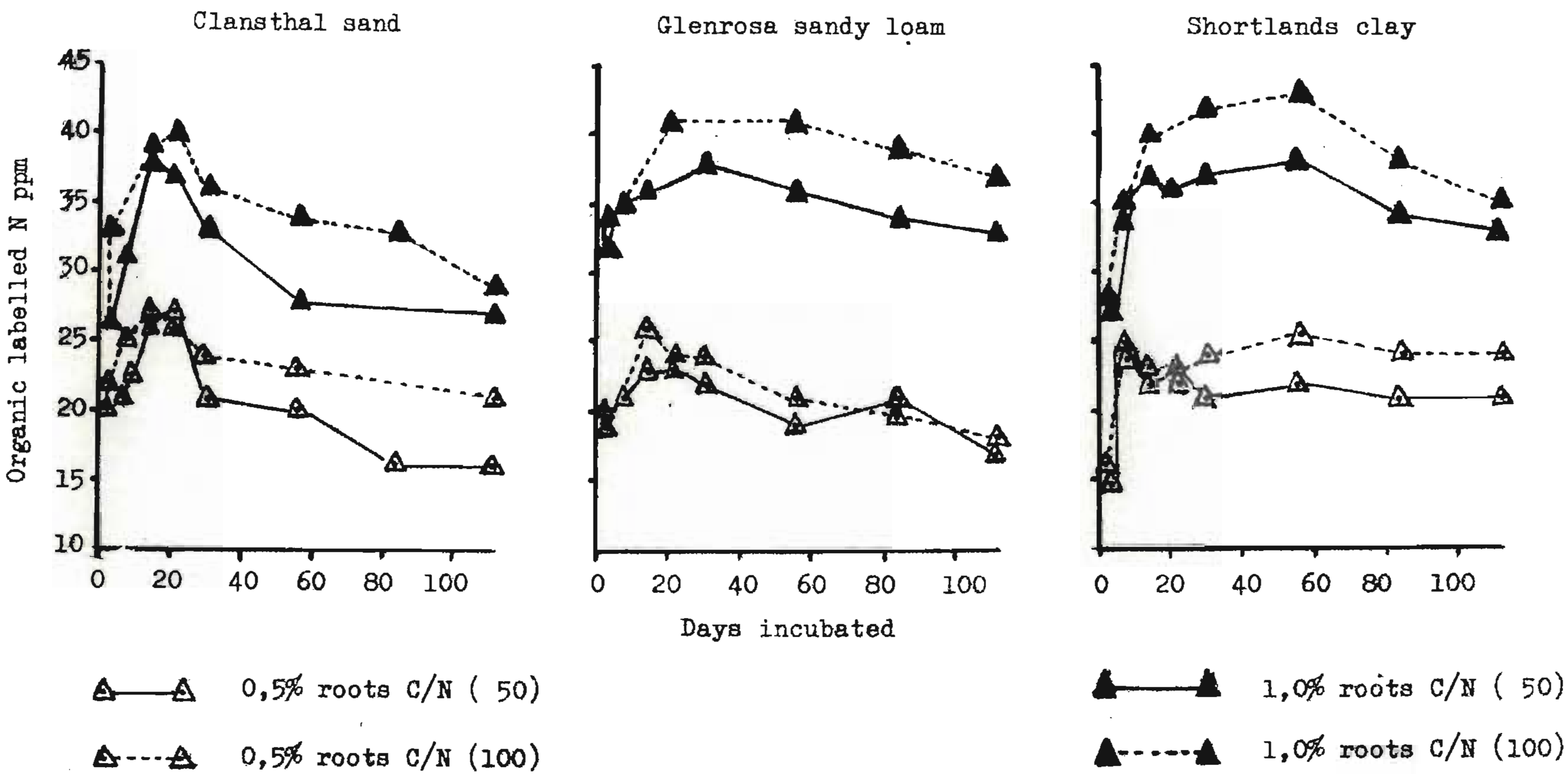


Fig. 23 Changes in immobilized (organic) fertilizer N with rate of applied root material and C/N ratio during the incubation period.

the pot experiment in Section A of this chapter. Further details regarding changes in mineral and organic N during the incubation period will be found in Appendix 5.

Carbon mineralization

Carbon balance data for the three soils under the various treatments is presented in Table 35, and shows that apart from the controls, net gains in organic matter were obtained in all treatments, and were always greater at the higher C/N ratio.

Despite an early positive effect of added N on C mineralization, this was generally shortlived and after 112 days large negative effects were apparent in most treatments, being reflected in Table 35 by the lower net gains in organic matter obtained in the absence of fertilizer N. Jansson (1958) attributes this to the effect of sulphate of ammonia in lowering soil pH thereby reducing microbial activity. This appears probable as the negative effects due to the fertilizer were more pronounced in the lightly buffered Clansthal and Glenrosa soils, than in the heavily buffered Shortlands clay.

Throughout the greater part of the incubation period, C mineralization in all soils was enhanced at the lower C/N ratio with or without applied N, at either level of root application. This is shown in Figure 24A and B for both unfertilized and fertilized treatments, which also depicts the generally higher level of microbial activity occurring in Clansthal sand at all levels of application, when compared with that in the other two soils.

Rates of mineralization and immobilization

The use of ^{15}N in this type of study makes it possible to measure actual turnover rates resulting from the opposing simultaneous processes of mineralization and immobilization.

TABLE 35. Carbon balance in various treatments after incubation of three soils for 112 days

Soil carbon (ppm)	Root C/N ratio	% root material added	C added from roots (ppm)	$(NH_4)_2SO_4$ present: C mineralized (ppm)	$(NH_4)_2SO_4$ present: Net loss or gain in C (ppm)	$(NH_4)_2SO_4$ absent: C mineralized (ppm)	$(NH_4)_2SO_4$ absent: Net loss or gain in C (ppm)
Clansthal sand							
	-	0	0	486	- 486	546	- 546
	50	0,5	2000	1389	+ 611	1888	+ 112
		1,0	4000	2798	+ 1202	3425	+ 575
5800	100	0,5	2200	1339	+ 861	1953	+ 247
		1,0	4400	2609	+ 1791	3487	+ 913
Glenrosa sandy loam							
	-	0	0	321	- 321	384	- 384
	50	0,5	2000	850	+ 1150	1441	+ 559
		1,0	4000	1615	+ 2385	2363	+ 1637
10200	100	0,5	2200	866	+ 1334	1263	+ 937
		1,0	4400	1723	+ 2677	1564	+ 2836
Shortlands clay							
	-	0	0	627	- 627	768	- 768
	50	0,5	2000	1569	+ 431	1899	+ 101
		1,0	4000	2490	+ 1510	2608	+ 1392
25200	100	0,5	2200	1529	+ 671	1698	+ 502
		1,0	4400	2224	+ 2176	2079	+ 2321

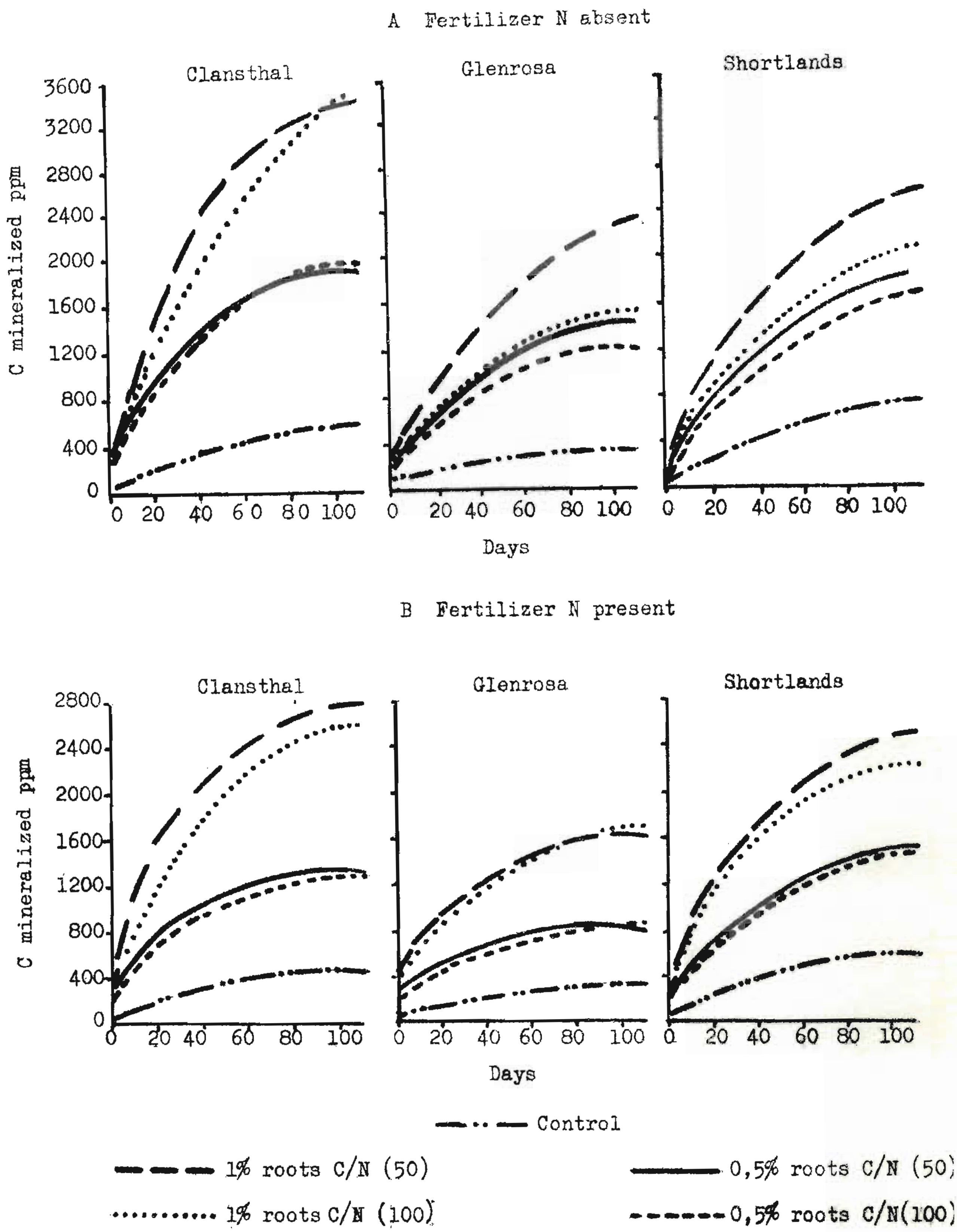


Fig. 24 Carbon mineralization in three soils as influenced by C/N ratio of added root material.

Calculation of mineralization and immobilization rates can be made from the equations of Kirkham and Bartholomew (1955), which are derived from the following differential equations:

$$\frac{dx}{dt} = m - i$$

and
$$\frac{dy}{dt} = \left(\frac{b - y}{a - x}\right) m - \frac{y}{x} i$$

where
x = total inorganic N (i.e. available N)

t = time

m = mineralization rate

i = immobilization rate

y = labelled inorganic N

a = total N in the system

b = total labelled N

Mineralization and immobilization rates were calculated according to the equations derived from Kirkham and Bartholomew's case 1, which are as follows:

$$m = \frac{x - xo}{t} \log e \frac{\left[\left(\frac{y}{b} - \frac{x}{a}\right)\left(\frac{xyo}{bxo} - \frac{x}{a}\right)\right]}{\left(\frac{xo}{x} \cdot \frac{a-x}{a-xo}\right)}$$

$$i = m - \frac{x - xo}{t}$$

Case 1 assumes that mineralization and immobilization rates are constant throughout a given period, and this is true if the time periods taken are sufficiently short, but would not hold for the entire duration of this experiment. For this reason several successive periods were selected as detailed in Table 36, which presents the rates obtained for the various fertilized treatments in the different soils.

Apart from the fertilizer control treatments, immobilization rates exceeded mineralization rates, resulting in net immobilization in

TABLE 36. N mineralization and immobilization (ppm N per day) in three soils containing root material of different C/N ratios and receiving labelled fertilizer N

Incubation period →	Clansthal sand							
	0-7 days		8-30 days		31-56 days		57-112 days	
Treatment	*m	**i	m	i	m	i	m	i
Control	2,76	2,33	1,00	0,43	1,47	1,05	0,50	0,11
	x(+0,43)		(+0,57)		(+0,42)		(+0,39)	
0,5% roots C/N (50)	10,12	12,97	3,48	3,00	3,86	3,36	1,36	0,85
	xx(-2,85)		(+0,48)		(+0,50)		(+0,51)	
0,5% roots C/N (100)	11,44	15,73	2,89	2,42	3,30	2,88	1,68	1,27
	(-4,29)		(+0,47)		(+0,42)		(+0,41)	
1,0% roots C/N (50)	22,10	30,24	2,42	1,81	3,25	2,71	2,03	1,55
	(-8,41)		(+0,61)		(+0,54)		(+0,48)	
1,0% roots C/N (100)	20,33	29,04	1,01	0,83	1,71	1,44	1,60	1,11
	(-8,71)		(+0,18)		(+0,27)		(+0,49)	

* m = ppm N mineralization per day

** i = ppm N immobilized per day

x (+)= net mineralization (ppm N per day)

xx (-)= net immobilization (ppm N per day)

TABLE 36. (Continued)

Incubation period →	Glenrosa sandy loam							
	0-7 days		8-30 days		31-56 days		57-112 days	
Treatment	m	i	m	i	m	i	m	i
Control	2,31	1,45	1,75	1,49	2,13	1,86	0,76	0,29
	(+0,86)		(+0,26)		(+0,27)		(+0,47)	
0,5% roots	9,95	12,81	3,37	3,06	3,50	3,12	1,74	1,37
C/N (50)	(-2,86)		(+0,31)		(+0,38)		(+0,37)	
0,5% roots	8,70	11,41	3,24	3,15	3,42	3,35	1,52	1,25
C/N (100)	(-2,71)		(+0,09)		(+0,07)		(+0,27)	
1,0% roots	14,81	19,38	4,48	4,87	3,56	4,02	1,36	1,22
C/N (50)	(-4,57)		(-0,39)		(-0,46)		(+0,14)	
1,0% roots	15,76	21,18	3,83	4,26	1,87	2,30	0,89	0,71
C/N (100)	(-5,42)		(-0,43)		(-0,43)		(+0,18)	

TABLE 36. (Continued)

Incubation period →	Shortlands clay							
	0-7 days		8-30 days		31-56 days		57-112 days	
Treatment	m	i	m	i	m	i	m	i
Control	0,95	0,09	1,32	0,97	1,71	1,44	0,58	-0,23
	(+0,86)		(+0,35)		(+0,27)		(+0,81)	
0,5% roots	9,88	12,59	3,67	3,36	3,45	2,76	1,96	1,58
C/N (50)	(-2,71)		(+0,31)		(+0,69)		(+0,38)	
0,5% roots	8,43	11,29	3,01	2,88	3,43	3,20	1,69	1,24
C/N (100)	(-2,86)		(+0,13)		(+0,23)		(+0,45)	
1,0% roots	13,39	19,11	3,18	2,79	2,75	2,59	2,23	1,57
C/N (50)	(-5,72)		(+0,39)		(+0,16)		(+0,66)	
1,0% roots	15,07	20,79	2,30	2,99	not		0,42	0,09
C/N (100)	(-5,72)		(-0,69)		available		(+0,33)	

all treatments during the first few days of incubation. Net immobilization was greater at the higher level of application of root material, which also was accompanied initially by higher rates of N turnover in all soils.

The enhanced microbiological activity occurring in the Clansthal sand was very noticeable in all treatments including the controls. This was particularly evident during the first week of incubation, when turnover rates in the Clansthal sand were compared with those on the other two soils. The higher level of activity was further reflected in the average daily net mineralization figures obtained for the subsequent incubation periods. In general these were greater in the Clansthal sand than in either the Shortlands or Glenrosa soils. Differences in soil pH values may be partly responsible as indicated by Broadbent and Tyler (1965), but Pauli (1965) has noted intense microbial activity in sandy soils above all others.

The favourable influence of root material with low C/N ratio on net mineralization, was apparent for most of the periods examined.

DISCUSSION

These results imply, that mineralization of N contained in root material is controlled primarily by the C/N ratio of the roots. This may influence the N nutrition of crops such as grass leys and sugarcane, which produce a large mass of roots often with low N content, that can immobilize several hundred kilograms of fertilizer N per hectare (Dilz and Woldendorp 1961, Power 1967). The results agree well with those of Jenkinson (1965), in which he followed the decomposition of 14 C-labelled ryegrass roots, and Power (1968) who studied mineralization of N in grass roots.

Difference in the amounts of available N found in the various soils at the end of the incubation period can largely be attributed to the extent to which mineral N was immobilized by soil micro-organisms following the different treatments. In the field the extent of immobilization will depend mainly upon how readily such micro-organisms, which abound in the rhizosphere, are able to decompose root residues, and exudates coming from the root system.

Harmsen and Kolenbrander (1965) state that the significance of immobilization of mineral N in the rhizosphere can be derived from the fact that recovery of applied N by a crop is always much less than the decrease in amount of inorganic N in the soil during the growth of the crop. This was evident from the results of the pot experiment reported in section A of this chapter. It is thought that the growing plant is able to exert a depressing effect on net mineralization of soil organic N compared to that occurring in a fallow soil (Goring and Clark 1948).

It appears that both the quantity and rate of N interchange in soils depends to a marked extent on the C/N ratio of the roots growing in them. It is suggested that those soils under established sugarcane which are inherently deficient and/or inadequately supplied with fertilizer N to allow for maximum plant growth, will tend to produce roots of high C/N ratio. Their decomposition will soon lead to the exhaustion of the soluble N pool (initial mineral soil N + fertilizer N addition), so that the only subsequent source of available N will be that remineralized from the soil.

Where insufficient mineralized soil N is available to maintain rapid decomposition, which as indicated in Chapter 7, must frequently occur under ratoon cane, particularly on certain sugar belt soils, net immobilization of N will result. This in turn must aggravate the existing deficiency and worsen the N nutrition of the crop. Conversely, adequate amounts of N (both from the soil and fertilizer sources) will have the effect of lowering the C/N ratio of roots and stimulating increased mineralization of N from the soil.

CHAPTER 10

UTILIZATION OF APPLIED NITROGEN AS INFLUENCED BY NITRIFICATION AND LEACHING

The importance to the cane plant of an adequate supply of inorganic N during the first few months of growth, either in the ammonium (NH_4-N) or nitrate (NO_3-N) form was emphasized in Chapter 4.

However, leaching losses of fertilizer N (usually as NO_3-N) applied at the onset of growth, are sometimes able to deprive the plant of much of its N supply before this can be properly utilized. Lysimeter studies (Dreibelbis 1954; Harrold and Dreibelbis 1951; MacIntire et al. 1952; and Takahashi 1967b) have shown that varying amounts of NO_3-N may be removed. Potential losses are seen to depend on (a) time, method and rate of N application (b) the presence or absence of a growing crop and (c) soil texture, which governs the distance a given quantity of water will move nitrates (Bates and Tisdale 1957; Maud 1964).

Losses can probably be reduced when applied N is retained by the soil in the NH_4-N form, before being converted to NO_3-N by nitrification. Providing that conditions such as soil moisture, temperature and oxygen supply are optimum, the most important factor remaining which governs the rate of nitrification is the soil pH value. Robinson (1963) has pointed out that if pH is not limiting and NH_4-N is readily available, then it will be converted to NO_3-N quite rapidly. However where pH is too low for optimum growth of nitrifying bacteria the population will only develop slowly and NO_3-N only accumulate gradually. Nitrification can also be delayed artificially by the addition of an inhibitor to the soil via the N fertilizer. (Goring 1962a, 1962b).

The sugar belt soils show a wide range of pH and it was felt that their nitrification rates might influence the utilization of fertilizer N by cane, particularly on sandy soils more prone to leaching. It was also considered that various N carriers might affect rates of nitrification by altering pH values when added to light textured weakly buffered soils.

Various aspects of nitrification in relation to pH were therefore investigated, in conjunction with the effects of leaching and delayed nitrification on the uptake of N by young cane.

A Nitrification in relation to pH

Delayed nitrification during mineralization of soil N

When measuring the potential of sugar belt soils to mineralize N reported in Chapter 7, it was noted that while ammonification usually proceeded rapidly, some soils showed a marked delay in nitrification even after several weeks. Comparative figures for a range of soils, showing the amount of NH_4-N and NO_3-N present at various times during an eight week incubation period, are given in Table 37.

In soils with low pH values there was a partial or almost complete delay in nitrification, which was most noticeable in the highly acid Shorrocks and Cartref series sands.

The effect of liming on delayed nitrification

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

Air dry soils representing six different series, four of which had previously shown delayed nitrification, were treated with reagent quality lime ($CaCO_3$) at rates equivalent to 0, 4,5 9 and 18 tons per hectare.

TABLE 37. Variable rates of nitrification occurring during incubation of various sugar belt soils

Soil series	pH	Total mineral N (NH_4 + NO_3) produced (ppm)							
		after 2 wks		after 4 wks		after 6 wks		after 8 wks	
		NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
No delay									
Dundee	5,5	tr	68	tr	78	tr	115	tr	123
Rydalvale	5,9	tr	56	tr	70	tr	105	tr	118
Doveton	5,8	tr	47	tr	62	tr	80	tr	90
Milkwood	5,8	tr	30	tr	42	tr	51	tr	62
Complete delay									
Shorrocks	4,8	47	4	54	4	65	4	76	60
Partial delay									
Mayo	5,1	37	7	29	23	35	22	40	25
Windermere	5,2	33	5	44	7	48	8	44	17
Cartref	4,9	16	5	29	6	32	7	35	9

tr = trace.

The soils were moistened to 60% WHC and incubated for four weeks at 35°C, after which amounts of NH_4-N and NO_3-N present were determined.

Table 38, shows that once the soil pH was raised sufficiently to provide a favourable environment for the nitrifying bacteria, the conversion to NO_3-N proceeded rapidly. In some soils liming also led to an increase in the amount of N mineralized.

The effect of different N carriers on nitrification

If different N carriers are able to influence soil pH and nitrification rate, it could be expected that this might lead to differential utilization of applied N by sugarcane, particularly on weakly buffered sandy soils.

TABLE 38. The effect of liming on nitrification (ppm N present after 4 weeks incubation)

Soil series	pH	equivalent tons $CaCO_3$ per hectare applied							
		Nil		4,5		9,0		18,0	
		NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Rydalvale	5,9	tr	116	tr	113	tr	108	tr	124
Inanda	5,5	3	49	1	51	1	57	3	61
Shorrocks	4,8	54	nil	tr	57	tr	57	tr	59
Cartref	4,9	32	nil	37	5	tr	38	12	30
Mayo	5,1	54	8	11	52	tr	65	tr	64
Windermere	5,2	36	16	tr	70	tr	92	tr	84
Mean		30	32	8	58	0	70	2	70

tr = trace.

Indirect evidence for the existence of this differential utilization, has been obtained from several N carrier experiments, designed to test the efficiency of various ammonium fertilizers among themselves and against a control with no applied N. The results from two such experiments carried out on a Cartref series sand and a Farmhill series clay are given in Tables 39 and 40.

All the N carriers significantly outyielded the control treatment both for tons cane and tons sucrose per hectare, but the ammonium fertilizer treatments differed significantly among themselves. Thus ammonium sulphate and urea were superior to ammonium nitrate and limestone ammonium nitrate (LAN) for both plant and first ratoon crops on the Cartref sand, and better than LAN on the Farmhill soil. In all crops, sulphate of ammonia significantly outyielded nitrate containing fertilizers. Table 40 reveals a tendency for LAN to be even less efficient in the presence of lime.

TABLE 39. Yield of cane as influenced by N carriers (Cartref series sand)

Treatment	Plant cane		First ratoon	
	tc/ha	t suc/ha	tc/ha	t suc/ha
Control	66,3	10,37	79,3	12,41
$(NH_4)_2SO_4$	92,7	14,47	116,5	18,08
Urea	91,2	14,36	113,6	17,99
NH_4NO_3	82,9	12,63	98,8	15,39
LAN	78,2	12,25	94,1	14,67
Mean	82,2	12,81	100,6	15,70
S.E. (trmt. means)	± 2,9	± 0,49	± 5,1	± 0,74
L.S.D. (0,05)	9,0	1,50	15,7	2,24
(0,01)	12,3	2,11	22,0	3,11
C.V.%	7,9	8,6	11,4	10,4

tc/ha = tons cane per hectare
t suc/ha = tons sucrose per hectare

Both crops given 132 kg N/ha and harvested at 19 months.

TABLE 40. Yield of cane as influenced by N carriers and liming (Farmhill series clay)*

Treatment	tons cane per hectare				tons sucrose per hectare			
	no lime (O)	lime (L)	mean	diff. (L-O)	no lime (O)	lime (L)	mean	diff. (L-O)
Control	65,9	90,3	78,1	24,4	11,51	15,46	13,48	3,95
$(NH_4)_2SO_4$	92,3	115,8	104,0	23,5	16,26	20,34	18,30	4,08
Urea	89,4	110,9	100,1	21,5	15,57	19,26	17,41	3,69
LAN	86,2	101,2	93,7	15,0	15,52	17,72	16,62	2,20
Mean	83,5	104,6	93,9	21,1	14,72	18,19	16,45	3,48
S.E. N trmt. means			± 3,3				± 0,58	
L.S.D. (0,05)			9,6				1,66	
S.E. N trmt. diff. (L-O)				± 4,7				± 0,81
L.S.D. (0,05)				13,7				2,35
C.V.% sub plots			10,0				9,9	

*Farmhill series. Dark brown very acid topsoil clay (25-45 cm thick).over

In an attempt to explain these differences, a laboratory experiment was conducted to follow the nitrification patterns occurring in sandy soils covering a range of pH values, after the addition to them of the N carriers used in the above field experiments.

PROCEDURE

800g air dry topsoil samples were taken representing three series of sandy soils, namely, Shorrocks (pH 4,6), Cartref (pH 4,8) and Clansthal (pH 6,2). Between them they account for approximately 30% of the acreage of the industry. They were treated as follows:

Treatment 1	Control - no N applied
Treatments 2-5	80 mg N (100 ppm) applied as $(NH_4)_2SO_4$, urea, NH_4NO_3 or LAN
Treatment 6	80 mg N - added as NH_4NO_3 + chemically pure $CaCO_3$ - 9 tons per hectare

The soils were moistened to 30% WHC with solutions of the above fertilizers and incubated at 30°C. After intervals of 0, 7, 14, 21 and 28 days samples of all treatments were withdrawn and pH, NH_4-N and NO_3-N determinations made.

RESULTS

Changes in soil pH, and amounts of NH_4-N and NO_3-N present during the four weeks following the various fertilizer additions are shown graphically in Figure 25A and B. The main effects of the different treatments were as follows:

(i) <u>Control</u> While nitrification was partially delayed during the first two weeks in the Shorrocks sand, little delay was noted in the other two soils.

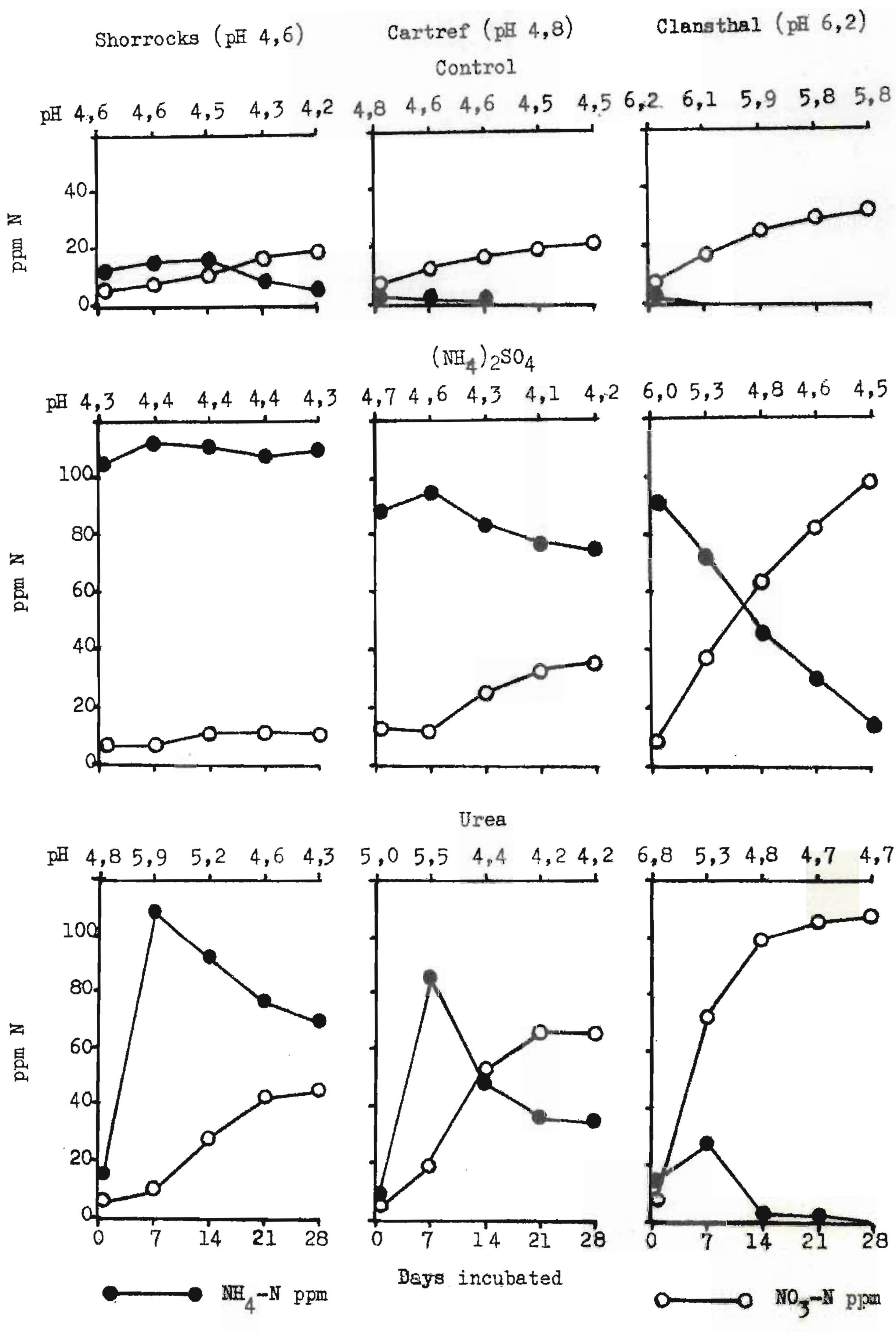


Fig. 25A Nitrification patterns and pH changes after adding $(NH_4)_2SO_4$ and urea to three sandy soils.

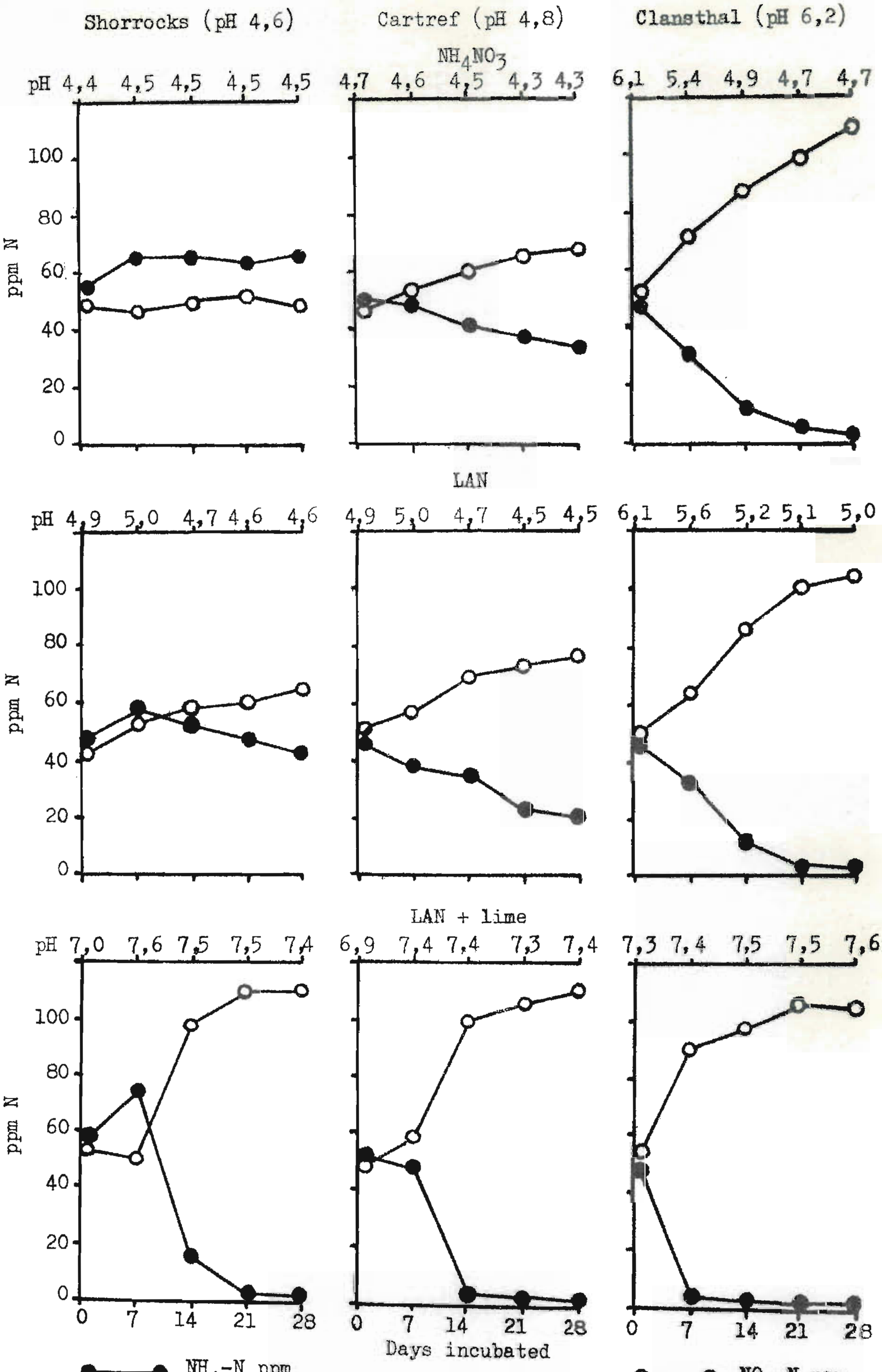


Fig. 25B Nitrification patterns and pH changes with time after adding NH_4NO_3, LAN and LAN + lime to three sandy soils.

(ii) $(NH_4)_2SO_4$ The acidifying action of this fertilizer coupled with the high natural acidity of the Shorrocks sand effectively prevented nitrification even after four weeks. In 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.

(iii) Urea The initial rise in pH following hydrolysis of the urea was apparently responsible for providing a more favourable environment for nitrification in the two more acid sands. As a result, over 30 ppm and 60 ppm NH_4-N respectively had been nitrified in the Shorrocks and Cartref series soils after four weeks. Nitrification was rapid in the Clansthal sand being complete within the first two weeks of incubation.

(iv) NH_4NO_3 Addition of this fertilizer also had an acidifying effect. In consequence, patterns and rates of NH_4-N conversion in the three soils were very similar to those obtained when $(NH_4)_2SO_4$ was applied, as indicated by the slopes of the graphs for these two fertilizer treatments.

(v) LAN. The limestone present in the NH_4NO_3 raised the pH sufficiently in both the more acid sands, to bring about an increase in their rate of nitrification compared with that when NH_4NO_3 only was used. Despite this, conversion to NO_3-N in the Shorrocks sand was still very slow.

(vi) NH_4NO_3 + lime This treatment markedly raised the pH value of all soils, and nitrification was greatly accelerated. It was complete within 21, 14 and 7 days for the Shorrocks, Cartref and Clansthal sands respectively.

(vii) pH values The soil pH data in Figures 25A and B show that apart from an initial reduction in acidity following the application of urea and LAN, acidity increased with in all NH_4 fertilizer treatments, except where the equivalent of 9 tons $CaCO_3$ per hectare was used in conjunction with NH_4NO_3. This is thought to be due to nitrification of the NH_4^+ ion which is replaced on the soil exchange complex by H^+ ions. The results indicate that these weakly buffered sands would soon tend to become more acid than they were prior to ammonium fertilizer application.

DISCUSSION

Results related to those cited above have been obtained elsewhere. Munk (1958) found that nitrification was greater in an acid soil (pH 4,4) in the presence of LAN or urea, than with $(NH_4)SO_4$. Dijkshoorn (1960) showed in pot experiments using $(NH_4)_2SO_4$, that nitrification was complete within 21 days at pH 7,0, considerably retarded at pH 5,3 and inhibited at pH 4,3. Botha (1960) demonstrated that urea nitrified more readily than $(NH_4)_2SO_4$ when applied to three soils of widely differing pH and texture.

Broadbent <u>et al</u>. (1957) suggested that inhibition of nitrification following NH_4 - fertilizer application may be due to either excessively low pH resulting from formation of nitrous and nitric acids, or the presence of free ammonia exerting selective inhibition on nitrate forming bacteria. This may partly explain the complete absence of nitrification in the highly acid Shorrocks sand when $(NH_4)_2SO_4$ and NH_4NO_3 were added. At low concentrations of NH_4-N (as in the control treatments, Figure 25A) a population of nitrifiers may have gradually been able to develop.

From the results it would appear that considerable delays in nitrification can be expected on the more acid sugar belt soils. Apart from the soil pH effect as such however, the particular N carrier applied influences to a greater or lesser extent, the rate of nitrification. This could be beneficial with regard to utilization of N by sugarcane especially on the more acid sandy soils. It provides the following explanation for differences in yield response to different N carriers, obtained in the field experiments described earlier.

The NH_4-N component in both $(NH_4)_2SO_4$ and urea was probably available to the developing plant for a longer period than that in the NH_4NO_3 or LAN, as double the amount of NH_4- N was present initially in the former two fertilizers. The NO_3-N component of the two latter fertilizers would have been prone to immediate leaching, in the event of rain, perhaps before much of it could be utilized, as will be shown later. If all the NO_3-N is leached rapidly beyond the root zone in these sandy soils only half or less of the original quantity of N applied would remain available for uptake. Enhanced nitrification in the case of LAN due to the presence of $CaCO_3$, especially where extra limestone was added, would further increase the possibility of leaching losses. This may explain why LAN was not as effective as NH_4NO_3 in the field experiment on the Cartref series sand (see Table 39), and apparently less efficient in the presence of lime applied to the Farmhill soil (see Table 40).

B The effect of leaching and delayed nitrification on N uptake by sugarcane

The following glasshouse experiment was carried out in order to examine further, certain aspects of the results in Section A of this chapter.

PROCEDURE

Pregerminated single budded cane setts were grown in pots containing 1,5 kg of either the Clansthal or Shorrocks series sands (pH 6,2 and 4,6 respectively). All pots were treated with $(NH_4)_2SO_4$

or $NaNO_3$ at a rate equivalent to 220 kg N per hectare (100 ppm N). In half the pots containing $(NH_4)_2SO_4$, the fertilizer was treated with N-Serve* (2% by weight). This is a nitrification inhibitor (2-chloro - 6 - (trichloromethyl) pyridine). A second series of pots received identical fertilizer treatments, but these were left unplanted.

The fertilizers were uniformly mixed with the soils beforehand. Each pot had a plastic seal to eliminate drainage losses, but apart from the time that leaching treatments were imposed, the pots were maintained at 50% WHC by daily watering. After eight weeks, tops and roots were harvested and analysed for N content. The uncropped soils were rapidly air dried before being analysed for NH_4-N and NO_3-N.

Leaching treatments The following leaching treatments were imposed on two replicates of all fertilizer treatments, both cropped and uncropped.

Clansthal sand

(i) Control - no leaching

(ii) 520 ml water ≡ 50 mm rainfall applied after one week

(iii) 520 ml water ≡ 50 mm rainfall applied after three weeks

Shorrocks sand

(i) Control - no leaching

(ii) 520 ml water ≡ 50 mm rainfall applied after one week

(iii) 520 ml water ≡ 50 mm rainfall applied after five weeks

In addition on the Clansthal sand, single cropped pots were leached with 260 mm water ≡ 25 mm rainfall, applied after one week and three weeks.

During leaching the required amount of water was applied dropwise to the surface of the pots, the soils having first been brought to 50% WHC, and the plastic seals removed. After drainage was complete the pots were resealed, and the leachate from each pot

* Trade name, Dow Chemical Company.

made up to a fixed volume. Aliquots were then taken for NH_4-N and NO_3-N determinations.

RESULTS AND DISCUSSION

Plant uptake of N

The amounts of N taken up by cane grown under the various fertilizer and leaching treatments during a period of eight weeks are shown in Table 41.

As anticipated, in both soils, the effect of leaching was to cause significant reductions in N uptake, these being most severe where $NaNO_3$ was applied, and least severe where N-Serve was added to $(NH_4)_2SO_4$. Uptake data for the Clansthal sand indicate that leaching effects, at the lower rate of water application (260 ml), were generally less severe than those at the higher rate (520 ml), this being particularly noticeable in the $NaNO_3$ treatments. Certain of the results from both soils suggest that the longer leaching was delayed the less applied N was lost, but this trend was not consistent throughout all treatments.

Amount and time of water application

Compared with a 260 ml application, 520 ml of water removed up to three times the amount of mineral N from the Clansthal series sand, as shown in Table 42. Leaching with 520 ml water after one week removed similar amounts of mineral N from cropped and uncropped pots receiving the same fertilizer treatment on both soils. However in the Clansthal sand significantly more N was leached from the $NaNO_3$ treated pots when compared to those which had received N-Serve.

Delaying leaching until three weeks after planting in the Clansthal sand, again resulted in fairly similar amounts of mineral N being removed from cropped and uncropped pots.

TABLE 41. The effect of different fertilizer and leaching treatments on N uptake by cane (mg N per pot - tops + roots)

Treatment	Clansthal sand			Shorrocks sand			Clansthal sand*	
	Control	520 ml H_2O after		Control	520 ml H_2O after		260 ml H_2O after	
		1 week	3 weeks		1 week	5 weeks	1 week	3 weeks
$(NH_4)_2SO_4$ only (150 mg N)	252,7	100,6	142,0	162,9	108,2	131,4	163,3	126,5
$(NH_4)_2SO_4$ + 2% N-Serve	255,7	144,6	148,0	221,3	137,1	145,0	184,1	157,0
$NaNO_3$ (150 mg N)	191,4	60,9	75,7	162,2	79,3	107,6	145,8	145,7
Mean uptake (mg N)	233,2	102,0	121,9	182,1	108,2	128,0	164,4	143,1
S.E. (treatment means)		± 10,3			± 8,2		* single pots	
L.S.D. (0,05)		33,0			26,2			
(0,01)		47,4			37,6			
C.V. %		9,6			8,3			

TABLE 42. Nitrogen lost as leachate from cropped and uncropped soils in relation to fertilizer and leaching treatment (mg N per pot)

Treatment (per pot)	Clansthal sand				Shorrocks sand				Clansthal sand	
	520 ml H_2O after 1 week		520 ml H_2O after 3 weeks		520 ml H_2O after 1 week		520 ml H_2O after 5 weeks		260 ml H_2O after 1 week	260 ml H_2O after 3 weeks
	C	U	C	U	C	U	C	U	Cropped only*	
$(NH_4)_2SO_4$ only (150 mg N)	88,5	91,5	63,5	79,0	62,0	63,0	16,5	53,0	28,5	31,5
$(NH_4)_2SO_4$ + 2% N-Serve	72,0	74,5	70,5	79,0	64,5	60,0	3,5	59,5	24,0	19,5
$NaNO_3$ (150 mg N)	115,5	112,5	120,0	152,0	77,0	†	75,0	105,5	46,5	52,5
Mean	92,0	92,9	84,9	103,4	67,7	-	31,7	72,7	33,0	34,5
S.E. (treatment means)	± 10,2				± 6,2					
L.S.D. (0,05)	31,6				19,2					
(0,01)	44,6				27,2					
C.V.%	15,4				15,0					

* single pots

† samples were contaminated. C = cropped pots U = uncropped pots

Apparently at this stage the nutrient supply from the germinating sett must still have been influencing growth, and it is likely that uptake of applied N was only just commencing. It was therefore decided to delay leaching of the Shorrocks sand treatments until five weeks after planting. Amounts of N leached from the cropped soils at this time were shown to be significantly lower than those from the uncropped soils, especially where ammonium fertilizer had been applied.

Form of N fertilizer and influence of N-Serve

Figures 26A and B show that in both soils, N losses from the ammonium fertilizer treatments for equal amounts of water applied were always less than those from the nitrate fertilizer treatment. Nonetheless considerable quantities of NH_4-N were leached from the soils even at five weeks. This observation is contrary to the findings of Bates and Tisdale (1957), Krantz et al. (1944) and Maud (1964) who state that downward movement takes place only in the nitrate form. Morgan and Jacobson (1942) however, did obtain substantial amounts of ammonium salts in leachates collected from sandy soils. This may be due to the soil exchange complex being fully saturated, so that an excess of easily leached NH_4^+ ions is present in these sandy soils of low cation exchange capacity.

The effect of N-Serve in delaying nitrification of $(NH_4)_2SO_4$ is apparent in Figure 26A, from the relatively small amounts of NO_3-N leached from the cropped and uncropped treatments of the Clansthal sand, when compared with the larger amounts leached when $(NH_4)_2SO_4$ only was applied. The same effect is demonstrated in Figure 27, which shows amounts of NH_4-N and NO_3-N remaining in the leached uncropped soils after eight weeks. In the slightly acid Clansthal sand in which nitrification readily occurs, no NH_4-N remained in the two leaching

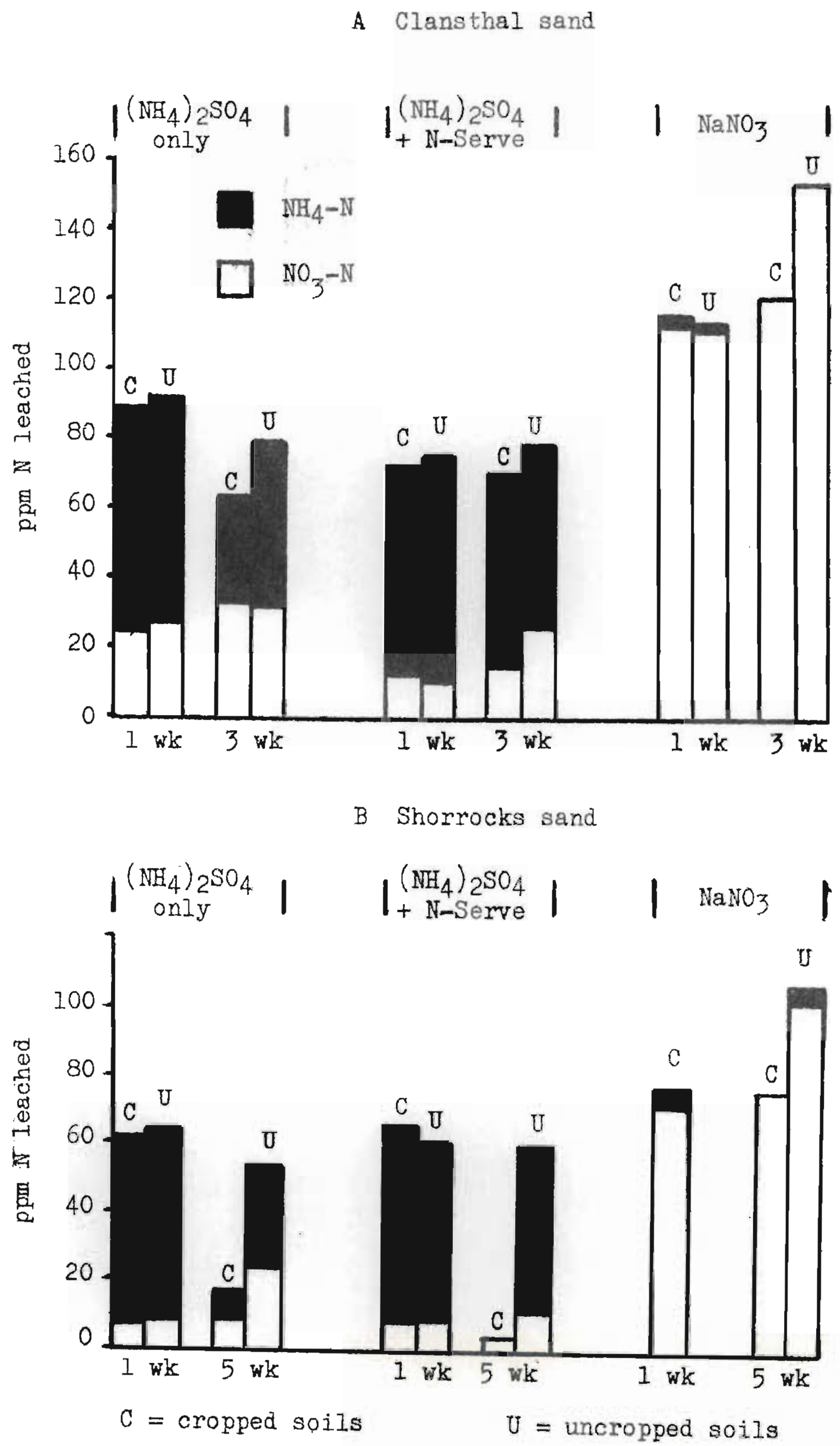


Fig. 26 Losses of NH_4-N and NO_3-N following leaching of cropped and uncropped soils. (520 ml H_2O applied to all pots after 1, 3, or 5 weeks).

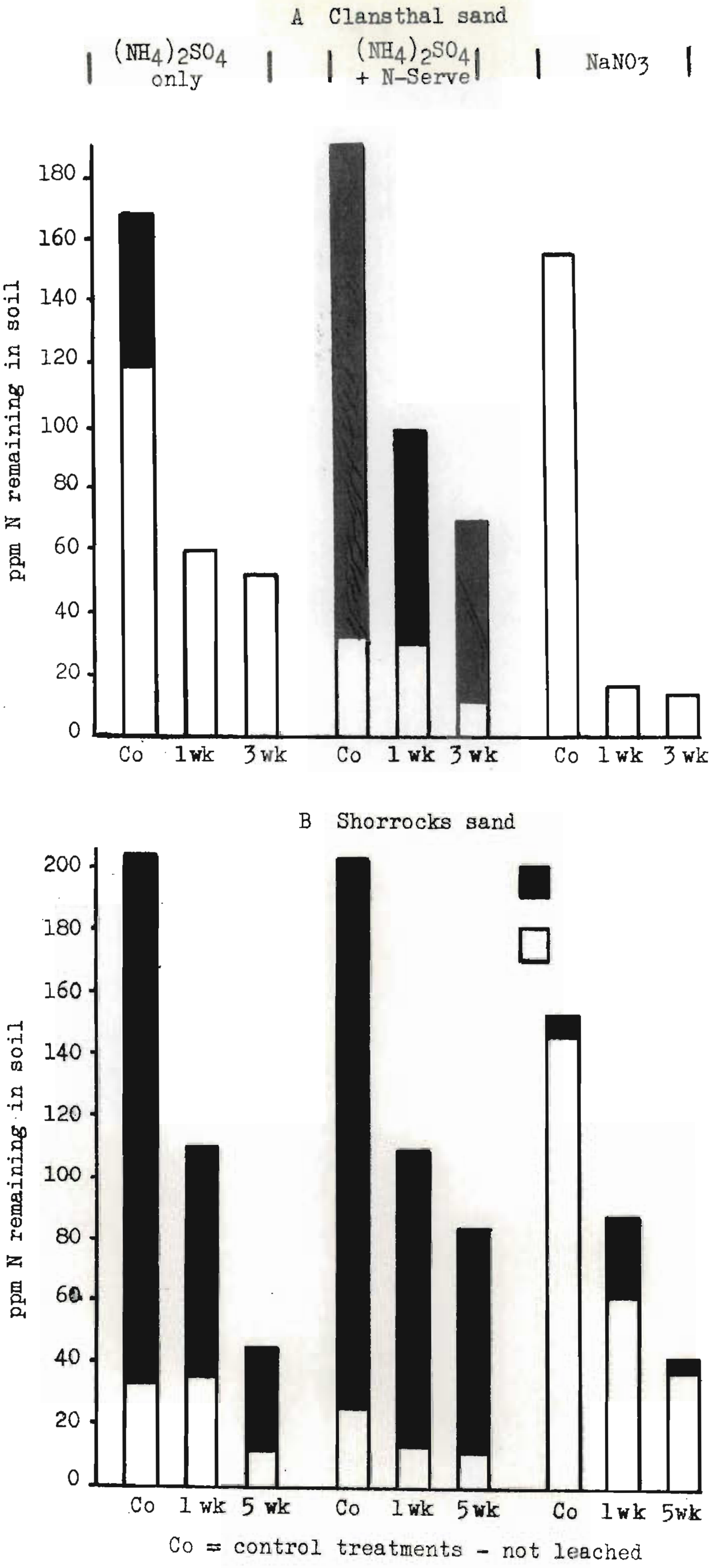


Fig. 27 Mineral N (NH_4-N + NO_3-N) remaining in uncropped soils after eight weeks. (520 ml H_2O applied to pots after 1, 3, or 5 weeks).

treatments which received $(NH_4)_2SO_4$ only, but considerable amounts were still present after eight weeks when N-Serve was added to the fertilizer.

Because nitrification normally proceeds slowly in the highly acid Shorrocks sand, substantial amounts of NH_4-N remained in the two leaching treatments which received $(NH_4)_2SO_4$ only, in this soil (see Figure 27B). Thus the effect of delayed nitrification due to N-Serve was much less pronounced.

Only traces of mineral N were found in any of the cropped soils after the eight week growth period.

Textural and pH effects.

A somewhat higher clay content in the Shorrocks sand, (14%) is considered partly responsible for the smaller amounts of mineral N leached throughout, from all treatments in this soil when compared to the larger amounts in the Clansthal sand (9%), as seen in Figure 26.

Apart from texture however, the difference in pH between these sands has obviously affected their behaviour to applied N as discussed in section A of this chapter. The results show that any factor that delays nitrification such as increased soil acidity will tend to reduce losses of NO_3-N due to leaching.

Leaching of N in the field

Some evidence indicating rapid leaching of N under young cane growing on a Clansthal series sand was obtained from the early stages of a fertilizer trial at the Sugar Experiment Station. In September at the onset of the rains, $(NH_4)_2SO_4$ was applied in the furrow at planting, at levels of 0, 27,5, 55,0 and 110 kg N per hectare. After eight weeks, during which almost 200 mm of rain were recorded, three soil profiles in the cane row at each N level were sampled at 30 cm intervals to a depth of 120 cm. Individual samples were immediately analysed for NO_3-N, and the results subsequently corrected for moisture content.

The meaned results for each sample depth to 120 cm for the various levels of applied N are shown in Figure 28. They indicate that considerable leaching of NO_3-N had occurred to depth, the amount leached generally increasing as N level increased.

<u>The efficacy of N-Serve in the field</u>

Information regarding the use of N-Serve to delay nitrification in soils under cane in the field is scanty and of a somewhat conflicting nature. Yield increases were noted in the Philippines (Lojo *et al*. 1964), following the use of both urea and $(NH_4)_2SO_4$ coated with 2% N-Serve. Recently in Louisiana, Parr *et al*. (1971) obtained increases in cane yields of 11-13 tons per hectare, where 110 kg N as anhydrous ammonia was applied with N-Serve (3% and 6% inhibitor levels), compared with NH_3 alone. Moreover yields from 110 kg N applied as NH_3+N-Serve at either inhibitor level were equal to that obtained from 165 kg NH_3-N alone.

These data imply that the efficiency of fertilizer N applied to sugarcane can be increased through suppression of nitrification with N-Serve. On the other hand (Parish 1965) reports that field trials have shown no increase in fertilizer N use efficiency for sugarcane in Mauritius. This is ascribed to the temporary nature of the toxic effect of N-Serve on soil nitrifying organisms, as it is volatile.

This effect was studied in the laboratory on soils from four different series, showing considerable variation in pH and texture. The soils were treated with 100 ppm N applied as $(NH_4)_2SO_4$ solution containing 0,5 1 and 4 percent N-Serve, expressed as a percentage of fertilizer N. They were moistened to 50% WHC, incubated at 30°C, and analysed for NH_4-N after periods of 2,4 and 6 weeks.

The results in Table 43 show that all three levels of N-Serve were extremely effective in delaying nitrification for at least six weeks in the sandier soils, particularly the acid Glenrosa sandy loam.

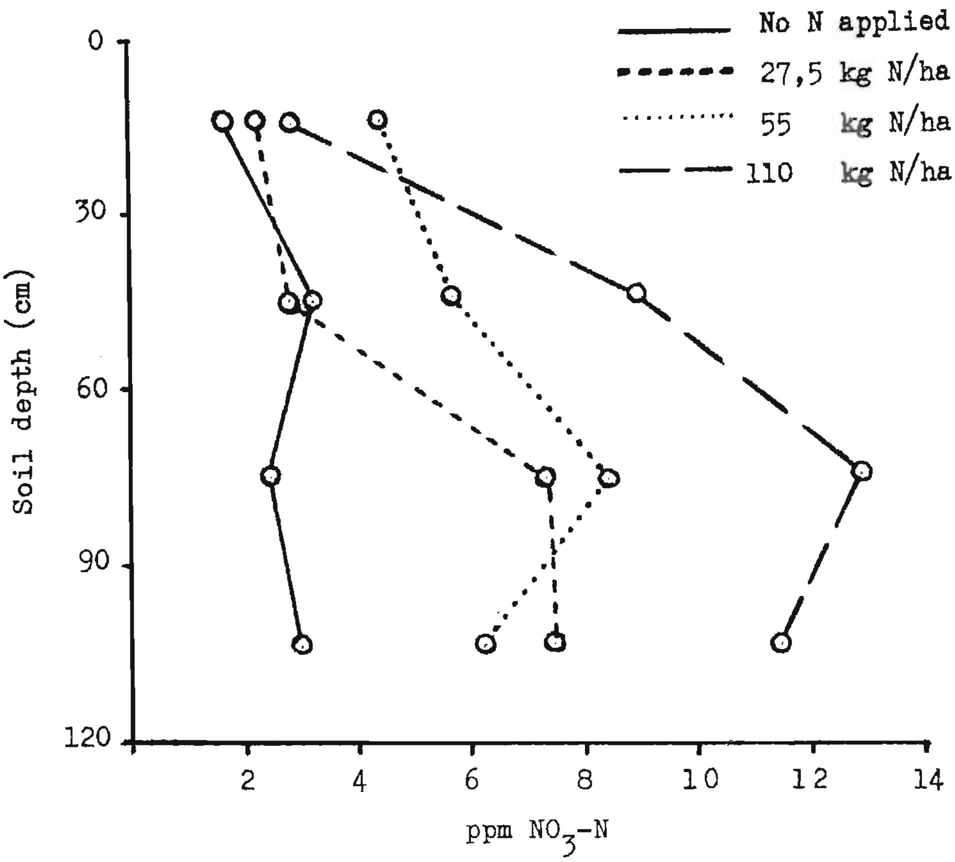


Fig. 28 Distribution of NO_3-N under young cane two months after application of $(NH_4)_2SO_4$ in the furrow (each point is mean of three samples)

TABLE 43. Amounts of NH_4-N retained by four different soils following addition of N-Serve at three levels (results expressed in ppm)

Soil series	% N-Serve added	100 ppm N applied $(NH_4)_2SO_4$ 2 weeks	4 weeks	6 weeks
Shortlands	0,5	32	4	0
clay	1	49	2	0
(pH 6,9)	4	84	'4	0
	Mean	55	3	0
Clansthal	0,5	62	36	40
sand	1	79	42	42
(pH 6,2)	4	115	92	54
	Mean	85	57	45
Glenrosa	0,5	102	92	94
sandy loam	1	105	99	105
(pH 5,6)	4	111	113	104
	Mean	106	101	101
Cartref	0,5	75	51	40
loamy sand	1	81	60	62
(pH 5,5)	4	101	84	84
	Mean	86	65	62

In the Shortlands clay however the effect was shortlived, even at the 4% level of N-Serve, negligible amounts of NH_4-N remaining at the end of four weeks.

Weir (1969) working with 2-amino-4chloro - 6 - methyl-pyrimidine (an inhibitor related to N-Serve) showed that the amount recovered from soils by acidified KCl was a logarithmic function of of time, clay content, cation exchange capacity and surface area of soils. Apparently adsorption by soil colloids is the predominant process by which organic nitrification inhibitors are immobilized.

Concluding remarks

Where leaching of N occurs under young cane, particularly on sandy soils, uptake of N by the plant maybe considerably reduced. If losses are severe depression in yield may result. The period of potential loss is probably greatest before the cane root system is fully established, following which, losses should normally be greatly reduced. However it is often during this early period of growth that high rainfall is experienced and marked leaching occurs.

In time the cane may partly be able to compensate for such losses, by subsequent recovery of leached N. This appears likely in the coastal sands of Natal in which actively absorbing roots have been found at depths of 210 cm and beyond (Wood and Wood 1967).

Provided the plant is in a position to fully utilize NO_3-N when it is applied, the efficiency of N carriers such as NH_4NO_3 and LAN would probably be equal to that of $(NH_4)_2SO_4$ or urea. This emphasises the importance, from the nutritional point of view, of correctly timing N fertilizer applications.

CHAPTER 11

THE EFFECT OF TIME OF APPLICATION AND PLACEMENT ON THE UTILIZATION OF FERTILIZER NITROGEN BY PLANT CANE

Several experiments have been carried out on sugar belt soils, to determine the optimum time of applying N fertilizer to the plant crop, all giving somewhat inconclusive results.

On an Inanda series soil 110 kg N per hectare was applied in two ways. Half in the furrow under the cane sett at planting and half as a top-dressing, compared with all the N as a single top-dressing 12 weeks after planting. Table 44 shows that the single application top-dressed noticeably increased yield, but this effect was offset by a relatively small increase in tons sucrose. However, results from a similar experiment on a Farmhill series soil (see Table 44) indicated that splitting the application of N may be advantageous.

TABLE 44. Cane and sucrose yields showing the effect of single vs. split applications of N to plant cane

Treatment	Inanda series soil		Farmhill series soil	
(kg N/ha)	tc/ha	t suc/ha	tc/ha	t suc/ha
55 kg N *(i.f.) 55 kg N **(t.d.)	160,2	24,26	95,6	16,78
110 kg N (t.d) at 12 weeks	168,7	24,71	87,8	15,57
S.E.	± 3,0	± 0,40	±3,9	± 0,67
L.S.D. p = 0,05	8,7	1,59	11,9	2,04
C.V.%	6,9	6,2	9,5	9,2

Throughout this chapter *(i.f.) = in furrow and

In Table 45 data from experiments on soils from a further three series are presented. In these the N was applied as a single dressing either in the furrow at planting or as a top-dressing, or the applications were split as shown in the table.

TABLE 45 Cane and sucrose yields showing the effect of single vs. split applications of N to plant cane

Treatment (kg N/ha)	Williamson		Clansthal		Trevanian*	
	tc/ha	t suc/ha	tc/ha	t suc/ha	tc/ha	t suc/ha
110 kg N (i.f.)	152,3	18,97	143,1	23,05	144,7	17,56
27,5 kg N (i.f.) 82,5 kg N (t.d.)	146,7	17,49	136,2	18,41	157,2	18,39
55 kg N (i.f.) 55 kg N (t.d.)	139,8	16,89	135,7	17,52	156,1	19,91
110 kg N (t.d.)	136,0	16,69	139,8	18,50	161,5	19,85

* Trevanian series soil - dark grey porous sandy clay loam (15 - 35% clay), 30 - 80 cm thick merging via a mottled clay subsoil, to rock. Slightly to moderately acid. Gemvale form.

In no case were statistically significant differences found between treatments although the results apparently favour placement of all N in the furrow in two out of three experiments.

In Chapter 10 the importance of correct timing of N fertilizer applications, to ensure maximum utilization by the young plant was stressed. From the work reported it appeared that application of all the fertilizer N in the furrow at planting could lead to serious losses through leaching, especially in light textured soils. However, the results of the field experiments just described do not indicate that yields were significantly reduced by furrow placement.

To study the effect of timing and placement on the utilization of fertilizer N by cane, two field experiments were carried out using labelled fertilizers.

PROCEDURE

Similar experiments were conducted simultaneously on two neighbouring but contrasting soils. These were a Clansthal series sand and a clay of the Rydalvale series.

Ammonium sulphate labelled with ^{15}N was applied at 84 kg N per hectare in single and split applications, and these were compared with a single top-dressing of $K^{15}NO_3$ (84 kg N/hectare). Treatments were as follows:

1) (S/A) all in the furrow (i.f.) at planting
2) (S/A) $\frac{1}{2}$ in furrow, $\frac{1}{2}$ top-dressed (t.d.), 10 weeks after planting;
3) (S/A) $\frac{1}{4}$ in furrow, $\frac{3}{4}$ top-dressed, 10 weeks after planting
4) (S/A) all top-dressed 10 weeks after planting
5) $K^{15}NO_3$ all top-dressed 10 weeks after planting

The design in each case was a randomised block experiment with three replications. Four three-budded setts of variety NCo 376 constituted each plot, which was surrounded by a metal cylinder 60 cm in diameter, open at both ends and pressed into the ground to a depth of 45 cm. The cylinders were used primarily to confine the area to be fertilized with labelled N (see Plate 6B).

A total of 2100 mg N was applied per plot of four setts. The $^{15}(NH_4)_2SO_4$ was diluted with sufficient normal $(NH_4)_2SO_4$ to give a final concentration of 2,080 atom percent ^{15}N excess. The $K^{15}NO_3$ had a final concentration of 4,719 atom percent ^{15}N excess.

Prior to planting, a furrow 18 cm deep was prepared in each cylinder, and single superphosphate (8,3%P) and muriate of potash (50% K) applied at rates of 440 kg and 220 kg per hectare respectively.

Furrow depth was reduced to 12,5cm by adding soil, and $^{15}(NH_4)_2SO_4$ applied where required. Furrow depth was further reduced to 6,5 cm and the setts planted and covered with soil. Poor germination was experienced at both sites and certain setts were replanted a week later.

Ten weeks after planting during which almost 250 mm of rainfall was recorded the required N top dressings were applied. The fertilizer was placed in shallow furrows 15 mm deep on either side of the plants. During the course of both experiments third leaf samples and accumulated trash (dead leaves and sheaths) were removed periodically from all cane stools, and analysed so that any differences in the cycling of N by the plant resulting from the various fertilizer treatments could be noted.

After 48 weeks (11 months) both experiments were harvested (see Plate 6A), plants being divided into leaf, stalk and a final bulked trash sample. Following field weighing, the various plant parts were oven dried to constant weight, and analysed for total N and ^{15}N content.

In addition a single replicate (one cylinder) from each treatment of both experiments was removed as an undisturbed core of soil 45 cm deep (see Plates 6B and C). Stubble and roots were separated by washing as shown in Plate 6D, and after weighing, prepared for N analysis. Following harvest, the remaining replicates of all treatments were allowed to ratoon for four months before removal of the tops and trash, in order to study uptake of residual fertilizer N.

RESULTS AND DISCUSSION

Yield

The yields of harvested stools were exceptionally variable and there was no significant relationship between time and method of application and the production of dry matter on either soil. However,

A

Cane stools at time of harvest
(Clansthal series sand)

B

Harvested stool with soil excavated
to reveal the cylinder

C

Cane root system exposed in
its soil core

D

Stubble and roots washed free of soil
(roots ≡ 10-15 tons/ha on a dry weight basis)

Plate 6 To illustrate growth habit of cane in field experiments where ^{15}N fertilizers were applied.

leaf + stalk yields on the Clansthal sand were least where all fertilizer N had been applied in the furrow, and greatest where it was top-dressed as KNO_3 ten weeks after planting. Visual differences between these two treatments were marked, especially during the first few months of growth as shown in Plates 7A and B.

Yield variability was attributed to lack of soil uniformity particularly of the Rydalvale clay, and to the somewhat erratic germination encountered at both sites.

Recovery of applied N

Despite yield variability, significant differences in recovery of applied N, related to timing, placement and type of fertilizer were obtained from both experiments (see Table 46).

TABLE 46. Percentage recovery of fertilizer N by cane harvested after 48 weeks (above ground parts only)

Treatment (kg N/ha)	Clansthal sand			Rydalvale clay		
	Leaves + stalk	Trash	Tops + trash	Leaves + stalk	Trash	Tops + trash
1) 84 kg N (i.f.)	7,22	1,47	8,69	12,65	4,22	16,87
2) 42 kg N (i.f.) 42 kg N (t.d.)	19,78	6,66	26,44	18,18	6,34	24,62
3) 21 kg N (i.f.) 63 kg N (t.d.)	18,41	8,85	27,26	21,37	8,19	29,59
4) 84 kg N (t.d.) as $(NH_4)_2SO_4$	14,56	9,62	24,18	22,50	8,03	30,53
5) 84 kg N (t.d.) as KNO_3	27,62	14,91	43,53	25,95	11,15	37,10
Mean	17,52	8,30	25,82	20,12	7,59	27,71
S.E. (trmt. means)	±2,20	±0,65	±2,75	±2,55	±0,70	±3,09
L.S.D. p = 0,05	7,17	2,11	8,96	8,31	2,29	10,09
= 0,01	10,44	3,07	13,03	12,09	3,33	14,68
C.V.%	21,7	13,5	18,4	21,9	16,0	19,3

A

84 kg N per hectare as $(NH_4)_2SO_4$ in furrow at time of planting

B

84 kg N per hectare as KNO_3 top-dressed ten weeks after planting

Plate 7 Growth difference 17 weeks after planting in cane grown on Clansthal sand, following application of N either in furrow at planting or top-dressed at ten weeks.

Further details of yield and recovery of ^{15}N during the course of both experiments is presented in Appendix 6.

Lowest recoveries on both soils were obtained when all the N was applied in the furrow at planting. Amounts recovered by the above ground parts of the plant from this treatment were significantly lower than from any other, except where N was split, half in the furrow, half top-dressed on the Rydalvale clay. Laboratory and field data reported in Chapter 10, strongly suggest that leaching was primarily responsible for low recoveries when all the N was applied in the furrow. In this event, the lower recovery of fertilizer N observed in the Clansthal sand, when compared to that from the Rydalvale clay, could have been expected.

Where some, or all of the N was top-dressed as $(NH_4)_2SO_4$, recovery was much improved particularly in the Clansthal sand, though no significant differences between these three treatments (ie. 2, 3 and 4) were found on either soil, for the entire above ground part of the plant. However, recovery figures based on trash only, showed a significantly lower recovery of N in the Clansthal sand where the application was split half in the furrow, half top-dressed, compared with treatments 3 and 4 where three quarters or all the N had been top-dressed. A similar trend was apparent in the Rydalvale clay.

The highest recoveries of N in both experiments were obtained where KNO_3 was applied as a top-dressing. Significantly more N was recovered from the nitrate top-dressing than from any other treatment on the Clansthal sand, and a similar trend was apparent on the Rydalvale clay. This could be explained by the fact that NO_3-N is much less involved in biological turnover than ammonium N. Jansson <u>et al</u>. (1955) have shown that NH_4-N is preferentially utilized by soil micro-organisms whereas NO_3-N is not as susceptible to immobilization by this means, so that larger amounts of N are available for absorption by the plant. It was not possible however to establish whether differences in immobilization of N from the two fertilizers had occurred in the field.

<u>Changes in ^{15}N levels during the experiments</u>

The effects of timing and placement on recovery of fertilizer N are most clearly demonstrated by the ^{15}N levels in the trash samples collected during the experiments from those treatments receiving $(NH_4)_2SO_4$ (see Figures 29A and B).

The first collection of trash was made 21 weeks after planting i.e. 11 weeks after all fertilizer N had been applied. Bearing in mind the initial concentration of 2,080 atom percent excess ^{15}N in the $(NH_4)_2SO_4$, it is apparent that considerable dilution of fertilizer N by soil N had occurred in the plants under all treatments on both soils after 21 weeks. The relative enrichment of trash from the Clansthal sand at this time, clearly reflects the three levels of N applied as a top-dressing at 10 weeks (42, 63 and 84 kg N per hectare), and suggests that the soil N was diluting the fertilizer N in proportion to these levels. A somewhat similar but less marked trend was apparent in trash from Rydalvale clay.

Where all the N had been applied in the furrow, trash enrichment on the Clansthal sand was considerably lower than that in any other treatment and it compared unfavourably with the similar treatment in the Rydalvale clay. This coupled with the poorer trash yield on the sand at 21 weeks indicates that much of the applied N must have been lost from this treatment before it could be utilized. Enrichment values in subsequent trash samples continued to reflect the differences in levels of top-dressed N in both soils, and the generally low enrichment where all the N had been applied in the furrow at planting.

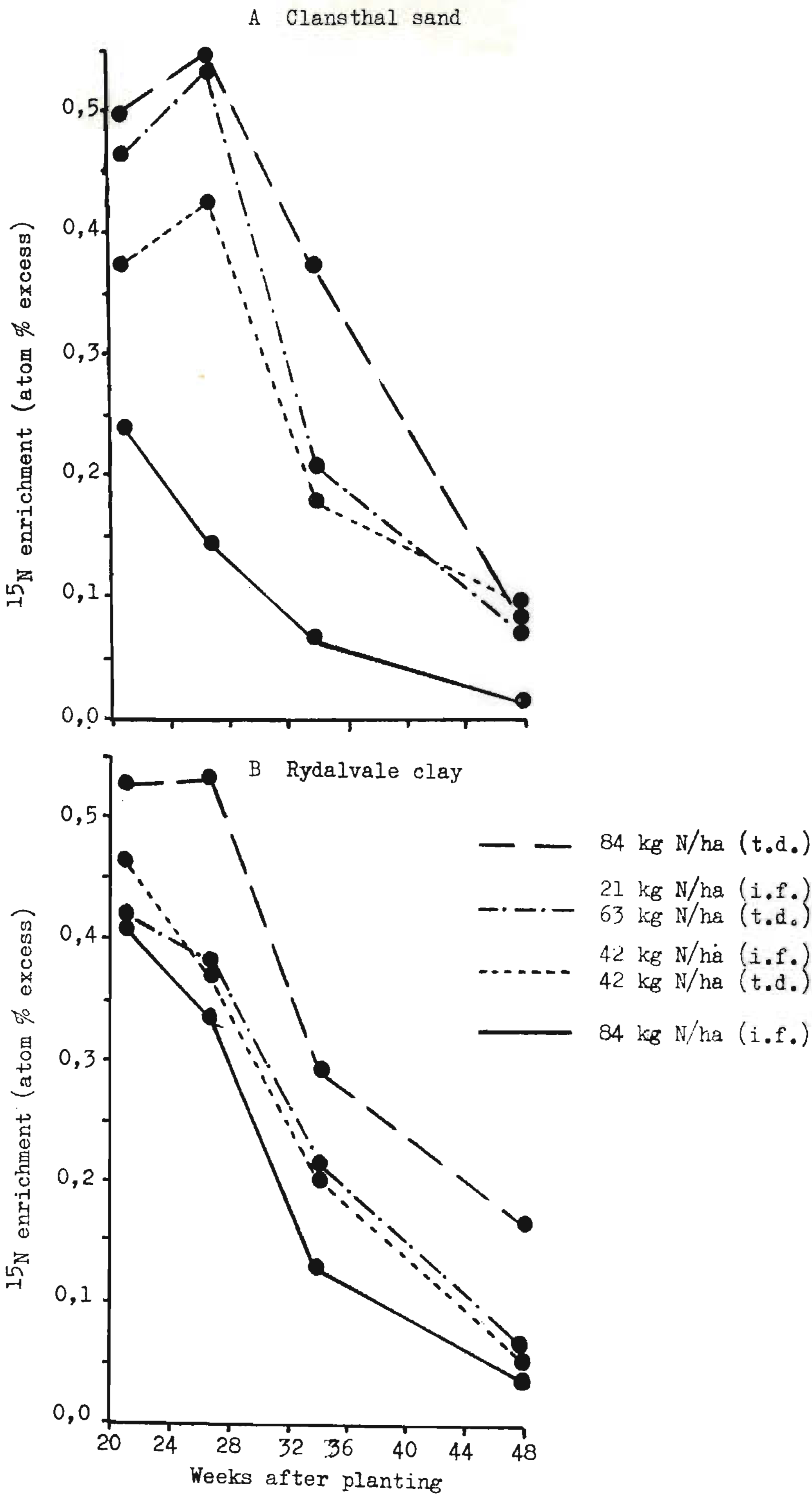


Fig. 29 The effect of splitting fertilizer N (applied as $(NH_4)_2SO_4$) between the furrow and as a top dressing, as shown by changes in ^{15}N levels in the leaf trash.

The mean cumulative loss of N in leaf trash for each $(NH_4)_2SO_4$ treatment, shown for both soils in Figures 30A and B also emphasises the relatively inefficient utilization of N applied in the furrow at planting especially in the Clansthal sand.

Enrichment values obtained by analysis of third leaf samples taken from the various $(NH_4)_2SO_4$ treatments (see Figures 31A and B), provide information on the behaviour of the in furrow N applications in the two different soils. In this instance the first sampling of leaves was made 10 weeks after planting, just prior to the application of the top-dressing treatments. In both soils at this time the enrichment values reflected the differences in amounts of N applied in the furrow (21, 42 and 84 kg N/ha). However, the corresponding values from the Rydalvale clay samples were far higher than those from the Clansthal sand despite higher average yields on the former soil. This again indicates that substantial N losses must have occurred from the sand, probably because of leaching, before efficient utilization by the plant could take place.

Following application of the N top-dressings, at 10 weeks, ^{15}N values from the samples taken at 18 weeks reversed the earlier trend on both soils, being greatest where all the N had been top-dressed (84 kg N/ha) and declining with decreasing amounts of applied N. Subsequent samplings revealed little additional information about the timing of N fertilizer applications on either soil.

Where $(NH_4)_2SO_4$ was applied, the proportion of fertilizer N found in the trash, expressed as a percentage of the total fertilizer N recovered in the Clansthal sand treatments is shown below.

84 kg N (i.f.)	17,0%
42 kg N (i.f.), 42 kg N (t.d.)	25,2%
21 kg N (i.f.), 63 kg N (t.d.)	32,5%
84 kg (t.d.)	39,3%

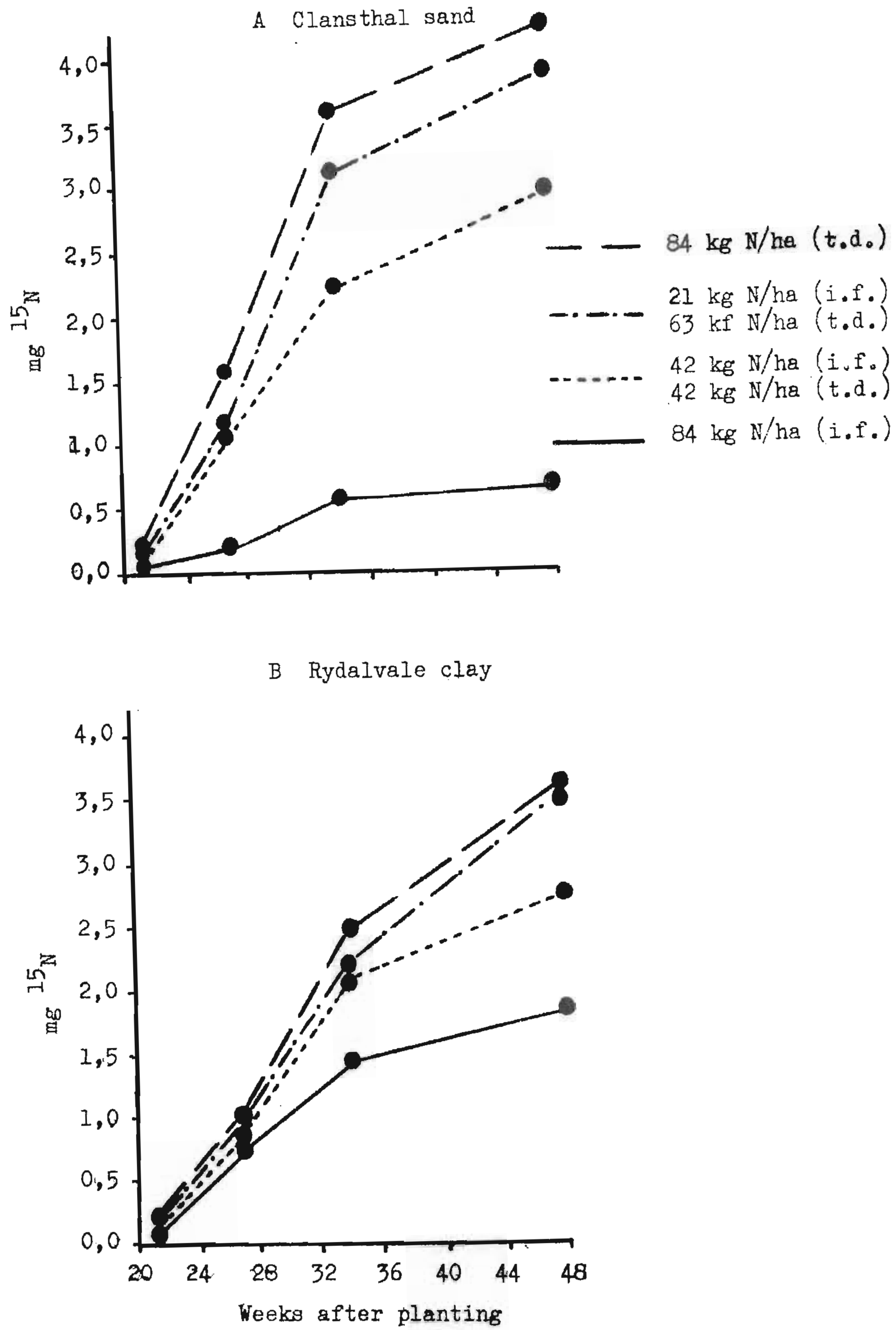


Fig. 30 Summary of the cumulative amounts of fertilizer N found in leaf trash expressed as mg of total ^{15}N nitrogen.

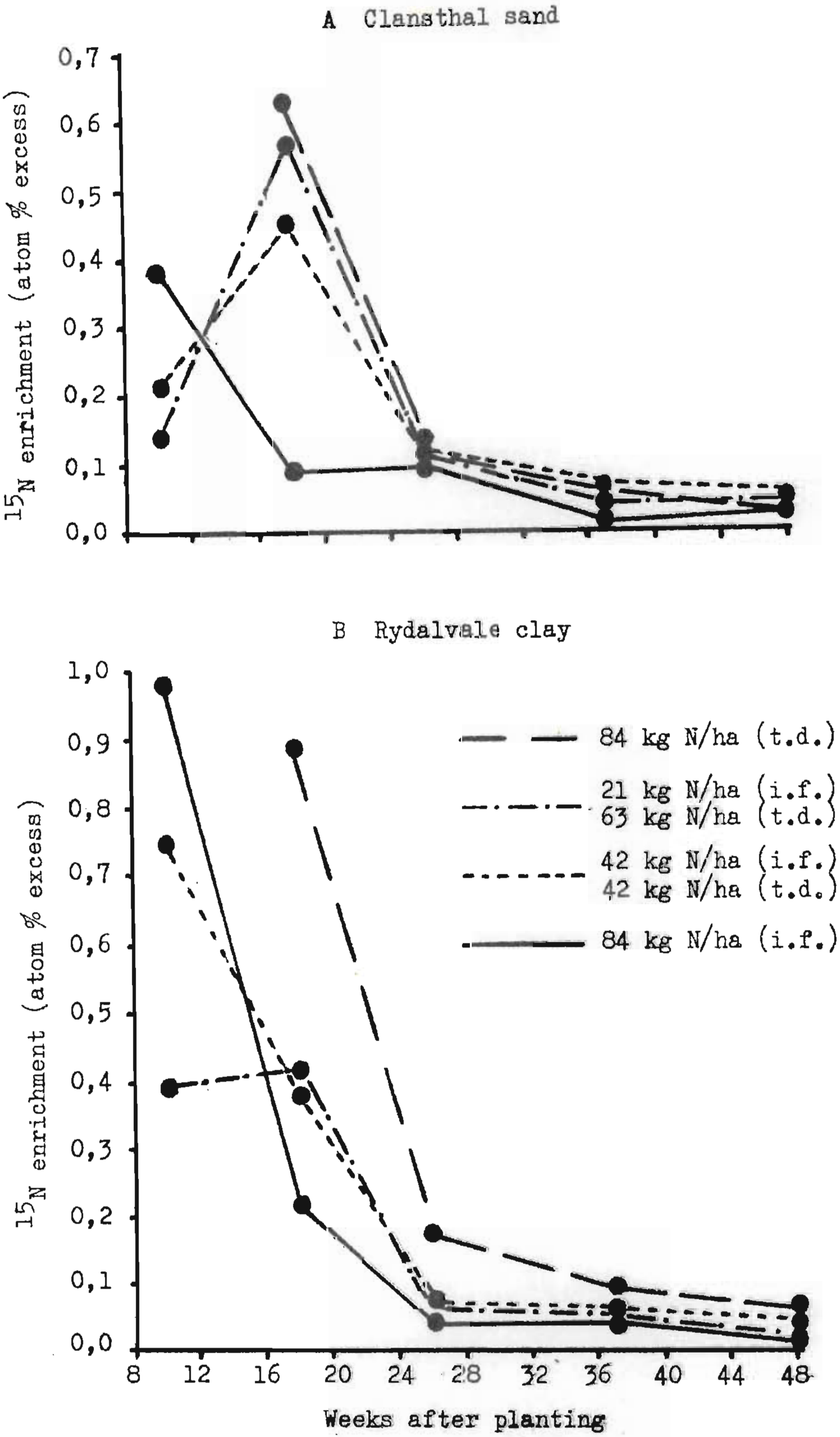


Fig. 31 Changes in N enrichment values of third leaf samples of cane following application of $(NH_4)_2SO_4$ to the furrow, and as a top-dressing.

From this it would appear that the practice of top-dressing strongly influenced the amounts of N removed in the trash on the sand. No such relationship was found on the Rydalvale clay, where approximately 25% of the total recovered fertilizer N was lost to the plant as trash from all $(NH_4)_2SO_4$ treatments.

Recovery of fertilizer N in the whole plant

Analysis of stubble and roots of single stools from each treatment (see Table 47) showed that on both soils recovery of fertilizer N from these plant parts followed a pattern similar to that found in the above ground parts in corresponding treatments. Percentage recovery of applied N in respect of stubble and roots averaged over both soils, ranged from 4,6% where N had been applied exclusively to the furrow to 12,1% where it had been top-dressed as KNO_3.

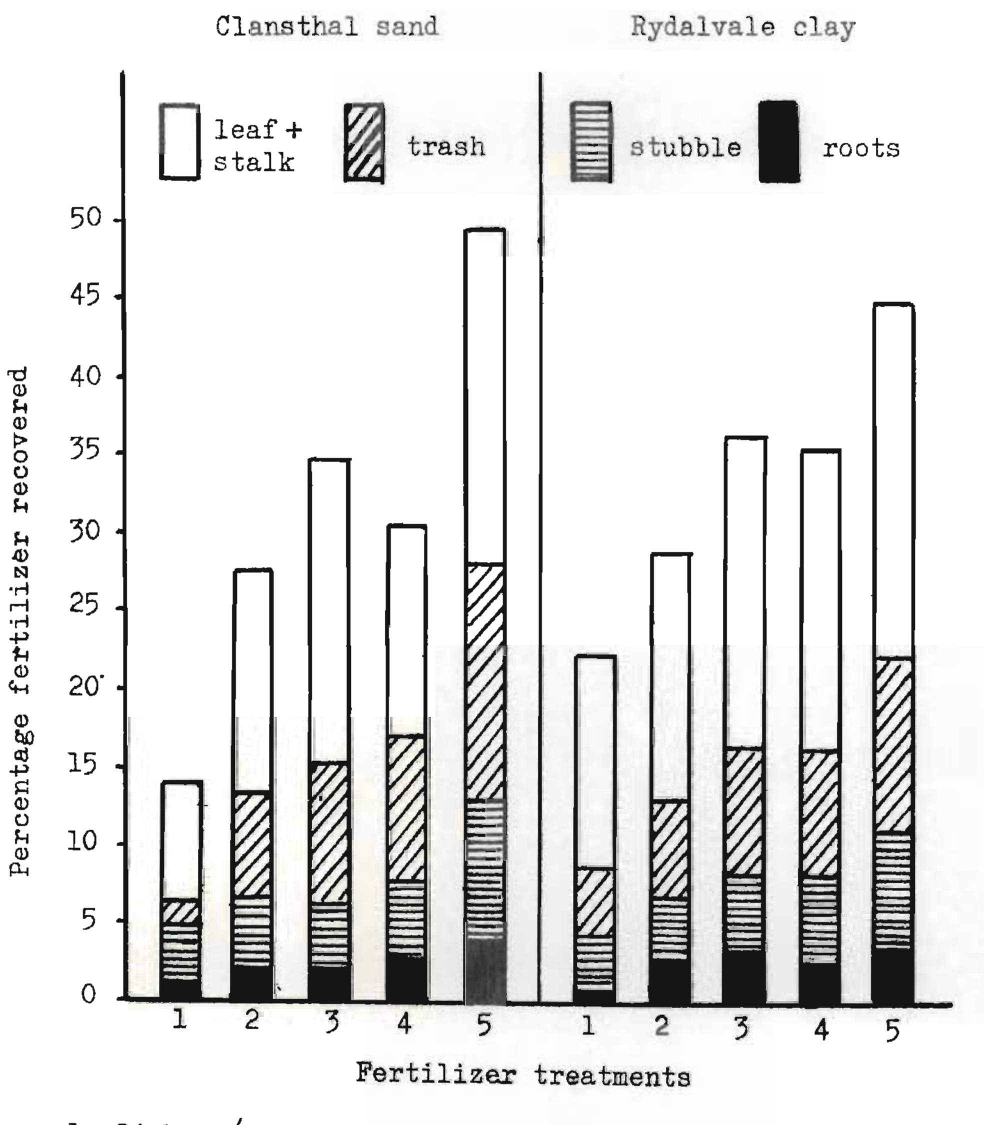
Percentage of applied N recovered by the ten entire stools that were examined (one per treatment on both soils) is shown in Figure 32. The similarity in overall pattern of N recovery between the two soils is quite remarkable considering the marked differences in their chemical and physical properties.

From Table 46, it appears that even where conditions were favourable for uptake of applied N in the ammonium form ie. when top-dressed at 10 weeks, only between 25% and 30% was utilised by the above ground part of the crop under field conditions. A recovery of between 37% and 43% was found however, when the nitrate form was applied.

Excluding the treatments where all N was furrow applied, percentage N recovery by entire plants was between 27% and 36% except where nitrate fertilizer was top-dressed. Even here recovery did not exceed 50%. This implies that the balance of N fertilizer was lost either through leaching or immobilization in the soil, though denitrification and volatilization losses may have occurred.

TABLE 47. Yield and recovery of ^{15}N from stubble and roots (single stools under all treatments).

Treatment	^{15}N applied mg	Yield mg N	^{15}N excess (atom %)	^{15}N recovered mg	^{15}N recovered % of applied	Yield mg N	^{15}N excess (atom %)	^{15}N recovered mg	^{15}N recovered % of applied	Total % recovery
Clansthal sand										
		Stubble				Roots				
84 kg N/ha (i.f.)	43,7	3950	0,040	1,580	3,62	850	0,058	0,493	1,13	4,75
42 kg N (i.f.), 42 kg N (t.d.)	"	2878	0,069	1,986	4,54	801	0,111	0,889	2,03	6,57
21 kg N (i.f.), 63 kg N (t.d.)	"	6015	0,031	1,865	4,27	1454	0,063	0,916	2,10	6,37
84 kg N/ha (t.d.)-$(NH_4)_2SO_4$	"	4555	0,046	2,095	4,79	1313	0,091	1,195	2,73	7,52
84 kg N/ha (t.d.)-KNO_3	99,1	5622	0,162	9,108	9,19	1390	0,271	3,767	3,80	12,99
Rydalvale clay										
		Stubble				Roots				
84 kg N/ha (i.f.)	43,7	5773	0,027	1,559	3,57	1602	0,022	0,352	0,81	4,38
42 kg N (i.f.), 42 kg N (t.d.)	"	3884	0,044	1,709	3,91	1105	0,109	1,204	2,76	6,67
21 kg N (i.f.), 63 kg N (t.d.)	"	4594	0,046	2,113	4,84	1321	0,107	1,413	3,23	8,07
84 kg N/ha (t.d.)-$(NH_4)_2SO_4$	"	2431	0,105	2,553	5,84	539	0,201	1,083	2,48	8,32
84 kg N/ha (t.d.) -KNO_3	99,1	5238	0,146	7,647	7,72	1092	0,308	3,363	3,39	11,11



1 84 kg N/ha in furrow at planting
2 42 kg N/ha (i.f.), 42 kg N/ha top-dressed at 10 weeks
3 21 kg N/ha (i.f.), 63 kg N/ha (t.d.)
4 84 kg N/ha (t.d.) as $(NH_4)_2SO_4$ at 10 weeks
5 84 kg N/ha (t.d.) as KNO_3 at 10 weeks

Fig. 32 Percentage fertilizer N recovered by entire plants (one replicate per treatment).

N losses due to leaching were confirmed in the Clansthal sand after harvest, when immobilized ^{15}N was detected at depths of up to 120 cm under most fertilizer treatments (see Table 48).

TABLE 48. Total N and ^{15}N enrichments in the Clansthal series sand to a depth of 120 cm, following harvest of the plant crop.

Treatment	Sample depth (cm)	Total N %	Total N mg/100g	^{15}N excess atom %	^{15}N mg/100g
84 kg N/ha (i.f.)	0- 45	0,0360	36,0	0,0040	0,00144
	46- 90	0,0123	12,3	0,0016	0,00020
	91-120	0,0112	11,2	0,0016	0,00018
42 kg N (i.f.), 42 kg N (t.d.)	0- 45	0,0284	28,4	0,0070	0,00199
	46- 90	0,0042	4,2	not detected	-
	91-120	0,0050	5,0	0,0001	0,00001
21 kg N (i.f.), 63 kg N (t.d.)	0- 45	0,0368	36,8	0,0119	0,00438
	46- 90	0,0133	13,3	0,0032	0,00043
	91-120	0,0109	10,9	0,0001	0,00001
84 kg N/ha (t.d.)-S/A	0- 45	0,0360	36,0	0,0079	0,00284
	46- 90	0,0078	7,8	not	-
	91-120	0,0050	5,0	detected	-
84 kg N/ha (t.d.)-KNO_3	0- 45	0,0336	33,6	0,0444	0,01492
	46- 90	0,0186	18,6	0,0211	0,00392
	91-120	0,0152	15,2	0,0221	0,00336

Similar data are not available for the Rydalvale clay though it is likely that substantial immobilization of applied N also occurred in this soil.

Uptake of residual fertilizer N

Yield and recovery of residual fertilizer N by the ratoon crops harvested after a period of four months are given in Table 49. Up to 6% of the N originally applied was utilized by the ratoon cane.

TABLE 49. Yield, and recovery of ^{15}N in leaf + stalk of four-month old ratoon crops

Treatment (kg N/ha)	^{15}N applied mg	Yield mg N	^{15}N excess (atom %)	^{15}N recovered mg	^{15}N recovered % of applied	Avge. % recovery	Yield mg N	^{15}N excess (atom %)	^{15}N recovered mg	^{15}N recovered % of applied	Avge. % recovery
			Clansthal series sand					Rydalvale series clay			
84 kg N (i.f.) as $(NH_4)_2SO_4$	43,7	14387	0,0008	0,115	0,26)	0,59	13897	Nil			
	"	10733	0,0037	0,397	0,91)		11127	Sample missing			-
42 kg N (i.f.) 42 kg N (t.d.)	"	15923	0,0136	2,166	4,96)	5,19	12737	0,0043	0,548	1,25)	2,48
	"	8677	0,0273	2,369	5,42)		12049	0,0134	1,615	3,70)	
21 kg N (i.f.) 63 kg N (t.d.)	"	11813	0,0072	0,850	1,95)	4,11	14494	0,0061	0,884	2,02)	1,73
	"	15540	0,0176	2,735	6,26)		20121	0,0031	0,624	1,43)	
84 kg N (t.d.) as $(NH_4)_2SO_4$	"	7621	0,0149	1,136	2,60)	1,78	10238	0,0229	2,345	5,37)	5,47
	"	14409	0,0029	0,418	0.96)		11758	0,0207	2,434	5,57)	
84 kg N (t.d.) as KNO_3	99,1	14467	0,0396	5,808	5,86)	5,79	11731	0,0465	5,455	5,50)	5,88
	"	13213	0,0428	5,655	5,71)		12027	0,0516	6,206	6,26)	

Recoveries by individual stools were rather variable, but on average were highest on both soils where N had been top-dressed as nitrate. The lowest average recovery was on the Clansthal sand where all the N had originally been applied to the furrow.

As none of the recoveries of N exceeded those obtained from the stubble plus roots under the various plant cane treatments, it seems likely that much of the residual fertilizer N found in the ratoon cane came from this source. However it is possible that remineralization of applied N previously immobilized in the soil, also contributed to the N recovered.

Concluding remarks

The results of these experiments indicate that application of all or a large proportion of fertilizer N to the furrow at time of planting would be unwise as losses, primarily due to leaching, are likely to be considerable. This apparently applies even to more heavily textured soils such as the Rydalvale clay.

The fact that cane yields do not necessarily reflect these losses on many soils, suggests not so much that the crop is able to satisfactorily utilize furrow applications of N as was previously supposed, but rather that the soil in question is capable of mineralizing sufficient N during the growing period to make good leaching losses that occur.

By top-dressing some weeks after planting, apparently the cane root system has developed sufficiently to allow for more efficient recovery of applied N so reducing losses due to leaching. This was shown in the field by the rapid greening up and improvement in tillering of those treatments that were top-dressed. (See Plate 7B).

It appears that even under conditions favourable for N uptake, only 25-30% of N applied in the widely used ammonium form, will be recovered in the above ground parts of the average cane crop. Of this amount up to 35% may be present in the trash. On average a further 8-10% of the applied N will be retained by stubble and roots. The remaining N is either immobilized or lost by leaching, while other losses may occur due to denitrification or volatilization.

The first ratoon crop is able to utilize some of the originally applied fertilizer N (up to 6% in these experiments), but it seems unlikely that substantial amounts would generally be available for use by succeeding crops. This confirms the results obtained in the pot experiment reported in section A of Chapter 9.

CHAPTER 12

SUMMARY AND CONCLUSIONS

The optimum N dressing for both rain grown and irrigated plant cane in South Africa is generally between 55 - 85 kg N per hectare, though on certain soils up to 110 kg N has been shown to be economic. For rain grown and irrigated ratoon crops amounts much in excess of 110 - 130 kg N per hectare are usually uneconomic. Compared with amounts of N required elsewhere for optimum cane yields it would appear that a reasonable standard of fertilizer efficiency has been achieved in South Africa.

Sugarcane response to applied N is influenced by many factors some of which are able to bring about differences in yield as great or greater than those obtained from fertilizer N itself. These include age and time of harvest, rainfall distribution and soil moisture conditions, time and method of N application, the N carrier applied, and the nature of the soil.

In many cases plant cane in South Africa is able to obtain much if not all of its N requirement directly from the soil. Ratoon crops are generally unable to obtain sufficient supplies of N from this source, as the amount of soil N released annually appears to diminish with each successive crop. Response of plant cane to applied N, is strongly influenced by the potential of the different soil series in the sugar belt to mineralize N. Large and significant differences exist between amounts of N taken up by the plant crop from soils of different series. These differences in N uptake are usually much smaller in the ratoon crop.

Precise measurement of N available to plant cane in the field remains difficult. Much depends on when the old ratoon crop is ploughed out and on the length of time the soil remains dry before replanting, as this affects the magnitude of soil N release upon rewetting. In South Africa greatest benefit from soil N release would probably be derived from planting the new crop in spring when rains normally follow a dryish winter period. Reliable assessment of quantity of soil N released to ratoon cane appears unlikely, as laboratory mineralization data bear little relation to N available for plant use. N application rates will therefore continue to be recommended largely on an empirical basis of management and expected yield.

Nitrogen supplying power of the sugarbelt soils is also dependent on how recently they were opened to cultivation. Virgin or newly opened soils exhibit a far higher level of bacterial acitivity, and a greater mineralization potential than their cultivated counterparts. This could be expected to influence crop response to applied N.

In the glasshouse trash incorporation has significantly depressed the uptake of fertilizer and soil N by cane grown in several different soils. Reductions in efficiency of N fertilizer usage by field grown cane may occur in the sandier soils of the sugar belt (eg. Cartref series) due to the presence of trash and other crop residues low in N.

Substantial amounts of applied N are immobilized in the soil organic phase whether soils are cropped or uncropped. Once immobilized, fertilizer N is only slowly released to succeeding crops, and application of additional N has a relatively small effect upon the release of previously immobilized fertilizer N.

Glasshouse experiment results indicate that it is unlikely that recovery of applied N by field harvested cane will ever exceed 45%–50% and will generally be far lower.

The C/N ratio of roots may have considerable effect on the utilization of N by a crop such as sugarcane which produces a dense root system. It is suggested that certain sugar belt soils under cane, which are inherently low in N and/or inadequately supplied with N fertilizer, will tend to produce roots of high C/N ratio. Their decomposition by soil micro-organisms will soon lead to the depletion of mineral N in the soil, resulting in net immobilization of N, so aggravating any deficiency and worsening the N nutrition of the crop.

Considerable delays in nitrification may be expected in the more acid sugar belt soils. Apart from the soil pH effect as such, the presence of a specific N carrier is apparently able to influence rate of nitrification, particularly in weakly buffered soils (eg. Cartref sand). Thus the carrier may accelerate or retard susceptibility to leaching of N, so affecting the utilization of fertilizer N by cane in the field.

Glasshouse studies indicate that leaching of NO_3-N from sandy soils planted to cane results in reduced uptake of N and may influence yield. The period of potential loss is probably greatest between planting and the establishment of the root system. In the field at this critical period high rainfall is often experienced and leaching of applied N occurs. It appears likely that the efficiency of fertilizer N applied to cane could be enhanced in the sandier coils of the industry by suppressing nitrification with an inhibitor such as N-Serve.

Field experiments have confirmed that application of all, or a large part of a N dressing to the furrow at time of planting can cause severe losses due to leaching even in heavily textured soils ($>$60% clay). The fact that cane yields do not necessarily reflect leaching losses on a particular soil suggests that the soil in question is capable of mineralizing sufficient N during the growing period to make good such losses. Top dressing some weeks after planting results in more efficient recovery of applied N. However, even under conditions favourable for N uptake only 25%-30% of N applied in the widely used ammonium form is recovered by the above ground parts of the average cane crop. A further 8%-10% will be retained by stubble and roots.

The utilization of N by sugarcane is therefore dependent on many factors which are able to influence directly or indirectly the response of cane to N. This study has emphasized the importance of the role played by N transformations in the soil in governing the availability of N to the crop, and has indicated various ways in which efficiency of N use could be increased. However, as growth of cane and ultimate yield are so strongly influenced by seasonal effects, it is considered that increased efficiency of N use in future will depend largely upon studies that will examine further the relationship between N utilization and the level and frequency of N application under the different climatic conditions prevailing in the sugar belt. Climatic variations would embody those differences which occur from year to year; between one locality and another; and due to the effect of planting and ratooning at different seasons under both irrigated and rain grown conditions. The use of labelled N fertilizers in this work would assist in determining the efficiency of N usage by the crop, and would enable a more accurate assessment of the contribution made by the various soil series to the N requirement of cane.

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APPENDIX 1

Calculation of results for ^{15}N analysis

The atom % ^{15}N (A) in any sample was calculated from the equation

$$A = 100/(2R + 1) \text{ atom \% } ^{15}N$$

where R is the ratio of the intensities of the ion currents in the mass spectrometer corresponding to mass 28 and mass 29.

The atom % excess ^{15}N (actual enrichment) of the sample was found by subtracting the ^{15}N content of normal air and soil N (0,37 atom %) from that found in the sample. The weights of excess ^{15}N in each sample was then calculated from the total N contents and the actual enrichment. The percentage of total N derived from that added as labelled fertilizer N was calculated as x in the following equation

$$x = \frac{C - B}{D} \times 100\%$$

C = atom % ^{15}N in the analysed sample

B = atom % ^{15}N in normal air and soil N (0,37%)

D = atom % ^{15}N in the labelled fertilizer

APPENDIX 2

Detailed results of pot experiment A in Chapter 7

Yield of tops (mg N per pot)

Soil series		Plant crop: Level of N applied 0kg	55kg	110kg	220kg	First ratoon: Level of N applied 0kg	55kg	110kg	220kg
Clansthal	1	36,29	64,32	89,38	154,69	15,71	38,02	56,72	98,52
	2	33,52	60,84	96,07	146,06	15,47	37,05	58,50	110,56
	3	36,71	59,56	89,65	156,21	19,47	32,03	57,92	104,60
	Mean	35,51	61,57	91,70	152,32	16,88	35,70	57,71	104,56
Inanda	1	37,51	58,24	93,94	150,58	13,82	33,25	59,52	102,73
	2	37,60	65,56	90,72	145,99	14,06	34,11	61,29	109,07
	3	34,24	61,00	84,41	141,04	14,45	32,26	56,21	113,34
	Mean	36,45	61,60	89,69	145,54	14,11	33,21	59,01	108,38
Mayo	1	44,51	70,98	93,24	160,66	21,51	57,53	72,62	108,64
	2	43,29	66,29	97,92	150,77	33,57	42,97	59,61	112,67
	3	47,19	66,78	95,92	166,00	30,86	38,51	63,74	112,38
	Mean	45,00	68,02	95,69	159,14	28,65	46,34	65,32	111,23
Rydalvale	1	47,33	58,35	64,98	155,92	11,68	33,43	53,48	97,23
	2	48,51	56,40	91,69	146,77	12,94	33,32	52,98	113,97
	3	44,41	67,62	89,64	118,26	8,38	35,67	52,48	104,52
	Mean	46,75	60,79	82,10	140,32	11,00	34,14	52,98	105,24
Dundee	1	48,48	97,31	91,12	178,15	22,05	36,74	70,54	117,16
	2	65,74	62,72	102,44	171,31	18,06	30,86	59,78	116,20
	3	43,52	64,90	124,39	181,25	21,70	35,03	55,02	100,80
	Mean	52,58	74,98	105,98	176,90	20,60	34,21	61,78	111,39
Shortlands	1	60,08	91,63	112,44	172,54	17,70	35,79	56,55	102,66
	2	60,20	92,88	105,96	172,69	30,46	35,49	55,99	106,93
	3	60,13	82,78	105,60	176,93	20,70	34,51	58,66	100,47

App. 2 cont.

Yield of tops (mg N per pot)

Soil series		Plant crop: Level of N applied				First ratoon: Level of N applied			
		0kg	55kg	110kg	220kg	0kg	55kg	110kg	220kg
Cartref	1	14,95	36,82	65,26	107,78	13,55	37,86	41,33	48,76
	2	17,87	40,90	65,47	112,03	14,11	39,00	37,16	45,68
	3	16,47	38,39	60,52	117,87	13,69	34,23	45,12	38,32
	Mean	16,43	38,70	63,75	112,56	13,78	37,03	41,20	44,25
Fernwood	1	14,64	44,54	71,14	126,57	11,35	31,78	53,75	30,88
	2	19,32	42,08	67,09	130,05	14,98	34,12	58,87	18,38
	3	17,76	55,78	70,86	121,01	13,91	32,97	52,58	28,07
	Mean	17,24	47,47	69,70	125,88	13,41	32,96	55,07	25,78
Windermere	1	25,74	57,47	72,24	146,20	13,13	25,14	40,53	81,54
	2	27,84	47,96	75,62	133,46	16,22	24,02	45,49	102,51
	3	23,87	54,12	78,21	137,57	15,45	25,92	43,86	87,13
	Mean	25,82	53,18	75,36	139,08	14,93	25,03	43,29	90,39
Milkwood	1	27,85	53,89	86,29	148,70	14,26	22,16	48,00	98,18
	2	27,67	55,41	90,51	147,29	13,94	23,84	36,38	92,78
	3	22,21	50,30	83,58	142,44	12,75	25,99	43,54	76,88
	Mean	25,91	53,20	86,79	146,14	13,65	24,00	42,64	89,28
Doveton	1	25,06	51,55	81,41	118,59	11,12	24,57	54,12	83,30
	2	26,15	53,80	79,55	147,97	10,31	25,86	38,72	85,66
	3	26,70	50,66	93,11	121,89	11,39	23,56	39,51	91,62
	Mean	25,97	52,00	84,69	129,48	10,94	24,66	44,12	86,86
Williamson	1	30,91	57,20	88,18	161,82	10,68	25,77	49,39	97,72
	2	30,77	59,13	87,98	160,21	13,70	28,77	47,58	95,51
	3	28,66	54,52	90,13	162,02	15,85	29,61	48,56	92,60
	Mean	30,11	56,95	88,76	161,35	13,40	28,05	48,51	95,28

APPENDIX 3

a) Sample localities of soils studied in uniformity trial

Soil series	No.	Location
Cartref	1	Tongaat Sugar Co., Sibutu section, Field 71, Dunlop
	2	Hackland, Diepkloof Farm, Mid Illovo
	3	Werner, Umtwalumi, South Coast
	4	Tongaat Sugar Co., Sibutu section, Field 99, Johnstone
	5	Huletts, Mount Edgecombe, Sykes lease, Inanda Rd.
	6	Tongaat Sugar Co., Sibutu section, above krantz, N.W. end
Mayo	1	Coles, Glenrosa station
	2	Mount Rosa, Reynolds Brothers, Umzinto
	3	Yates, Esperanza Estate, Esperanza
	4	E. Norris Jones, Fairfield farm, Eston, Field 13
	5	Injambile Estates, Umzumbe, South Coast
	6	J.G.B. Andrew, Devon farm, Umzumbe
Shortlands	1	E. Norris Jones, Fairfield farm, Eston, Field 2
	2	Huletts, Mount Edgecombe, Cornubia, Gobells land
	3	Tongaat Sugar Co., Klipfontein section, SAR field
	4	Huletts, Mount Edgecombe, Flanders Estate, Field 200 B
	5	Tongaat Sugar Co., Tongaat section, Quarry field
	6	Tongaat Sugar Co., Tongaat section, Paul field

App. 3 (b) Analytical data - soils from uniformity trial

Soil series	No.	Mech. composition % *				pH	% N	ppm P	Exchangeable bases me %				me % CEC
		CS	FS	S	C				K	Ca	Mg	Na	
Cartref	1	56	24	3	17	5,3	0,055	71	0,29	0,8	0,8	0,04	2,4
	2	52	30	4	14	5,0	0,059	78	0,25	0,8	0,2	0,01	1,3
	3	53	30	2	15	5,4	0,065	7	0,16	1,4	0,9	0,10	3,7
	4	59	21	4	16	5,0	0,055	50	0,19	0,6	0,5	0,03	1,7
	5	66	20	2	14	5,7	0,042	7	0,29	0,2	0,4	0,02	1,6
	6	59	22	6	13	5,8	0,058	39	0,48	1,3	1,2	0,11	4,3
Mayo	1	47	17	11	24	4,8	0,117	20	0,27	1,7	1,4	0,07	6,9
	2	48	16	10	29	5,1	0,143	23	0,87	3,3	1,8	0,09	8,9
	3	41	20	8	31	6,1	0,161	34	0,24	11,0	4,5	0,19	16,3
	4	41	23	7	29	5,8	0,118	29	0,75	3,5	1,6	0,05	9,0
	5	48	30	6	19	5,0	0,086	6	0,19	1,1	1,7	0,10	6,0
	6	52	16	5	25	5,9	0,138	10	0,59	2,1	2,6	0,13	9,0
Shortlands	1	7	11	12	61	5,3	0,214	11	1,33	3,2	3,5	0,10	13,6
	2	9	14	10	65	6,9	0,170	7	0,23	11,5	3,1	0,19	16,4
	3	10	14	10	65	5,2	0,209	31	2,32	5,0	2,2	0,10	13,0
	4	7	14	15	58	8,2	0,215	145	1,38	28,5	4,1	0,31	19,6
	5	4	12	9	73	5,3	0,236	45	1,76	7,0	3,0	0,13	15,8
	6	3	6	12	75	5,6	0,203	16	0,26	4,7	6,0	0,37	18,4

* CS = coarse sand, FS = fine sand, S = silt, C = clay

App. 3 (c) Detailed results of pot experiment B in Chapter 7

Yield of tops (mg N per pot)

Soil number	Cartref series		Mayo series		Shortlands series	
	Levels of N applied					
	0kg	55kg	0kg	55kg	0kg	55kg
	19,02	49,11	37,28	68,85	72,73	94,54
1	22,33	45,19	38,54	62,19	62,83	100,47
	20,58	49,96	39,61	68,00	67,82	98,21
Mean	20,64	48,09	38,48	66,35	67,79	97,74
	19,37	49,52	32,80	56,86	31,68	55,92
2	20,89	48,93	32,18	55,48	33,98	63,73
	18,37	42,95	32,91	59,75	30,12	57,04
Mean	19,54	47,13	32,63	57,36	31,93	58,90
	25,80	56,34	30,93	52,52	82,45	115,97
3	26,43	51,51	29,84	51,61	86,51	121,24
	28,18	53,70	29,11	58,45	74,77	112,72
Mean	26,80	53,85	29,96	54,19	81,24	116,64
	18,33	54,90	21,50	51,77	36,61	64,16
4	18,59	45,14	22,27	48,48	37,57	61,31
	17,85	43,84	24,88	45,87	38,92	62,13
Mean	18,26	47,96	22,88	48,71	37,70	62,53
	20,93	42,36	34,03	61,14	55,88	87,75
5	18,33	49,42	32,08	61,61	56,19	87,70
	22,77	50,32	33,19	62,04	56,97	86,07
Mean	20,68	47,37	33,10	61,60	56,35	87,17
	29,23	55,94	34,70	62,57	70,96	105,84
6	29,36	58,21	37,60	64,51	78,17	110,51
	29,83	63,81	33,26	62,11	65,06	102,26
Mean	29,47	59,32	35,19	63,06	71,40	106,20

APPENDIX 4

(a) Detailed results of pot experiment in section A of Chapter 9

Total N and fertilizer N recovered by whole plant
(top + roots + sett - mg N per pot)

Clansthal sand

Trash treatment	N applied (mg per pot) 0		45		112,5	
	Total N	Fert. N	Total N	Fert. N	Total N	Fert. N
absent	51,0	nil	89,4	24,4	119,3	58,4
	55,3	nil	82,0	21,1	148,1	69,7
Mean	53,2	-	85,7	22,8	133,7	64,1
present	19,2	nil	28,7	3,4	54,6	17,8
	20,7	nil	26,9	2,6	52,5	17,3
Mean	20,0	-	27,8	3,0	53,6	17,6

Glenrosa sandy loam

Trash treatment	N applied (mg per pot) 0		45		112,5	
	Total N	Fert. N	Total N	Fert. N	Total N	Fert. N
absent	35,9	nil	78,1	25,8	139,4	75,8
	38,9	nil	74,0	26,8	137,7	76,1
Mean	37,4	-	76,1	26,3	138,6	76,0
present	12,8	nil	20,2	3,0	69,7	34,0
	12,9	nil	23,0	3,6	70,8	35,1
Mean	12,9	-	21,6	3,3	70,3	34,6

Shortlands clay

Trash treatment	N applied (mg per pot) 0		45		112,5	
	Total N	Fert. N	Total N	Fert. N	Total N	Fert. N
absent	81.3	nil	109,5	27,6	159,7	67,3
	80,1	nil	111,2	26,4	168,8	75,2
Mean	80,7	-	110,4	27,0	164,3	71,3
present	30,5	nil	48,4	8,1	96,6	43,0
	35,3	nil	48,0	7,9	95,5	40,5

App. 4 (b) Plant uptake and recovery of N (mg N per pot) Analysis of pooled data from pot experiment in Section A of Chapter 9

Parameters examined	N applied mg/pot	Clansthal		Glenrosa		Shortlands	
		(-T)	(+T)	(-T)	(+T)	(-T)	(+T)
i) Total N present in whole plant	0	53,2	20,0	37,4	12,9	80,7	32,9
	45	85,7	27,8	76,1	21,6	110,4	48,2
	112,5	133,7	53,6	138,6	70,3	164,3	96,1
	Mean	90,9	33,8	84,0	34,9	118,4	59,1
S.E. (treatment means)				± 3,8			
L.S.D. (0,05)				11,4			
(0,01)				15,6			
C.V. %				7,7			
ii) Fertilizer N present in whole plant	45	22,8	3,0	26,3	3,3	27,0	8,0
	112,5	64,1	17,6	76,0	34,6	71,3	41,8
	Mean	43,4	10,3	51,1	18,9	49,1	24,9
S.E. (treatment means)				± 2,1			
L.S.D. (0,05)				6,5			
(0,01)				9,1			
C.V. %				9,0			
iii) Soil N present in whole plant	0	53,2	20,0	37,4	12,9	80,7	32,9
	45	62,9	24,8	49,8	18,3	83,4	40,2
	112,5	69,7	36,0	62,6	35,7	93,0	54,3
	Mean	61,9	26,9	50,0	22,3	85,7	42,4
S.E. (treatment means)				± 2,4			
L.S.D. (0,05)				7,2			
(0,01)				9,9			
C.V. %				7,1			
iv) Percent total N derived from fertilizer N	45	26,5	10,5	34,7	15,1	24,5	16,6
	112,5	48,1	32,8	54,9	49,2	43,3	43,5
	Mean	37,3	21,6	44,8	32,1	33,9	30,1
S.E. (treatment means)				± 0,9			
L.S.D. (0,05)				2,7			
(0,01)				3,7			
C.V. %				3,7			
v) Percent recovery of fertilizer N - whole plant	45	50,5	6,6	58,5	7,3	60,0	17,8
	112,5	57,0	15,6	67,5	30,8	63,3	37,1
	Mean	53,7	11,1	63,0	19,0	61,6	27,4
S.E. (treatment means)				± 3,1			
L.S.D. (0,05)				6,7			
(0,01)				9,4			
C.V. %				7,8			

(-T) trash absent (+T) trash present

App. 4 (c)

Recovery of labelled N from three successive crops grown in Clansthal sand in the absence and presence of trash
(Composite sample data from the pot experiment in Section A of Chapter 9)

		Trash absent						Trash present					
		Fertilizer N originally applied											
		45 mg N per pot			112,5 mg N per pot			45 mg N per pot			112,5 mg N per pot		
Crop	Plant part	Yield mg N	Labelled N mg	^{15}N excess atom %	Yield mg N	Labelled N mg	^{15}N excess atom %	Yield mg N	Labelled N mg	^{15}N excess atom %	Yield mg N	Labelled N mg	^{15}N excess atom %
First	Tops	49,3	14,7	1,300	93,5	47,2	2,191	17,0	2,2	0,577	28,2	10,9	1,669
	Setts	15,0	3,0	0,880	24,8	10,5	1,843	9,6	0,8	0,363	13,4	3,5	1,181
Second +N	Tops	35,7	1,9	0,231	59,4	5,9	0,429	42,6	2,9	0,300	56,9	5,8	0,441
	Setts	7,9	0,3	0,164	12,7	0,7	0,233	10,4	0,3	0,126	16,6	0,9	0,224
Second -N	Tops	28,2	1,7	0,261	33,4	3,9	0,511	36,5	2,6	0,308	34,3	5,5	0,689
	Setts	8,0	0,2	0,130	8,9	0,6	0,298	9,3	0,3	0,142	8,7	0,7	0,355
Third +N	Tops	45,2	0,6	0,060	61,0	2,4	0,170	41,6	1,5	0,151	46,8	2,3	0,212
	Setts	26,2	0,5	0,022	28,1	0,6	0,087	21,2	0,3	0,054	29,5	0,8	0,115
Third -N	Tops	28,1	0,8	0,126	32,1	1,8	0,246	32,9	1,1	0,151	28,6	1,7	0,253
	Setts	26,2	0,2	0,037	18,0	0,5	0,109	20,6	0,2	0,044	17,5	0,3	0,081

Original enrichment of $^{15}(NH_4)_2SO_4$ = 4,330 atom % excess

+N indicates that additional unlabelled N was applied to 2nd and 3rd crops

-N indicates that no further N was applied

App. 4 (c) cont.

Glenrosa sandy loam

		Trash absent						Trash present					
		Fertilizer N originally applied											
		45 mg N per pot			112,5 mg N per pot			45 mg N per pot			112,5 mg N per pot		
Crop	Plant part	Yield mg N	Labelled N mg	^{15}N excess atom %	Yield mg N	Labelled N mg	^{15}N excess atom %	Yield mg N	Labelled N mg	^{15}N excess atom %	Yield mg N	Labelled N mg	^{15}N excess atom %
First	Tops	53,9	19,4	1,552	102,3	53,3	2,259	11,1	2,3	0,909	46,5	25,1	2,344
	Setts	10,1	2,0	0,858	13,8	5,3	1,663	8,9	0,8	0,397	11,8	3,6	1,338
Second +N	Tops	27,4	1,8	0,283	73,4	7,5	0,442	27,7	1,9	0,296	68,3	8,1	0,518
	Setts	12,1	0,5	0,192	17,2	1,3	0,326	9,0	0,3	0,149	13,0	1,3	0,439
Second -N	Tops	14,4	0,9	0,271	15,0	1,8	0,508	18,4	1,1	0,259	16,5	2,9	0,772
	Setts	9,7	0,5	0,206	9,9	0,5	0,233	8,0	0,3	0,153	9,8	0,7	0,358
Third +N	Tops	36,6	1,2	0,140	78,2	5,8	0,323	43,8	2,2	0,218	67,1	3,1	0,203
	Setts	17,6	0,3	0,071	30,6	0,9	0,131	18,8	0,4	0,102	38,7	1,6	0,179
Third -N	Tops	30,3	0,5	0,075	21,5	1,0	0,200	26,8	0,9	0,140	29,9	1,2	0,171
	Setts	16,8	0,1	0,031	19,8	0,4	0,095	13,7	0,2	0,072	15,8	0,7	0,180

Original enrichment of $^{15}(NH_4)_2SO_4$ = 4,330 atom % excess

+N indicates that additional unlabelled N was applied to 2nd and 3rd crops

-N indicates that no further N was applied

App. 4 (c) cont.

		Shortlands clay											
		Trash absent						Trash present					
		Fertilizer N originally applied											
		45 mg N per pot			112,5 mg N per pot			45 mg N per pot			112,5 mg N per pot		
Crop	Plant part	Yield mg N	Labelled N mg	^{15}N excess atom %	Yield mg N	Labelled N mg	^{15}N excess atom %	Yield mg N	Labelled N mg	^{15}N excess atom %	Yield mg N	Labelled N mg	^{15}N excess atom %
First	Tops	87,3	21,1	1,051	127,9	58,9	1,990	36,8	6,7	0,786	79,2	37,2	2,044
	Setts	14,7	3,0	0,876	21,2	8,0	1,630	10,2	1,3	0,539	14,7	4,7	1,402
Second +N	Tops	45,0	1,6	0,155	92,2	7,7	0,361	53,7	2,5	0,201	84,2	6,6	0,341
	Setts	7,7	0,2	0,103	15,2	0,9	0,269	8,8	0,2	0,117	10,1	0,5	0,212
Second -N	Tops	30,9	1,1	0,148	41,5	6,5	0,682	40,8	2,2	0,229	39,6	4,5	0,491
	Setts	6,7	0,1	0,076	8,1	0,8	0,402	7,7	0,2	0,130	8,4	0,6	0,291
Third +N	Tops	54,2	0,8	0,063	83,0	1,7	0,088	62,8	1,6	0,112	108,8	4,5	0,178
	Setts	14,9	0,1	0,021	23,2	0,2	0,032	19,6	0,2	0,045	19,9	0,3	0,064
Third -N	Tops	34,6	0,4	0,055	34,1	1,3	0,159	39,5	1,1	0,118	30,9	1,6	0,224
	Setts	12,3	0,1	0,019	18,0	0,2	0,040	15,1	0,1	0,038	10,8	0,2	0,076

Original enrichment of $^{15}(NH_4)_2SO_4$ - 4,330 atom % excess

+N indicates that additional unlabelled N was applied to 2nd and 3rd crops

-N indicates that no further N was applied

APPENDIX 5

(a) Changes with time of mineral N, labelled N and ^{15}N enrichment in soil receiving root material of different C/N ratios. (As detailed in section B of Chapter 9)

Clansthal sand

Treatment	Total min. N ppm	Labelled N ppm	^{15}N excess atom %	Total min. N ppm	Labelled N ppm	^{15}N excess atom %
	Day 0			Day 3		
1	44	41	4,221	63	38	2,719
2	47	43	4,152	45	19	1,903
3	48	45	4,248	38	19	2,255
4	47	39	3,732	26	10	1,736
5	48	46	4,300	15	*	*
	Day 7			Day 14		
1	67	39	2,633	75	38	2,290
2	43	18	1,875	44	16	1,652
3	33	16	2,129	34	14	1,855
4	6	1	0,739	0	0	nil
5	0	0	nil	0	0	nil
	Day 30			Day 56		
1	80	37	2,080	91	37	1,850
2	54	18	1,486	67	19	1,306
3	44	*	*	55	18	1,512
4	20	8	1,709	34	7	0,933
5	12	3	1,122	13	2	0,822
	Day 84			Day 112		
1	99	38	1,734	113	43	1,701
2	86	23	1,210	96	33	1,555
3	67	21	1,398	78	23	1,316
4	48	9	0,848	61	16	1,219
5	28	6	0,917	40	8	0,936

Original enrichment of $^{15}(NH_4)_2SO_4$ = 4,510 atom % excess

* insufficient gas evolved

Trmt. 1 = Control

2 = 0,5% roots, C/N(50)   4 = 1,0% roots, C/N(50)

3 = 0,5% roots, C/N(100)   5 = 1,0% roots, C/N(100)

App. 5 (a) cont.

Glenrosa sandy loam

Treatment	Total min. N ppm	Labelled N ppm	^{15}N excess atom %	Total min N ppm	Labelled N ppm	^{15}N excess atom %
	Day 0			Day 3		
1	50	47	4,206	61	44	3,252
2	49	46	4,211	43	27	2,832
3	49	47	4,296	34	27	3,613
4	49	*	*	22	13	2,752
5	49	48	4,414	21	15	3,300
	Day 7			Day 14		
1	65	43	2,985	67	38	2,557
2	40	20	2,255	41	20	2,200
3	40	23	2,593	39	21	2,426
4	22	10	2,192	17	6	1,524
5	16	9	2,544	17	7	1,900
	Day 30			Day 56		
1	71	35	2,223	78	36	2,084
2	47	*	*	57	21	1,649
3	42	18	1,934	44	19	1,936
4	19	6	1,325	7	1	0,713
5	14	5	1,654	3	1	0,698
	Day 84			Day 112		
1	84	35	1,881	104	41	1,770
2	70	24	1,542	78	25	1,452
3	52	21	1,833	59	22	1,715
4	8	1	0,622	15	1	0,248
5	6	1	0,490	13	2	0,803

Original enrichment of $^{15}(NH_4)_2SO_4$ = 4,510 atom % excess

* insufficient gas evolved

Trmt. 1 = Control

2 = 0,5% roots, C/N(50)

3 = 0,5% roots, C/N(100)

4 = 1,0 roots, C/N(50)

5 = 1,0 roots, C/N(100)

App. 5 (a) cont.

Shortlands clay

Treatment	Total min. N ppm	Labelled N ppm	^{15}N excess atom %	Total min. N ppm	Labelled N ppm	^{15}N excess atom %
	Day 0			Day 3		
1	50	44	3,972	59	38	2,904
2	50	43	3,893	46	25	2,449
3	55	48	3,958	41	24	2,638
4	51	44	3,860	32	13	1,831
5	51	44	3,861	24	11	2,066
	Day 7			Day 14		
1	62	38	2,793	66	32	2,240
2	41	17	1,803	46	22	2,166
3	40	*	*	42	19	2,033
4	17	*	*	18	6	1,151
5	17	6	1,670	14	4	1,368
	Day 30			Day 56		
1	70	31	1,982	77	29	1,726
2	48	16	1,532	66	20	1,346
3	43	17	1,772	49	16	1,498
4	8	1	0,689	12	1	0,467
5	0	0	nil	0	0	nil
	Day 84			Day 112		
1	94	31	1,479	111	37	1,495
2	72	18	1,148	87	20	1,063
3	59	17	1,292	74	19	1,192
4	29	3	0,498	49	5	0,493
5	15	1	0,430	29	3	0,297

Original enrichment of $^{15}(NH_4)_2SO_4$ = 4,510 atom % excess

* insufficient gas evolved

Trmt. 1 = Control

2 = 0,5% roots, C/N(50)

3 = 0,5% roots, C/N(100)

4 = 1,0 roots, C/N(50)

5 = 1,0 roots, C/N(100)

App. 5 (b) Changes with time in total N, organic labelled N and ^{15}N enrichment in soil receiving root material of different C/N ratios (as detailed in section B of Chapter 9)

Clansthal sand

Treatment	Total org. N ppm	Org. labelled N ppm	^{15}N excess atom %	Total org. N ppm	Org. labelled N ppm	^{15}N excess atom %
	Day 3			Day 7		
1	507	4	0,038	524	4	0,036
2	540	20	0,167	563	21	0,170
3	557	22	0,176	574	25	0,192
4	596	26	0,194	619	31	0,225
5	549	26	0,217	591	33	0,252
	Day 14			Day 21		
1	518	*	*	537	4	0,036
2	622	26	0,190	605	27	0,197
3	552	27	0,223	549	26	0,216
4	622	38	0,277	633	37	0,266
5	580	39	0,303	571	40	0,313
	Day 30			Day 56		
1	504	3	0,031	501	*	*
2	596	21	0,161	612	20	0,146
3	532	24	0,206	529	23	0,196
4	613	33	0,240	594	28	0,219
5	554	36	0,293	554	34	0,275
	Day 84			Day 112		
1	470	2	0,018	465	2	0,017
2	546	16	0,131	546	16	0,131
3	524	*	*	521	21	0,184
4	571	*	*	568	27	0,212
5	553	33	0,272	512	29	0,251

Original enrichment of $^{15}(NH_4)_2SO_4$ = 4,510 atom % excess

* insufficient gas evolved

Trmt. 1 = Control

2 = 0,5% roots, C/N(50) 4 = 1,0% roots, C/N(5C)

3 = 0,5% roots, C/N(100) 5 = 1,0% roots, C/N(1[illegible])

App. 5 (b) cont.

Glenrosa sandy loam

Treatment	Total org. N ppm	Org. labelled N ppm	^{15}N excess atom %	Total org. N ppm	Org. labelled N ppm	^{15}N excess atom %
	Day 3			Day 7		
1	518	4	0,037	487	5	0,044
2	574	20	0,157	546	21	0,176
3	560	19	0,153	532	*	*
4	596	32	0,238	594	35	0,267
5	619	34	0,240	580	35	0,268
	Day 14			Day 21		
1	493	7	0,061	490	6	0,056
2	538	23	0,191	557	23	0,189
3	580	26	0,200	535	24	0,198
4	605	36	0,269	613	*	*
5	568	36	0,286	619	41	0,298
	Day 30			Day 56		
1	468	6	0,057	487	6	0,060
2	543	22	0,181	534	19	0,164
3	552	24	0,196	512	21	0,181
4	591	38	0,293	605	36	0,270
5	580	38	0,299	577	41	0,319
	Day 84			Day 112		
1	465	6	0,060	456	6	0,059
2	507	21	0,184	507	17	0,150
3	507	20	0,174	493	18	0,168
4	577	34	0,268	577	33	0,255
5	557	39	0,314	560	37	0,295

Original enrichment of $^{15}(NH_4)_2SO_4$ = 4,510 atom % excess

* insufficient gas evolved

Trmt. 1 = Control

2 = 0,5% roots, C/N(50)　　4 = 1,0% roots, C/N(50)

3 = 0,5% roots, C/N(100)　　5 = 1,0% roots, C/N(100)

App. 5 (b) cont.

Shortlands clay

Treatment	Total org. N ppm	Org. Labelled N ppm	^{15}N excess atom %	Total org. N ppm	Org. labelled N ppm	^{15}N excess atom %
	Day 3			Day 7		
1	1674	3	0,008	1663	5	0,015
2	1728	15	0,038	1725	25	0,064
3	1694	16	0,043	1733	24	0,062
4	1778	27	0,068	1764	35	0,090
5	1744	28	0,073	1746	34	0,088
	Day 14			Day 21		
1	1700	7	0,017	1705	6	0,015
2	1747	22	0,057	1775	23	0,059
3	1714	23	0,059	1736	22	0,058
4	1817	37	0,091	1856	36	0,088
5	1798	40	0,099	1777	38	0,095
	Day 30			Day 56		
1	1728	*	*	1680	6	0,016
2	1761	21	0,054	1711	22	0,059
3	1753	24	0,063	1725	26	0,067
4	1823	37	0,092	1859	38	0,091
5	1806	42	0,106	1814	43	0,106
	Day 84			Day 112		
1	1670	5	0,013	1627	5	0,013
2	1719	21	0,054	1705	21	0,055
3	1730	24	0,063	1677	24	0,064
4	1747	34	0,088	1764	33	0,085
5	1697	38	0,100	1714	35	0,092

Original enrichment of $^{15}(NH_4)_2SO_4$ = 4,510 atom % excess

* insufficient gas evolved

Trmt. 1 = Control

2 = 0,5% roots, C/N(50)

3 = 0,5% roots, C/N(100)

4 = 1,0% roots, C/N(50)

5 = 1,0% roots, C/N(100)

APPENDIX 6

Yield, and recovery of fertilizer N* by above-ground parts of plant cane crop
(Time of N application and placement experiment)

Treatment 1 84 kg N/ha in furrow at planting

Clansthal sand

Age of crop (weeks)		^{15}N applied mg	Yield mg N	^{15}N excess atom %	^{15}N recovered mg	^{15}N recovered % of applied
			Leaf and stalk			
10	leaf	43,7	35	0,3830	0,134	0,31
18	leaf	"	51	0,0843	0,043	0,10
26	leaf	"	408	0,1037	0,423	0,97
37	leaf	"	663	0,0180	0,119	0,27
48	leaf	"	8847	0,0223	1,970	4,51
"	stalk	"	4275	0,0109	0,464	1,06
TOTAL			14279		3,153	7,22
			Trash			
1-21		43,7	11	0,2360	0,026	0,06
22-27		"	125	0,1400	0,175	0,40
28-34		"	623	0,0620	0,385	0,81
35-48		"	593	0,0098	0,058	0,13
TOTAL			1352		0,644	1,47
GRAND TOTAL			15631		3,797	8,69

Rydalvale clay

Age of crop (weeks)		^{15}N applied mg	Yield mg N	^{15}N excess atom %	^{15}N recovered mg	^{15}N recovered % of applied
			Leaf and stalk			
10	leaf	43,7	52	0,9750	0,507	1,16
18	leaf	"	92	0,2100	0,193	0,44
26	leaf	"	951	0,0392	0,373	0,85
37	leaf	"	1188	0,0487	0,579	1,32
48	leaf	"	11003	0,0164	1,802	4,12
"	stalk	"	8441	0,0245	2,072	4,74
TOTAL			21727		5,526	12,65
			Trash			
1-21		43,7	32	0,4063	0,130	0,30
22-27		"	197	0,3376	0,665	1,52
28-34		"	510	0,1253	0,639	1,46
35-48		"	1110	0,0369	0,410	0,94
TOTAL			1849		1,844	4,22
GRAND TOTAL			23576		7,370	16,87

* weighted means of three replicates - original enrichment of $^{15}(NH_4)_2SO_4$ = 2,080 atom % excess
- total fertilizer N applied = 2100 mg

App. 6 cont.

Treatment 2 42 kg N/ha in furrow, 42 kg N/ha top-dressed at 10 weeks old

Clansthal sand

Age of crop (weeks)		^{15}N applied mg	Yield mg N	^{15}N excess atom %	^{15}N recovered mg	^{15}N recovered % of applied
			Leaf and stalk			
10	leaf	43,7	42	0,2120	0,089	0,20
18	leaf	"	69	0,4430	0,306	0,72
26	leaf	"	586	0,1154	0,676	1,55
37	leaf	"	825	0,0662	0,546	1,25
48	leaf	"	9177	0,0528	4,841	11,08
"	stalk	"	6037	0,0362	2,185	5,00
TOTAL			16736		8,643	19,78
			Trash			
1-21		43,7	25	0,3720	0,093	0,21
22-27		"	230	0,4210	0,968	2,22
28-34		"	639	0,1767	1,129	2,58
35-48		"	843	0,0852	0,718	1,64
TOTAL			1737		2,908	6,65
GRAND TOTAL			18473		11,551	26,43

Rydalvale clay

Age of crop (weeks)		^{15}N applied mg	Yield mg N	^{15}N excess atom %	^{15}N recovered mg	^{15}N recovered % of applied
			Leaf and stalk			
10	leaf	43,7	50	0,7440	0,372	0,85
18	leaf	"	92	0,3830	0,352	0,81
26	leaf	"	851	0,0702	0,597	1,37
37	leaf	"	1079	0,0512	0,552	1,26
48	leaf	"	9850	0,0397	3,913	8,95
"	stalk	"	7450	0,0290	2,158	4,94
TOTAL			19372		7,944	18,18
			Trash			
1-21		43,7	30	0,4630	0,139	0,32
22-27		"	215	0,3680	0,791	1,81
28-34		"	571	0,2036	1,163	2,66
35-48		"	1191	0,0567	0,675	1,54
TOTAL			2007		2,768	6,33
GRAND TOTAL			21379		10,712	24,61

App. 6 cont.

Treatment 3 21 kg N/ha in furrow, 63 kg N/ha topdressed at 10 weeks

Clansthal sand

Age of crop (weeks)		^{15}N applied mg	Yield mg N	^{15}N excess atom %	^{15}N recovered mg	^{15}N recovered % of applied
			Leaf and stalk			
10	leaf	43,7	37	0,1380	0,051	0,12
18	leaf	"	81	0,5650	0,458	1,05
26	leaf	"	643	0,1240	0,797	1,82
37	leaf	"	946	0,0423	0,400	0,92
48	leaf	"	11242	0,0438	4,922	11,26
"	stalk	"	6964	0,0203	1,416	3,24
TOTAL			19913		8,044	18,41
			Trash			
1-21		43,7	23	0,4570	0,105	0,24
22-27		"	210	0,5310	1,115	2,55
28-34		"	911	0,2044	1,862	4,26
35-48		"	1069	0,0734	0,785	1,80
TOTAL			2213		3,867	8,85
GRAND TOTAL			22126		11,911	27,26

Rydalvale clay

Age of crop (weeks)		^{15}N applied mg	Yield mg N	^{15}N excess atom %	^{15}N recovered mg	^{15}N recovered % of applied
			Leaf and stalk			
10	leaf	43,7	41	0,3930	0,161	0,37
18	leaf	"	96	0,4110	0,395	0,90
26	leaf	"	1319	0,0660	0,870	1,99
37	leaf	"	1612	0,0500	0,804	1,84
48	leaf	"	15197	0,0344	5,222	11,95
"	stalk	"	11470	0,0163	1,875	4,29
TOTAL			29735		9,327	21,34
			Trash			
1-21		43,7	31	0,4130	0,128	0,29
22-27		"	220	0,3800	0,834	1,91
28-34		"	716	0,2127	1,523	3,49
35-48		"	1775	0,0616	1,094	2,50
TOTAL			2742		3,579	8,19
GRAND TOTAL			32477		12,906	29,53

App. 6 cont.

Treatment 4 84 kg N/ha top-dressed 10 weeks after planting (applied as $(NH_4)_2SO_4$)

Clansthal sand

Age of crop (weeks)		^{15}N applied mg	Yield mg N	^{15}N excess atom %	^{15}N recovered mg	^{15}N recovered % of applied
			Leaf and stalk			
10	leaf	-	-	-	-	-
18	leaf	43,7	68	0,6180	0,420	0,96
26	leaf	"	616	0,1200	0,739	1,69
37	leaf	"	816	0,0572	0,467	1,07
48	leaf	"	9147	0,0310	2,837	6,49
"	stalk	"	6827	0,0278	1,898	4,34
TOTAL			17474		6,361	14,55
			Trash			
1-21		43,7	41	0,4950	0,203	0,46
22-27		"	253	0,5344	1,352	3,09
28-34		"	543	0,3690	2,004	4,59
35-48		"	775	0,0830	0,643	1,47
TOTAL			1612		4,202	9,61
GRAND TOTAL			19086		10,563	24,16

Rydalvale clay

Age of crop (weeks)		^{15}N applied mg	Yield mg N	^{15}N excess atom %	^{15}N recovered mg	^{15}N recovered % of applied
			Leaf and stalk			
10	leaf	-	-	-	-	-
18	leaf	43,7	102	0,8760	0,894	2,05
26	leaf	"	561	0,1700	0,953	2,18
37	leaf	"	810	0,0925	0,749	1,71
48	leaf	"	7253	0,0632	4,582	10,49
"	stalk	"	4862	0,0567	2,656	6,08
TOTAL			13588		9,834	22,51
			Trash			
1-21		43,7	22	0,5270	0,116	0,27
22-27		"	122	0,5320	0,649	1,49
28-34		"	497	0,2924	1,453	3,32
35-48		"	771	0,1672	1,289	2,95
TOTAL			1412		3,507	8,03
GRAND TOTAL			15000		13,341	30,54

App. 6 cont.

Treatment 5 84 kg N/ha top-dressed 10 weeks after planting (applied as KNO_3)

Age of crop (weeks) (Clansthal sand)		^{15}N applied mg	Yield mg N	^{15}N excess atom %	^{15}N recovered mg	^{15}N recovered % of applied	Age of crop (weeks) (Rydalvale clay)		^{15}N applied mg	Yield mg N	^{15}N excess atom %	^{15}N recovered mg	^{15}N recovered % of applied
			Leaf and stalk							Leaf and stalk			
10	leaf	-	-	-	-	-	10	leaf	-	-	-	-	-
18	leaf		85	1,8790	1,597	1,61	18	leaf		112	1,6800	1,882	1,90
26	leaf		752	0,2935	2,207	2,23	26	leaf		802	0,2456	1,970	1,99
37	leaf		960	0,1273	1,222	1,23	37	leaf		1028	0,1398	1,437	1,45
48	leaf		11204	0,1004	11,248	11,35	48	leaf		9702	0,1153	11,187	11,29
"	stalk		9967	0,1114	11,099	11,20	"	stalk		6957	0,1329	9,246	9,33
TOTAL			22968		27,373	27,62	TOTAL			18601		25,722	25,96
			Trash							Trash			
1-21			52	1,3170	0,685	0,69	1-21			43	1,3330	0,573	0,58
22-27			298	1,5614	4,653	4,70	22-27			199	1,2120	2,411	2,43
28-34			694	0,8772	6,088	6,14	28-34			676	0,7772	5,254	5,30
35-48			993	0,3378	3,354	3,38	35-48			1080	0,2610	2,818	2,84
TOTAL			2039		14,690	14,91	TOTAL			1998		11,056	11,15
GRAND TOTAL			25005		42,063	42,53	GRAND TOTAL			20599		36,778	37,11