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Growth and yield of sugar beet on contrasting soils in relation to nitrogen supply

II. Growth, uptake and leaching of nitrogen

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SUMMARY

Nine field experiments with sugar beet in 1968–70 tested eight amounts of nitrogen fertilizer (0–290 kg N/ha) on a shallow calcareous loam (Icknield Series), on a deep sandy loam (Newport Series) and on a heavy clay loam (Evesham Series). The amount of mineral nitrogen in the top and sub-soils was determined before applying fertilizer and at monthly intervals from May to October in plots given 0, 125 and 250 kg N/ha. The crop on these plots was also sampled at monthly intervals throughout the growing season and the yield and nitrogen uptake determined. The soil analyses indicated that in springs with average rainfall, the leaching losses of nitrogen fertilizer are negligibly small, although there was some evidence that losses may be greatest on sandy loams. In very wet springs such as 1969, with almost double the normal rainfall, losses through leaching are considerable – on average, 40 kg N/ha. Dry-matter yields and response to nitrogen fertilizer differed between the three soils consistently from year to year. On the calcareous loam, neither amount of fertilizer changed the dry-matter yield of roots in any year. The crop on the clay loam needed a small dressing and on the sandy loam a larger dressing of fertilizer for maximum root dry-matter yield. Uptake of nitrogen by the crops usually paralleled the decreases in soil mineral nitrogen although on the clay loam nearly a third of the nitrogen applied could not be accounted for in the soil or plants, suggesting that some denitrification may have taken place. When the amount of nitrogen taken up by unfertilized crops is allowed for, the percentage recovery of applied fertilizer nitrogen at final harvest ranged from 42% on the calcareous loams to 62% on the sandy loams.

INTRODUCTION

The overall objects of the investigation have already been described in Part I (Last & Draycott, 1975). Part II reports results of soil and plant analyses made throughout the growing season, together with dry-matter yields of the crop. Particular attention has been given to assessment of any losses of nitrogen fertilizer caused by leaching in spring as the beet crop, with its tap root extending to a depth of 120–180 cm under normal conditions, would seem to be a crop which would ultimately be less affected by leaching of mineral-nitrogen compared with more shallow-rooting crops. Indeed, Last & Draycott (1972) tested the efficacy of a series of top dressings of nitrogen fertilizer compared with applications to the seed bed and concluded that during 1959–61 leaching was unimportant as no greater yield was obtained

by top dressings of nitrogen fertilizer to counter-balance any leaching of nitrate-nitrogen.

An attempt has also been made to balance nitrogen uptake by the crop, from June onwards, with the decrease in soil mineral nitrogen, as this had not been done before. Since there is much evidence from abroad that the nitrate-nitrogen concentration in sugar-beet petioles reflects the nitrogen status of the crop, we looked for relationships between petiole nitrate and soil mineral-nitrogen concentrations.

EXPERIMENTAL PROCEDURE

The location of the field experiments, design, fertilizer treatments, method of soil sampling and harvesting were described in Part I (Last & Draycott, 1975). Starting at the beginning of June, plant and soil samples were taken at monthly intervals

throughout the growing season from plots given 0, 125 and 250 kg N/ha.

Soil sampling

Top and sub-soil was sampled, taking 20 cores per plot from the top soil and three cores from the sub-soil. The five replicates of each treatment were mixed and analysed fresh for mineral-nitrogen concentration by extracting with acidified potassium sulphate and subsequent steam distillation by the method of Bremner (1965).

Plant sampling

On the first sampling occasion, 100 plants were selected at random from each plot before the plants were singled. Thereafter, two plants were taken from each of the middle six rows of each plot and each plot sample was then treated separately. The plants were sub-divided into roots, petioles and leaves, washed and weighed and the dry matter of each plant part determined by drying sub-samples at 80 °C. After drying, samples from the five plots of each treatment were mixed for total nitrogen determination after being ground to less than 2 mm. A sub-sample was also ashed at 440 °C and the resulting solution analysed for sodium, calcium and magnesium by atomic absorption and for potassium by flame emission. The phosphorus concentration of the extract was determined colorimetrically using the vanado-molybdate complex. On each occasion, 20 young mature leaves were selected at random from each plot, the leaves and petioles separated, washed, sub-sampled and two 20 g samples of both plant sections were macerated in a high-speed blender, and the resulting suspensions analysed for nitrate-nitrogen concentration.

Dry-matter yield

Table 1 shows the average effect of nitrogen on the dry-matter yield of roots, petioles and leaves throughout the growing period on each of the three soils. The smaller dressing of fertilizer (125 kg/ha) increased the yield of leaves and petioles significantly on all the soils on nearly every occasion, the largest effect being on the crop growing on the sandy loam and the least on the calcareous loam. The larger dressing (250 kg/ha) also further increased the yield of leaves and petioles from July onwards on the sandy and clay loams but had little effect on the calcareous loam until the last harvest.

In the sugar-beet crop, the important component is the dry-matter yield of roots, which is closely correlated with sugar yield (Draycott & Webb, 1971). There were clear differences between responses on the three soils and the average results in the table reflect consistent effects from year to year. Neither amount of fertilizer changed the dry-matter yield of roots in any year on the calcareous

loam, a surprising result but confirming the results of soil analyses which showed that this soil contained much available and potentially available nitrogen. On the clay loam, the smaller dressing of nitrogen increased the root dry-matter yield but the larger dressing had no further effect. The root dry-matter yield of the crop on the sandy loam responded greatly to the smaller dressing and the larger dressing increased it a little more, consistently but not significantly.

The crops on the sandy loams gave early and most frequent significant responses in both petiole and leaf dry matter. There were significant increases in dry matter for both plant parts on the clay loams by the third harvest. On the calcareous loam, the crop responded to applied nitrogen later in the season and only at the last sampling date was there any significant response in dry matter to 250 kg/ha.

The proportion of the total dry matter in the petioles was similar on all three soil types throughout the season, but the proportion of dry matter in the roots on the calcareous loams was consistently lower than in crops grown on the other soil types. On the heavily fertilized plots, only 58% of the total dry matter was in the roots at final harvest. By October, averaged over all treatments, the roots from the clay loam and the sandy loam contained about 71% of the total dry matter, whilst those from the calcareous loam contained only 63%. The small value on the calcareous loam was probably due to the large supply of soil nitrogen from that soil. The yield of leaves continued to increase during autumn every year on the calcareous loam, whereas on the other two soils the yield of leaves remained constant or declined from July onwards.

Figure 1 shows the distribution of dry matter at the three sites, averaged over 3 years, and treatments.

Uptake of nitrogen

Table 2 shows the amount of nitrogen taken up by the crops given 0, 125 and 250 kg N/ha on each of the three soils averaged over the 3 years. Total uptake of nitrogen increased throughout the season in every case, except on the sandy loam from August onwards. Giving 125 kg N/ha increased the amount of nitrogen in the crop in September, on average, by 60 kg/ha compared with giving none. A double dressing of fertilizer (250 kg/ha) increased the amount in the crop by a further 60 kg/ha. The crop without fertilizer contained most nitrogen when grown on the clay loam (140 kg/ha) and least on the sandy loam (80 kg/ha) by September.

There were large differences in uptake between crops on the three soils early in the season but these largely reflected crop growth. Uptake on the calcareous loam was slow during June and July but giving nitrogen fertilizer increased it only

Table 1. *Effect of nitrogen fertilizer on dry-matter yield of roots, petioles and leaves*

Means of 3 experiments, 1968-70.

	N dressing (kg/ha)	Dry matter (t/ha)				
		June	July	August	September	October
Calcareous loam						
Roots	0	0.05	1.33	3.81	7.45	—
	125	0.05	1.38	3.81	7.38	—
	250	0.05	1.25	3.89	7.68	—
S.E.D.	—	± 0.005	± 0.096	± 0.226	± 0.380	—
Petioles	0	0.05	0.60	1.45	1.83	—
	125	0.05	0.70	1.86	2.66	—
	250	0.07	0.70	1.88	3.16	—
S.E.D.	—	± 0.005	± 0.036	± 0.134	± 0.161	—
Leaves	0	0.12	0.85	1.35	1.56	—
	125	0.12	0.89	1.78	2.08	—
	250	0.15	1.00	1.93	2.33	—
S.E.D.	—	± 0.003	± 0.052	± 0.112	± 0.118	—
Sandy loam						
Roots	0	0.25	1.81	5.65	7.30	7.91
	125	0.28	2.31	6.47	9.01	10.32
	250	0.35	2.28	6.85	9.59	10.52
S.E.D.	—	± 0.042	± 0.151	± 0.370	± 0.353	± 0.693
Petioles	0	0.12	0.65	1.35	1.35	1.35
	125	0.20	1.15	2.21	2.51	2.48
	250	0.25	1.25	2.96	3.51	3.09
S.E.D.	—	± 0.038	± 0.069	± 0.132	± 0.174	± 0.278
Leaves	0	0.22	0.85	1.13	0.95	0.90
	125	0.33	1.48	1.68	1.51	1.61
	250	0.38	1.58	2.26	2.21	2.16
S.E.D.	—	± 0.030	± 0.100	± 0.100	± 0.115	± 0.113
Clay loam						
Roots	0	0.75	3.74	8.93	—	—
	125	0.90	4.34	10.37	—	—
	250	0.85	4.57	10.09	—	—
S.E.D.	—	± 0.050	± 0.188	± 0.548	—	—
Petioles	0	0.43	1.38	2.21	—	—
	125	0.58	1.86	2.81	—	—
	250	0.55	2.03	3.11	—	—
S.E.D.	—	± 0.054	± 0.088	± 0.133	—	—
Leaves	0	0.70	1.45	1.45	—	—
	125	0.85	1.88	1.93	—	—
	250	0.90	2.26	2.16	—	—
S.E.D.	—	± 0.042	± 0.132	± 0.105	—	—

S.E.D., standard error of the difference between the treatment means.

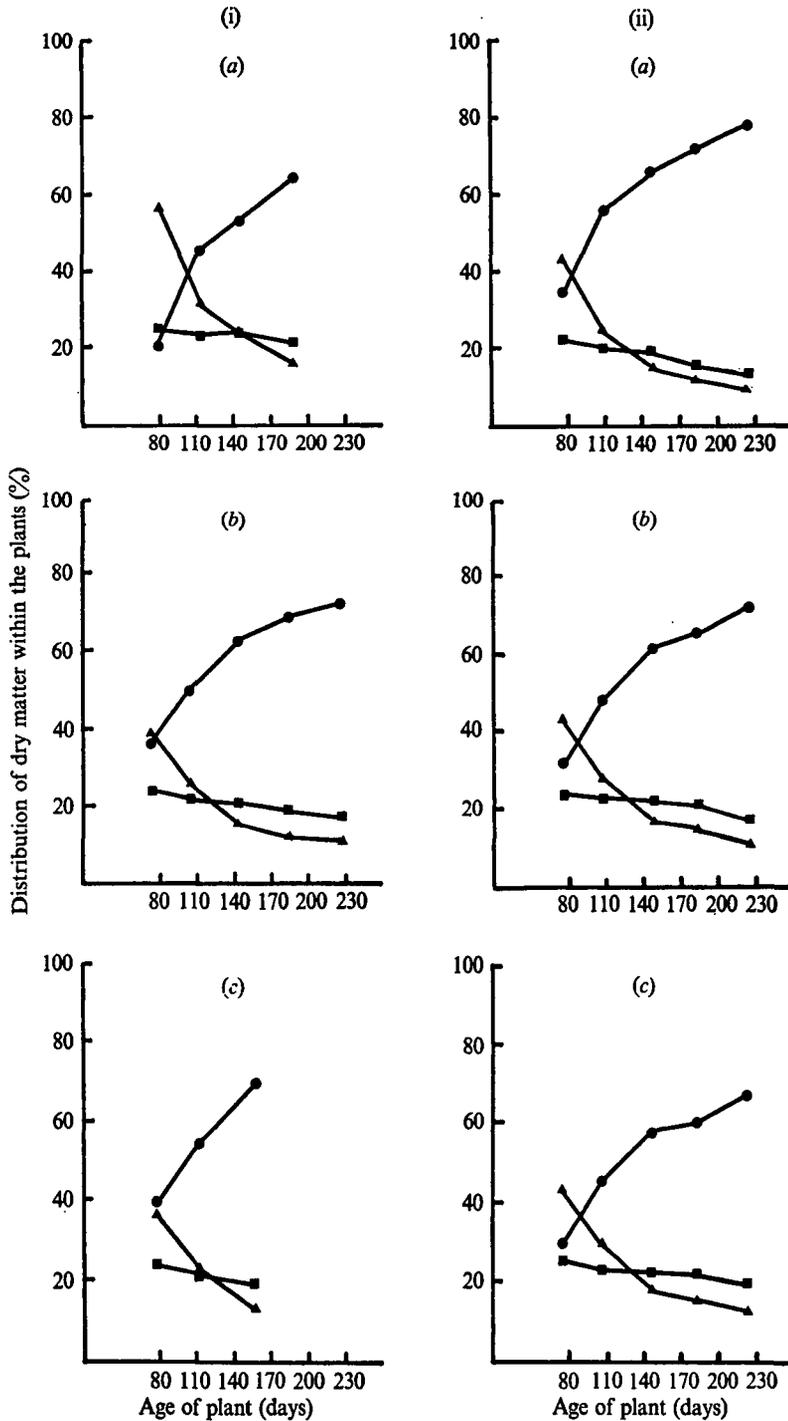


Fig. 1. Dry matter apportioning in crops grown on three different soil types, 1968-70. (i): (a) Calcareous loam; (b) sandy loam; (c) clay loam. (ii): (a) No N fertilizer; (b) 125 kg N/ha; (c) 250 kg N/ha. ●, Roots; ▲, leaves; ■, petioles.

Table 2. Total uptake of nitrogen during the growing period. Means, 1968-70

	N uptake (kg/ha)				
	June	July	August	September	October
Calcareous loam					
N dressing (kg/ha)					
0	8.5	58.0	91.5	121.0	(171.2)
125	8.6	78.2	145.7	177.6	(214.7)
250	9.3	81.3	173.4	227.8	(257.6)
S.E.D.	± 0.73	± 3.58	± 8.00	± 7.64	(± 14.36)
Sandy loam					
N dressing (kg/ha)					
0	15.9	58.7	82.0	81.3	86.8
125	26.1	114.3	137.3	142.2	163.7
250	31.7	133.4	212.3	231.0	237.8
S.E.D.	± 2.49	± 6.62	± 7.32	± 6.41	± 10.06
Clay loam					
N dressing (kg/ha)					
0	49.8	111.5	130.8	(140.8)	(130.5)
125	70.4	154.3	188.7	(181.0)	(172.5)
250	75.4	201.6	235.3	(241.8)	(239.8)
S.E.D.	± 2.70	± 6.97	± 8.37	(± 11.21)	(± 10.61)

() Means of one or two years only.

S.E.D., standard error of the difference between treatment means.

slightly and significant effects of the heavy dressing were not apparent until late August. On the clay and sandy loams, uptake was much more rapid during the same period and both amounts of fertilizer had increased it significantly by the second harvest (late June) and dry-matter yield was increased. These results were consistent from year to year.

The crop on the calcareous loam at Felsted grew slowly early in the season every year. Clearly, this was not a result of shortage of nitrogen because the soil contained a good supply and giving more in fertilizer increased growth and uptake little until later in the year. However, on the sandy loam at Newark there was a severe shortage of nitrogen where none was given and fertilizer increased yield and uptake greatly throughout the season. The position on the clay loam at Nottingham was, on average, similar to that on the sandy loam, although in 1970 growth and uptake were little affected by nitrogen fertilizer as the soil contained a large supply.

Maximum uptake in the leaves on the clay loam at Nottingham was during August and early September but increased in both roots and petioles throughout the growing season. On the calcareous loam at Felsted, uptake of nitrogen was maximal in the leaves after the fourth harvest. Nitrogen uptake by petioles generally followed the same pattern. The total amount of nitrogen contained in

the petioles was rather less than that present in the leaves and the amounts ranged, on average, from about 69 kg/ha at final harvest on heavily fertilized plots to 29 kg/ha on unfertilized plots.

Uptake of nitrogen by the roots increased throughout the season over 3 years, on average, on all soil types and with all treatments, although the effects of treatments were different for the early harvests. By late June (second harvest), 125 and 250 kg/ha had increased uptake of nitrogen by roots (the heavier dressing significantly) on the sandy loam at Newark, whilst on the other two soils the only significant effect was of 125 kg/ha on the clay loam at Nottingham. At final harvest, plots receiving the heavy nitrogen dressing on the calcareous loam at Felsted contained less than 78 kg/ha in the roots; although uptake of nitrogen with both fertilizer treatments was continuing rapidly, there was no extra dry matter in the roots. Similar effects were recorded on the heavily fertilized plots at Newark and Nottingham.

Leaching of nitrogen

Table 3 shows the loss of nitrogen fertilizer each year in the interval between applying the fertilizer and establishment of the crop. The values were calculated from the concentrations of mineral nitrogen (ammonium plus nitrate-nitrogen) in the soil and assuming 10 cm soil weighs 1.5×10^6 kg/ha. Table 3 also shows the rainfall during March to

Table 3. *Loss of nitrogen fertilizer during spring (March–May inclusive) and rainfall*

Nitrogen dressing (kg/ha) ...	Loss* (kg N/ha)		Rainfall (mm)
	125	250	
Calcareous loam (0–60 cm)			
1968	0	0	95
1969	25	64	157
1970	15	78	153
Mean	13	47	135
Sandy loam (0–90 cm)			
1968	34	40	112
1969	47	24	238
1970	21	11	151
Mean	34	25	167
Clay loam (0–75 cm)			
1968	0	0	124
1969	50	35	278
1970	0	0	121
Mean	17	11	174

* Amount N applied – (soil mineral N with fertilizer – soil mineral N without fertilizer).

May inclusive, for it is considered likely that loss of nitrogen fertilizer in this period resulted from leaching.

Rainfall in the spring of 1968 was similar to the long-term mean on all the fields and no fertilizer was lost from the calcareous loam nor from the clay loam. However, 112 mm rainfall on the sandy loam caused losses of 30–40 kg/ha. In 1969, more than twice as much rain fell as in 1968 and much nitrogen was leached on all three fields – on average, 40 kg/ha. The rainfall in the spring of 1970 was near the long-term averages on the sandy and clay loams and leaching losses on these two fields were negligibly small – on average, 8 kg/ha. In both 1969 and 1970, a large amount of nitrogen was lost from the calcareous loam which had been given a large amount of fertilizer. This is difficult to explain as the rainfall, although above average, was not particularly great, nor was much lost where less fertilizer had been given.

In general, it appears that when rainfall is average in the spring, leaching losses of nitrogen fertilizer are negligibly small on sugar-beet fields such as these. There was some evidence that losses may be greatest on the sandy loam, which is supported by further analyses given later. In very wet springs such as 1969, with double the normal rainfall, losses through leaching are considerable.

On both the clay loam at Nottingham and the sandy loam at Newark, early and late leaching was associated with higher optimum nitrogen requirement for maximum yield at final harvest and with largest responses in sugar yield to applied nitrogen,

but when the movement or loss of nutrient was later in the season at these sites, response in sugar yield to applied nitrogen was not increased. On the calcareous loam at Felsted, neither early nor late leaching was associated with increased nitrogen fertilizer requirement or response by the beet crop and was relatively unimportant.

Concentration of petiole nitrate

Several reports (particularly by Ulrich, 1950, and his co-workers) have shown that the concentration of nitrate-nitrogen in sugar-beet petioles (or leaves) is a good guide to the nitrogen status of the crop. Thus each time the crops were sampled, nitrate determinations were made on the youngest fully expanded leaf and its petiole by methods described by Last & Tinker (1968). As the leaf values followed the same pattern as the petioles, although at lower concentrations, only the petiole concentrations are considered here.

Table 4 shows that early in the season when the petioles contained much nitrogen, the concentration was related to the amount of mineral-nitrogen in the soil. This suggests that petiole concentration reflects what is available from the soil but the results confirmed that the age of the plant was the main factor affecting the concentration of petiole nitrate-nitrogen (Last & Tinker, 1968) for the concentration fell rapidly during July and August. There were consistent differences, however, between nitrogen fertilizer treatments and between the three soils. In several experiments, particularly on the sandy loam, there was clear evidence of a small

Table 4. Concentration of nitrate-nitrogen in the petioles of plants given 0, 125 and 250 kg N/ha
Means, 1968-70.

	Nitrate-nitrogen (mg/kg)				
	July	August	September	October	November
Calcareous loam					
N dressing (kg/ha)					
0	358	139	85	70	(30)
125	391	336	155	132	(105)
250	690	416	275	216	(209)
Sandy loam					
N dressing (kg/ha)					
0	289	84	20	38	(75)
125	503	193	62	77	(93)
250	638	296	184	121	(152)
Clay loam					
N dressing (kg/ha)					
0	300	143	42	(46)	—
125	516	240	84	(135)	—
250	618	361	189	(288)	—

() 1 or 2 years' results only.

increase in petiole nitrate in autumn. This reflected a secondary 'flush' of mineralization of soil organic nitrogen as shown in the section above dealing with soil mineral nitrogen.

In all years, the concentrations were greatest in sugar beet from the calcareous loam and least from the sandy loam. In all experiments, the concentrations were greatest in the wet summer of 1968 and least in the dry summer of 1970. Late in the season, when the petiole contained little nitrate, there was no relationship between its concentration and the amount of mineral-nitrogen in the soil. Last & Tinker (1968) have previously investigated relationships between concentration of petiole nitrate, sugar yield and response to nitrogen fertilizer and the present study confirmed that the relationships are close for individual fields but tenuous when averaged over fields and seasons. For example, when sugar yield was plotted against concentration of petiole nitrate at harvest, on most fields there was a clear optimum concentration of nitrate. The optima, however, were different for different fields, although always less than 150 mg/kg at harvest.

Last & Tinker (1968) have reported previously that when petioles contain more than 600 mg nitrate-nitrogen/kg after 73 days' growth, final sugar yield does not increase with application of extra nitrogen fertilizer. For eight of the nine trials recorded here, this was also true and no response field was missed; the large experimental error in 1970 at Felsted caused by irregular plant density and long dry spells affecting yields made interpretation of optima difficult for this trial. Every increment of 106 mg nitrate-nitrogen/kg present in

petioles at harvest depressed sugar percentage by 1%, although the effect of excess nitrate-nitrogen was less in the wet year, 1968, and more deleterious to sugar percentage on the calcareous loams.

The critical concentration (Ulrich, 1950) of nitrate-nitrogen in beet petioles for maximum yield is 80 mg/kg for a period of 11-12 weeks prior to harvest. The relatively early final harvests on the clay loam at Nottingham necessitated comparing critical concentrations obtained from these sites in late June to mid-July with critical concentrations obtained in mid-August from the other two sites, when internal dilution could account for large differences in concentration of petiole nitrate-nitrogen. A more comparable value for the critical concentrations could be assigned to the trials by allotting a specific date to the critical concentration and this could be 11-12 weeks prior to the average lifting date of the beet crop - say mid-August. The critical concentrations for petiole nitrate would then be, on average, 125 mg/kg.

Mineral-nitrogen present in soil profile

Table 5 shows the amount of mineral nitrogen in the soil throughout the growing season June-November. For simplicity, only means of the three years are given and any marked deviations in individual years will be mentioned.

On average in June, the amount of mineral nitrogen was similar in all three soils, plots given no fertilizer containing about 130 kg/ha and those given 250 kg N/ha containing about 350 kg/ha. The amount present decreased rapidly during June and July and slowly during the remainder of the

Table 5. Amount of mineral nitrogen in the soil of plots given 0, 125 and 250 kg N/ha

Means, 1968-70.

	Mineral nitrogen (kg/ha)					
	June	July	August	September	October	November
Calcareous loam (0-60 cm)						
N dressing (kg/ha)						
0	133	112	122	84	47	(37)
125	240	179	193	115	74	(19)
250	339	251	258	176	87	(27)
Sandy loam (0-90 cm)						
N dressing (kg/ha)						
0	127	107	79	43	35	(58)
125	196	165	113	68	46	(56)
250	321	248	176	79	48	(81)
Clay loam (0-75 cm)						
N dressing (kg/ha)						
0	143	106	63	55	(26)	—
125	258	142	111	61	(35)	—
250	383	234	114	81	(25)	—

() One year's results only.

season. The rate of decrease was slowed by autumnal flushes of mineralization which occurred at Newark on the sand loam in all 3 years and on the calcareous loam in 1969. The decrease was most rapid on plots given 250 kg/ha, where the amount present commonly declined by 100 kg/ha in one month. By October-November, the amount of mineral-nitrogen in plots with and without fertilizer was somewhat similar and near to the amount found before applying fertilizer in March (Table 2, Part I).

Exceptions were the sandy and clay loam sites in 1969, for the spring leaching already discussed removed most of the nitrogen fertilizer from the top soil but much of this fertilizer was present in the sub-soil. During the season, the mineral-nitrogen in the top soil decreased only slightly but the amount in the sub-soils declined greatly.

The concentration of mineral-nitrogen in the top soils was less in 1969 than in the previous very wet year and, as in 1968, the calcareous loam at Felsted contained the highest mineral-nitrogen concentration for all treatments at comparable dates. On the fertilized plots at Nottingham, the concentration of mineral-nitrogen was half that in 1968. In 1970, the mineral-nitrogen values in the calcareous loam were very similar to those obtained in 1969 but on the sandy loam at Newark they were enhanced when compared with the low 1969 values, perhaps due to the light spring rainfall in the Midlands during 1970. Extremely high values were obtained in the top soil at Nottingham initially during 1970, attributed to the previous cropping

and, when coupled to the lack of response to applied nitrogen fertilizer here, demonstrated the dominant role that previous cropping has on nitrogen requirement of sugar beet.

By final harvest, the sugar-beet crop generally removed nearly all the nitrogen fertilizer dressing from the depth of soil investigated, even when 250 kg/ha (double the recommended dressing) was given and both top soil and sub-soil mineral-nitrogen values had returned to, or were below, the amount found before the fertilizer was applied. The amount present in the crop is described below.

Figure 2 shows the amounts of nitrogen fertilizer unaccounted for each month during the growing period by calculation from the soil mineral-nitrogen concentrations and crop uptakes with and without fertilizer. It is interesting to compare these with the values given in Table 3. On the calcareous loam, the June values reflect the spring leaching losses so all the nitrogen fertilizer is accounted for on this soil. During the remainder of the season, there was a loss of a further 20 kg/ha where 125 kg N/ha had been given and about 50 kg/ha where 250 kg/ha was given. Part of this loss may be accounted for in senescing leaves, part to leaching and part to denitrification. On the sandy loam, after the initial spring leaching, there was no further loss on plots given 125 kg/ha but plots given 250 kg/ha lost about 40 kg/ha. On the clay loam, loss of nitrogen was much greater than on the other two soils, amounting to 30 and nearly 100 kg/ha on plots given 125 and 250 kg/ha respectively. It seems

likely that such losses were greater on this soil due to denitrification, but further study would be needed to verify this.

Other major elements in the soils and plants

Appendix Table 1 shows the concentration of exchangeable cations in the top and sub-soil of each experimental field in spring, and the uptake of major nutrients by the crops at harvest. The soil

analysis indicates that the clay loams were well supplied with cations, whereas the sandy loams, particularly the sub-soils, contained little.

The analysis for calcium showed comparatively small amounts in the sandy loam but the calcareous loam and the clay loam contained minimal values of 7500 and 6900 mg/kg in top and sub-soils respectively, with very little difference between years or depth of sampling. Potassium and magnesium

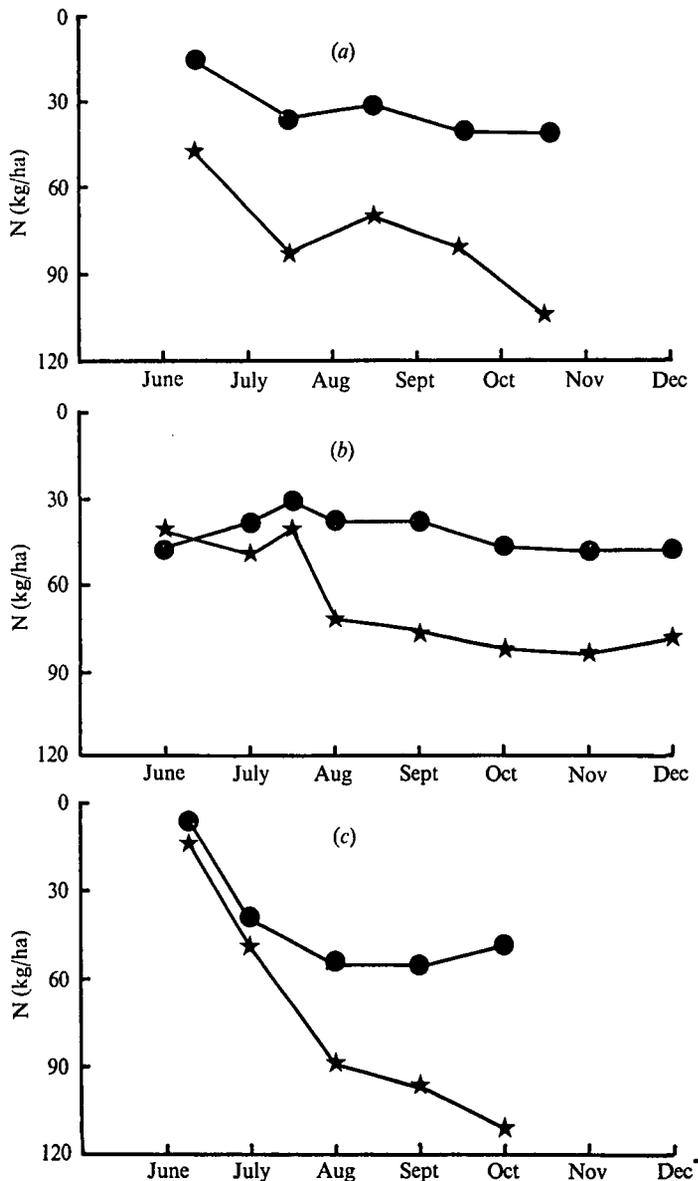


Fig. 2. Amount of applied nitrogen lost (kg/ha) from the three soil profiles, 1968-70. (a) Calcareous loam, Icknield Series; (b) sandy loam, Newport Series; (c) clay loam, Evesham series. ★, 250 kg applied N/ha; ●, 125 kg applied N/ha.

showed the largest relative differences between the sites: the potassium value on the sandy loam was only 65 mg/kg averaged over the 3 years and in 1970 was in the A.D.A.S. Index 0. Potassium values on the calcareous loam were intermediate in value, ranging from 118 to 140 mg/kg, Indices 1 and 2, but analyses of the clay loam showed large amounts of potassium and magnesium to be present, on average about 390 mg/kg for potassium and 260 mg/kg for magnesium in top soils. Generally, the three sites on the sandy loam at Newark were, to some extent, potassium-deficient and low in calcium.

Large uptakes of all nutrients were recorded from fertilized plots on the clay loam at Nottingham, and these plots always contained the most potassium, but the greatest uptake of calcium was from the calcareous loam at Felsted, where even the beet from the unfertilized plots contained more calcium (129 kg/ha) than was present in the fertilized plots on the other two soil types. The large amount of calcium present in the beet from the calcareous loam may be a luxury consumption at the expense of other nutrients, particularly magnesium and phosphorus; beet on the calcareous loam took up only 21 and 16 kg/ha respectively of these elements, whereas at Newark and Nottingham, with about 16% more total dry matter, the uptakes of the two nutrients almost doubled. This needs further investigation, as it may explain why the crop grew slowly on the calcareous loam and was slow to establish.

Fertilized beet grown on the calcareous loam contained an extra 127 kg/ha of calcium when compared with the amount present in crops receiving the same treatment grown on the other soil series, and most of the extra calcium was present in the petioles which contained 98 kg/ha on average, whereas crops from the other two soil types contained, on average, only 24 kg/ha in the petioles. The large calcium uptakes were associated with much lower proportions of sodium and magnesium in the dry matter but potassium uptake was only slightly decreased.

On average, the beet at final harvest from the clay loam contained the greatest amounts of phosphorus, potassium and sodium from all treatments tested and even the crops which received no nitrogen fertilizer on these fertile soils removed similar amounts of these nutrients, as did fertilized crops on the other two soil types.

No pattern was established in the analysis of the dry matter of roots relating any particular nutrient with differing amounts of nitrogen fertilizer, but the percentage of potassium in the dry matter of leaves and petioles tended to decrease with increasing nitrogen fertilizer application throughout the growing season.

Juice purity of the roots was lowest at Nottingham where nutrient uptake was largest, and highest at Newark where at final harvest the roots contained the smallest concentration of potassium, the main impurity factor in molasses production.

CONCLUSIONS

The fresh weight and dry-matter yields from the experiments varied between years and soil types but, on average, the crops grown on clay loam soils of the Evesham Series gave the largest dry-matter yields (12.6 t/ha) and uptakes of nitrogen (131 kg/ha) from unfertilized plots. Equivalent plots from the calcareous loam yielded only 10.8 t/ha and 121 kg/ha respectively. The dry-matter yields of crops grown on heavily fertilized plots on the sandy loam of the Newport Series and on the clay loam were similar and uptakes of nitrogen increased on average throughout the growing season to 238 kg/ha at final harvest. Although senescence and drought caused some decrease in fresh weight of leaves, on average both total fresh and dry weights for all treatments increased throughout the season on all three soil types.

With one exception, 125 kg N/ha increased dry-matter yields of leaves and petioles at all harvests and in the later stages of growth the second increment of nitrogen fertilizer also did not, averaged over the three years, nitrogen did not affect the root dry-matter yield on the calcareous loam at Felsted. The crops on the sandy and clay loams on average gave significant increases in root dry matter in response to only 125 kg N/ha, but no further significant increase from more nitrogen fertilizer.

The results show that an early response in dry-matter yield in the leaves to either dressing of nitrogen fertilizer is a prerequisite for any subsequent substantial response in root dry-matter production. On the sandy loam at Newark in 1969 and 1970, 250 kg N/ha increased root dry matter at final harvest by 0.83 t/ha and 1.16 t/ha respectively, compared with the smaller fertilizer dressing. Although not statistically significant, these effects were the largest obtained in the investigation.

Leaves contained the greatest concentration of nitrogen and roots the smallest at all harvests and both applications of nitrogen fertilizer increased the concentration of nitrogen in the plant dry matter. All concentrations decreased as the plants aged and at final harvest the uptake of nitrogen by crops which had received a dressing of 250 kg/ha ranged from only 227 to 237 kg/ha. The uptake of nitrogen from the unfertilized plots ranged from 87 kg/ha on the sandy loam to 133 kg/ha on the clay loam. With the exception of the early harvests at Felsted, both treatments of nitrogen fertilizer

increased total uptakes of nitrogen significantly on all three soil types.

There was a little leaching during the early part of the season on the sandy loam in 1968 and a considerable loss of nitrogen through leaching on all sites in 1969. When nitrogen fertilizer was leached early in the season, the nitrogen requirement for maximum growth was increased. Amounts of nitrogen unaccounted for by soil and plant analyses in summer and autumn were due either to senescence or denitrification and are the subject of further investigations now in progress.

The concentrations of nitrate-nitrogen in both petiole and leaves were strongly related to nitrogen

dressings in individual trials and a concentration by mid-August of 125 mg nitrate-nitrogen/kg in petioles, or 75 mg nitrate-nitrogen/kg in leaves, was optimal for maximum sugar yield at harvest with all soil types. After 10–11 weeks' growth, a maximum of 600 mg nitrate-nitrogen/kg in petiole tissue ensured maximum yields at final harvest.

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Appendix Table 1. Concentration of exchangeable cations in soil before fertilizer application and uptake by the crop at harvest

	Concentration (mg/kg)							
	Top soil				Sub-soil			
	K	Na	Mg	P	K	Na	Mg	P
Calcareous loam								
1968	140	20	70	22	52	14	45	7
1969	118	11	54	13	30	16	24	6
1970	128	8	56	15	36	10	22	8
Sandy loam								
1968	70	9	70	44	30	9	48	15
1969	68	14	83	26	20	9	33	7
1970	56	8	52	20	42	7	48	8
Clay loam								
1968	526	38	335	37	170	24	215	7
1969	400	23	220	13	140	23	175	7
1970	234	22	220	14	140	22	220	4
	Uptake* (kg/ha)							
	K	Na	Mg	Ca	P			
Calcareous loam	280	44	21	214	16			
Sandy loam	243	39	40	88	28			
Clay loam	361	102	37	84	32			

* Means of years and of plots given 125 and 250 kg N/ha.