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Nitrogen requirement of sugar beet grown on mineral soils

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SUMMARY

The effect of nitrogen fertilizer on the yield of sugar beet was tested in 170 experiments done between 1957 and 1966; results of 88 experiments, some testing five and six amounts of N, have not previously been published.

On most sites, nitrogen increased sugar yields sharply and almost linearly up to an optimum beyond which yield changed little or decreased only slightly up to 1·8 cwt N/acre, the largest amount tested. In the two series of experiments giving most information, the mean increase from sub-optimal amounts of N was 2·5 cwt sugar/0·1 cwt N/acre.

Usually 0·4–0·8 cwt N/acre was enough for maximum yield; more was needed on a few sites and on about a fifth of them nitrogen fertilizer was not needed. In 7 of the 10 years, the average optimum was 0·6–0·8 cwt N/acre; less was needed in the other years, the driest three years of the decade.

In most, though not all, years, site-to-site differences in response between 0·9 and 1·8 cwt N/acre were no greater than could be expected from experimental error alone; much of the apparent difference in response between seasons were also attributable to this source.

After taking account of experimental error, there were substantial between-site differences in response to amounts of N up to 0·9 cwt/acre, but attempts to explain them in terms of weather, soil and husbandry factors had little success. There was slight evidence of diminished responses to N where sugar beet followed crops other than cereals, and of responses somewhat greater than average on Chalky Boulder Clay soils of the Hanslope and Stretham Series; no other relationships were large or consistent enough to be useful for prediction.

As between-site differences in response are largely unpredictable, and because a grower risks much greater crop losses by applying too little N than by applying too much, the recommended dressing is 1·0 cwt N/acre, substantially more than is needed, on the average, to obtain maximum yield. More N should be given on soils of the Hanslope and Stretham Series and on light sands poor in organic matter; less need be applied where crop residues are likely to supply much nitrogen.

INTRODUCTION

The nitrogen requirement of sugar beet grown on mineral soils has been studied in many experiments in Great Britain during the past 30 years. Summarizing the results of 360 experiments done between 1934 and 1949, Boyd, Garner & Haines (1957) concluded that, in each factory area, the mean optimal dressing was 1·0–1·2 cwt N/acre, but was much less than this on fields ploughed up from grass and somewhat less on fields given farmyard manure (FYM). From the results of 41 experiments done in 1957–60, Adams (1962) found the optimum to be 1·0 cwt N/acre where the beet followed two or more cereal crops but only about 0·6 cwt N/acre after other crops, or where FYM was applied; 1·8 cwt N/acre often gave less yield than 1·2 cwt N/acre. From 42 experiments done between 1959 and 1962,

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Table 1. *Experiments testing N for sugar beet*

Series	Years	No. of sites	Amounts tested (cwt N/acre)								No. of replicates	Basal manuring	Previous publication
I	1957–60	52	0*	—	0·60	—	1·20	—	—	1·80	9	†	Adams (1962)‡
II	1959–61	23	0	—	0·60	0·90	1·20	—	1·50	1·80	3	PKNa	—
IIa	1962	11	0	—	0·60	—	1·20	—	—	1·80	5	PKNa	—
III	1959–62	42	0	—	0·60	—	1·20	—	—	—	2	PKNa	Tinker (1965)
IV	1963–4	24	0	0·45	—	0·90	—	1·35	—	1·80	5 (1963) 4 (1964)	PKNa	—
V	1964–6	18	0	—	0·60	—	1·20	—	—	1·80	2	Mean {PK PKNa	—

* Extra plots not in factorial scheme.
† Means of nine factorial combinations of 3P × 3K.
‡ 41 trials only.

Tinker (1965) found 1·0 cwt N/acre to be optimal with K and Na, the optimum being a little less without Na.

In this paper the optimal dressing of N for sugar beet is re-examined in the light of the experiments listed in Table 1, which includes those discussed by Adams and Tinker.

The results of 88 of the 170 experiments (Series II, IV and V, and some sites of Series I) have not previously been published. All were done on commercial farms by staff of the British Sugar Corporation in co-operation with members of Broom's Barn Experimental Station. The experiments were planned and controlled by S. N. Adams before 1961, by P. J. Last in 1961, by P. B. H. Tinker from 1962 to 1965 and by A. P. Draycott from 1965 onwards.

In all experiments the test dressings of N and the basal fertilizers were applied on the seed bed; on almost all sites the crop was drilled at least a week later.

In Series I, N was tested factorially with three amounts of P (0, 0·5 and 1·0 cwt P_2O_5/acre) and three amounts of K (0·8, 1·6 and 2·4 cwt K_2O/acre); one additional plot/block received no N but the mean dressing of P and K. Interactions with P and K proved negligible. Most of the 52 experiments also tested fertilizers with FYM, but we have used the results from blocks without FYM. In addition to results of 41 experiments reported by Adams (1962), less one site on a peaty soil, results are included of 8 experiments in which FYM was not tested and of 4 experiments in which amounts of K were smaller.

In Series II, III and IV, the results reported are for plots given basal P, K and Na. Other treatments, not discussed here, tested top-dressed N (Series II) and amounts of K and Na (Series III). A full discussion of the results of Series III is given by Tinker (1965). Series V tested Na and FYM as well as N, with basal PK. Detailed results will be published by Draycott; those included here are for blocks without FYM and are averages of plots with and without Na.

Choice of sites and conduct of experiments

As only few trials could be made by the staff at each factory in a single year, the trials had to be widely dispersed over the beet-growing areas of the country. The criteria for an initial selection of sites by field staff were that the farm should be well run, so that competent treatment of soil and crop could be expected; that the soil of the field should be of a kind widespread in the factory area, and of importance for sugar beet there (in practice, 'soil' often meant texture in this context); that the field should be uniform and have a known cropping history for the previous 3 or 4 years. These sites were then visited by staff from Broom's Barn Experimental Station (Dunholme before 1962) who made the final selection, using auger borings and soil analyses. In Series IV, incubation methods were used in an attempt to select sites with unusual response characteristics. All soils were later described by members of the Soil Survey of England and Wales, though many of the soils proved to be in unnamed series. If a particular series was of special importance in a factory area, experiments were sited on it repeatedly. The selected soils are thought to represent reasonably well those mineral soils used for sugar beet in Great Britain, but there may have been a tendency to select fields of medium soil texture and to reject extremes.

The general methods used in the field were described by Adams (1962) and the beet analyses by Tinker (1965). The few experiments in which serious mistakes in layout, cultural practices or harvesting were found were discarded in whole or part. The fertilizer was distributed by hand. Careless application of nitrogen fertilizer will show up clearly as crop unevenness, and this was very rarely seen.

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The proportion of the trials harvested by machine increased with time, and reached about one half at the end of the period. Fewer of the very small beets will be harvested by machine than by hand and these occur mainly on plots without N; Willey (1964) found losses of almost 10% from mechanical harvesting.

The average S.E./plot was 4·2 cwt sugar/acre or about 8% of the mean yield of 52 cwt sugar/acre; the percentage error is intermediate between that of cereals and that of potatoes.

Table 2 compares the national estimates of the total sugar yield/acre of crop (by courtesy of the British Sugar Corporation) with the annual means from the experiments. The 10-year average for the national crop resembled the average experimental yield without N. On plots with N, yields were 26% more than the national average in the first 5 years, and 17% more in the last 5 years, suggesting that the experiments have become more representative of commercial crops. Plot yields are usually 10–20% greater than the average commercial crop. In part this is because field yields usually include headlands and other uncropped areas, but perhaps mainly because only well-managed farms tend to be selected and because the few experiments that suffer large losses from flood, drought, poor germination, pest and disease attack, etc. are likely to be abandoned without yields being taken. These considerations must also affect comparisons of the responses to N both on experiments and on commercial farms, though to a less extent than of mean yields. However, the amount of the optimal dressing should be almost unaffected.

Mean responses to nitrogen

Table 3 shows the average effects of N fertilizer in each series.

In all five series the mean response to 0·6 cwt N/acre was between 7 and 10 cwt sugar/acre, but the

Table 2. *Mean British sugar yields, mean yield of experiments and response to N* (1957–66).

Cwt sugar/acre.

			Mean yields of experiments		Response to N (cwt/acre)		
Year	Total crop	No. of sites†	Without N	With N	0·6–0·0	1·2–0·6	1·8–1·2
1957	34·2	15	40·6	42·5	2·6	−0·5	−1·1
1958	41·9	15	40·8	50·2	8·8	1·8	−1·8
1959	45·3	24	54·0	59·0	5·0	0·2	−0·3 (16)
1960	51·9	28	51·7	63·0	10·4	1·8	−1·0 (20)
1961	44·6	22	47·0	59·1	11·4	1·7	−1·2 (9)
1962	40·8*	24	40·5	50·0	9·2	1·2	−1·6 (11)
1963	42·9	15	39·0	52·0	11·4	2·3	0·3
1964	51·5	13	49·2	57·6	9·2	−1·1	−0·1
1965	47·7	7	44·4	53·7	9·0	1·1	−1·4
1966	47·7	7	44·7	56·6	9·4	3·6	0·2
1957–61	43·6	104	46·8	54·8	7·6	1·0	−1·1
1962–6	46·1	66	43·6	54·0	9·6	1·5	−0·5
1957–66	44·8	170	45·2	54·4	8·6	1·3	−0·8

* Severe frost prevented delivery of whole crop.

Note: total crop yield by courtesy of British Sugar Corporation.

† For the years 1959–62 the numbers of sites giving information on the response (1·8–1·2) cwt N/acre are given in brackets.

Table 3. *Effect of different amounts of N on sugar yield* (*cwt sugar/acre*)

			Cwt N/acre								
Series	Years	No. of sites	0·0	0·45	0·60	0·90	1·20	1·35	1·50	1·80	Pooled S.E.
I	1957–60	52	44·8	—	51·9	—	52·2	—	—	50·9	0·19*
II	1959–61	23	52·3	—	61·7	63·3	63·3	—	63·2	62·9	0·53
IIa	1962	11	39·5	—	48·7	—	49·1	—	—	47·5	0·47
III	1959–62	42	48·0	—	56·7	—	58·6	—	—	—	0·36
IV	1963–4	24	44·2	53·3	—	56·2	—	55·8	—	56·0	0·35
V	1964–6	18	43·8	—	52·9	—	54·4	—	—	54·0	0·50

* Not applicable to yield without N.

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Table 4. *Effect of N on sugar content and juice purity*

Series	Years	No. of sites	cwt N/acre 0·0	0·6	1·2	1·8
			% sugar			
I	1957–60	41	—	16·5	16·1	15·6
II, II*a*	1959–62	34	17·1	17·0	16·5	16·0
IV	1963, 1964	24	18·8	18·8	18·4	17·8
V	1964, 1965	11	17·9	17·9	17·3	16·4
All	—	110	(17·3)	17·3	16·8	16·3
			Juice purity			
I	1960	9	—	92·9	92·6	92·3
II, II*a*	1960–2	29	94·2	94·1	93·4	92·9
IV	1963, 1964	24	95·7	95·4	94·8	94·0
V	1964, 1965	11	95·2	94·9	94·4	93·3
All	—	73	(94·7)	94·5	93·9	93·2

Note: values interpolated where necessary.

response from 0·6 to 1·2 cwt N/acre was much less. No series showed any yield increase from more than 1·2 cwt N/acre and most showed a small decrease. For each amount of N, Series I gave less than the average response.

Growers are paid slightly less for beet of smaller sugar content Small dressings of N may decrease sugar percentage slightly, and this effect increases with increasing dressings (Table 4); except for Series I there was no mean percentage less than 16·0. The value of a given sugar yield after factory processing depends on the juice purity (percentage of sugar to total dissolved solids in beet juice after clarification), which, as Table 4 shows, was also decreased by nitrogen.

The fertilizer/yield relationship

To determine the form of the fertilizer/yield relationship, at least five, and preferably more, well-chosen amounts must be tested and the treatments must be replicated, to ensure that the yield estimates are reasonably accurate and to indicate the experimental errors and whether they differ with treatment. Accuracy is needed so that the relationship can be examined for individual trials, or for small groups of trials showing similar responses.

Whatever the form of the response curve, averages of many experiments in which optimal dressings differ, as in Table 3, will tend to lie on a smooth curve. Thus a quadratic fitted to the annual mean yields of Series II (excluding 1959) and Series IV accounted for, respectively, 95, 99, 98 and 78 % of their variance, and a cubic accounted for more than 99·9 % of the variance in 3 years and for 98·4 % in the fourth. However, the success of these and similar curves in describing average yields does not mean that they truly reflect underlying physiological relationships.

Until now, Series I (Adams, 1961) has provided the only published information on the effect of four amounts of N on yield of total sugar; from this Boyd (1961) concluded that the response curve might be a parabola. The results of experiments with more than four amounts of N—Series II tested six and Series IV five—show this conclusion is wrong. Examination of the results of individual sites of these two series showed that the general form of the relationship of fertilizer N to sugar yield has a linear or slightly curved rising portion for small and moderate amounts of N, with a fairly sharp transition to an almost linear and nearly horizontal portion for larger dressings. The individual results for each year (except 1959, when all sites gave similar responses) were grouped according to the amount of their response. Figures 1 and 2 give the mean yields of each group, the groups being identified by year and by letter within years; the number of sites is given in brackets.

For each group either all the yields lie on or near a straight line, as for 1959 and 1960A, or can be satisfactorily represented by two straight lines. The linearity of the fertilizer/yield relationship beyond the transition is well-established; where, as in 1959, 1960A and B, 1961A, 1963A and B and 1964A, four or more yields seem to lie on the same straight line, deviations from this line did not exceed what would be expected from experimental error alone. Nor, for these experiments, did the slopes of the lines representing responses to larger dressings differ materially, though, as shown below, there is evidence of small but real seasonal differences between the amount of gain or loss in yield when results of all ten seasons are taken into account.

Because the experiments give so much information on this part of the fertilizer/yield relationship, they leave the form of response to small N dressings

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in doubt. For most of the groups of Figs. 1 and 2 this response could equally well be represented by a curve or by a straight line; evidence against a curved relationship comes from the two groups of very responsive sites, 1961B and 1963D; their responses up to 0·90 cwt N/acre were linear. In Fig. 1 the increment/unit N for 1960B and 1961A could well be greater than that shown; for 1963A and B and 1964A in Fig. 2 the form of response to amounts less than 0·60 cwt N/acre is unknown and they have been arbitrarily given the same average slope (shown by dashed lines) as 1963C and D and 1964B. Only those for 1961B, 1963C and 1963D are well-determined; these gave a mean increment of 12·8 cwt sugar from the first 0·50 cwt N/acre.

Seasonal differences in response

All series gave information on yields at 0·0, 0·6, 1·2 and 1·8 cwt N/acre, except Series III in which the 1·8 cwt N/acre was not given, and Series IV for which values for 0·6 and 1·2 cwt N/acre were obtained by interpolation. Table 2 shows that there was some increase in yield from amounts greater than 0·6 cwt N/acre except in 1957 and 1964; it may be relevant that in most of Eastern England these years and 1959, when there was little response, were the driest 3 years of the decade. Except in 1957 and 1959, mean responses to the first dressing of 0·6 cwt N/acre were large and consistent, (mean 9·7, range 8·8–11·4 cwt sugar/acre); however, because both unresponsive and responsive sites were included, mean annual yield increases from 0·5 cwt N/acre were only one-half to two-thirds of those quoted in the previous section.

The poor yield and small N responses in 1957 were associated with a widespread outbreak of virus yellows on the experiments and on commercial crops. Adams (1961) found between-site differences in response to dressings greater than 0·6 cwt N/acre to be unrelated to yellows incidence; however, of the 15 sites, seven with fewer than 20 % infected plants had a mean response to 0·6 cwt N/acre of 5·0 cwt sugar/acre, whereas, with more than 20 %, response was 0·4 cwt sugar/acre. The exceptionally mild winter and early spring of 1957 may not only have influenced aphid numbers, as shown by Watson (1966), but also made the crop less dependent on fertilizer N, by encouraging early mineralization of soil organic matter.

Seasonal differences in response to larger amounts of N were small. Increasing N dressings from 1·2 to 1·8 cwt N/acre decreased average yields by 0·8 cwt sugar/acre, with a range from a decrease of 1·8 cwt in 1958 to an increase of 0·3 cwt in 1963. About half the variation in response between seasons was attributable to experimental errors. The response to each amount of N was greater in the second than in the first 5 years of the decade; this may be a real trend in response, as the mean response to 0·8 cwt N/acre during the period 1934–47 was only 4·2 cwt/acre (Boyd *et al.* 1957), less than half the average for 1957–66.

Differences in response between sites

In previous papers attention was drawn to the variability of N response from site to site, but attempts to explain these differences had little success. However, not all the apparent differences in response from site to site come from real differences in crop requirements on different fields and farms; responses also differ because of experimental error, which often accounts for much of, and sometimes all, the between-site variation in response.

In ascertaining whether there were real 'between-site' differences in the response of sugar beet to nitrogen, the two portions of the response curve, represented by amounts of N greater and less than 0·9 cwt/acre, are considered separately.

Responses to more than 0·9 *cwt N/acre*

Most information on responses from 0·9 cwt N/acre is given by Series II, testing four amounts of N, and by Series IV, testing three amounts. The average S.E. of a response (averaging over replicates) was 3·4 cwt sugar/acre for Series II and 2·4 cwt sugar/acre for Series IV; thus, even if crops on all sites responded similarly, large apparent differences from the mean response (some in a positive and some in a negative direction) would occur by chance. Without any real effect of the treatments, a difference of three times the S.E. of a treatment mean should occur by chance in about 5 % of trials. For Series II, with 23 experiments and six possible pairs of responses the expected number of 'significant' responses is $23 \times 6 \times 0{\cdot}05 = 6{\cdot}9$; the actual number was seven. Similarly in Series IV, with 24 trials and three possible pairs, the expected number is $24 \times 3 \times 0{\cdot}05 = 3{\cdot}6$; the actual number was five. Thus in the population of farms of which these sites are a sample, real differences in response to amounts of N greater than 0·9 cwt N/acre must be rare.

When there are few experiments, such tests are not very sensitive and the same question may be approached in a somewhat different way by comparing the 'between-site' variance of the responses with the 'within-site' variance, i.e. the experimental error variance. For Series II the average values of the two variances were almost the same (Table 5), but for Series IV the 'between-site' variance somewhat, though not significantly, exceeded the experimental error variance. Thus after allowing for experimental error, the 'between-site' variance/treatment in Series II was negligible; the corresponding value for Series IV was larger, but

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still of little economic significance, despite the deliberate attempt, noted above, to select sites of contrasted mineralizable-N values.

A similar calculation for the response (1·8–1·2) cwt N/acre of Series I showed that experimental errors could account for all the between-site differences between responses in three of the four seasons, but in 1958 the experimental error variance was only about one-fifth of the between-site variance. On one site, on Hanslope Series in East Suffolk, yields increased from only 15 cwt sugar/acre without N to 43 cwt/acre with 1·8 cwt N/acre, and the increase from 1·2 to 1·8 cwt N/acre was 8·9 cwt sugar/acre; by contrast, on two sites in Norfolk there were decreases of 7·5 and 6·9 cwt sugar/acre. All three fields were in an arable rotation and the site details do not suggest any reason for the differences in response.

Responses up to 0·9 cwt N/acre

Turning to the effects of amounts of N from 0·0 to 0·9 cwt N/acre, Table 5 shows that, on the average, experimental error accounted for only about one-quarter of the between-site variation in response, indicating that there were real differences from place to place in response to these smaller amounts of N. Indeed, as Figs. 1 and 2 show, on some sites N was quite ineffective, whereas on others there was a linear response up to 0·9 cwt N/acre.

Accounting for between-site differences in response

For many crops, differences in previous cropping have been found to influence nitrogen requirements and in experiments specially designed to test this factor with sugar beet, differences between leys and arable cropping influenced N response (Hull & Webb, 1967; Boyd, 1968). Between-site comparisons for Series I (Adams, 1961) seemed to show that more N was needed for beet in a cereal rotation, but Tinker (1965) did not confirm this from the results of Series III.

In general, the five series of experiments give little information on the effect of previous cropping on N response, as almost 90% of the crops followed a cereal. Potatoes were the next most common crop to precede sugar beet (9 sites); average responses to each amount of N were somewhat less than the general average (Table 6).

There is evidence that crops need more N when grown on heavy and poorly-drained clay soils where root range is restricted, and in an earlier series of experiments, Boyd *et al.* (1957) found that crops on heavy-textured soils derived from the Chalky Boulder Clay in Essex and Suffolk gave unusually large responses to N. In the present series the average response on these soils on 25 sites differed only slightly from the general average (Table 7). There was slight evidence of greater N responses of sites on the Hanslope and Stretham Series, especially

Table 5. *Between-site variance of responses and pooled experimental error variances*

Variances/plot (cwt sugar/acre)^2.

		Series II				Series IV		
Year		1959	1960	1961	Mean	1963	1964	Mean
				Responses 0·0–0·9 cwt N/acre				
Between sites	D.F.	8	16	16	40	28	16	44
	variance	27·5	80·8	94·7	75·7	117·3	48·0	92·1
Within sites		18·2	14·8	25·4	19·7	30·4	15·8	25·1
				Responses 0·9–1·8 cwt N/acre				
Between sites	D.F.	12	24	24	60	28	16	44
	variance	23·0	16·2	19·9	19·0	16·0	24·0	18·9
Within sites		19·1	20·9	17·4	19·1	10·8	17·1	13·1

Table 6. *Effect of previous cropping on mean yield and responses*

Cwt sugar/acre.

	Mean yield without N	Responses to N fertilizer (cwt N/acre)		
		0·6–0·0	1·2–0·6	1·8–1·2
After potatoes (9)	49·3	7·0	−1·6	−1·9
All sites 1957–66	45·2	8·6	1·2	−0·8

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Table 7. *Mean yields and responses on Chalky Boulder Clay Soils*

Cwt sugar/acre.

	Mean yield without N	Responses to N fertilizer (cwt N/acre)		
		0·6–0·0	1·2–0·6	1·8–1·2
Hanslope series (9)	45·5	11·5	3·1	0·8
Stretham series (6)	42·2	10·1	3·4	2·2
Ashley series (9)	48·3	8·9	1·7	−2·2
All chalky boulder clay (25)	45·1	9·8	2·6	0·0
All sites 1957–66	45·2	8·6	1·2	−0·8

Table 8. *Mean yields of Woburn Ley-Arable Experiment*, 1965–7

Cwt sugar/acre.

cwt N/acre	0·35	0·70	1·05	1·40	1·75	2·10	
After ley	63·9	68·4	68·0	68·6	—	—	±0·97
After arable	—	(60·2)	65·8	67·6	66·3	(68·1)	

Table 9. *Comparison of results of magnesium experiments with estimated yields and responses of Series II and IV*, 1961–3

Cwt sugar/acre.

	Mean yield with 0·5 cwt N/acre	Responses to N fertilizer (cwt N/acre)	
		1·0–0·5	1·5–1·0
Magnesium experiments (14)	45·9	3·7	1·1
Series II and IV, 1961–3 (35)	51·0	3·8	−0·7

to dressings of more than 0·6 cwt N/acre; however, for the Hanslope Series the larger response was largely attributable to the one very responsive centre mentioned in the previous section. Results for the sandier and non-calcareous Ashley Series did not differ materially from the general average.

Experience with other crops suggests that more fertilizer N is needed on sandy soils poor in organic matter. Three groups of sites on sands, loamy sands and sandy loams were examined: those in the East and West Midlands (Allscott, Kidderminster, Nottingham and Newark factory areas), mainly on Newport and Bridgnorth Series; postglacial sands of the Vale of York (York and Selby factory areas) including Naburn and Kexby Series; and, in East Anglia, sites on the Freckenham, Moulton, Worlington and Euston Series (Bury St Edmunds, Cantley, King's Lynn and Wissington factory areas). The mean yields without N and the mean responses to each amount of N scarcely differed from the general mean. No other grouping of the sites by soil series or texture showed any important differences from the general mean response.

Two other sources give information on the N requirement of sugar beet grown on sandy soils. In the years 1965–7 the Woburn Ley Arable Experiment, conducted on a fine sandy loam having only about 1% organic matter in the topsoil, tested amounts of N for sugar beet grown in contrasted rotations, ley and arable, with and without FYM (Boyd, 1968). After ley, 0·7 cwt N/acre was sufficient for maximum yield, whereas rather more than 1·0 cwt N/acre seems to have been needed after arable crops (Table 8).

Tinker (1967) gives the results of 14 experiments testing magnesium, and N, K and Na, on very light-textured soils. Table 9 shows that, compared with experiments of Series II–IV in the same years, the mean responses up to 1·0 cwt N/acre were similar; from 1·0 to 1·5 cwt N/acre the magnesium experiments gave a slightly larger average response, though the extra yield was only enough to pay for the extra fertilizer given. In these experiments, N effects are complicated by possible negative interactions between nitrogen and magnesium fertilizers (Tinker, 1967); also beet on these soils may suffer from Docking disorder (Dunning & Cooke, 1967), which may affect nitrogen response.

The efficiency with which N fertilizer is used by the crop can be affected by the application of sodium (Na). From Series III, Tinker (1965) found that the average response (1·2 − 0·6 cwt N/acre) was some-

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what increased when Na was also given. Information is also obtainable from Series V in which four amounts of N were tested with and without Na; these results will be reported more fully by Draycott (in the Press).

On 14 of the 18 sites there was little or no response to more than 0·6 cwt N/acre; with N, about the same mean yield was obtained on these sites whether or not Na was given. On the other four sites, all on loamy sands or sandy loams, the crops continued to respond up to 1·2 cwt N/acre and there were substantial effects of Na:

	cwt N/acre				
	0·0	0·6	1·2	1·8	Pooled
	cwt sugar/acre				S.E.
No Na	38·0	41·5	47·0	52·3	1·70
With Na	35·0	46·5	55·4	51·3	

With Na, responses followed much the same pattern as that shown for responsive sites in Figs. 1 and 2. Without Na, response to N continued up to the largest amount tested but the increase per 0·50 cwt N/acre was only 3·8 cwt sugar without Na compared with 9·5 cwt sugar with Na; thus the crop seems to have used N fertilizer much less efficiently when Na was limiting.

In a further attempt to explain the variation in response to small and moderate amounts of N, six independent variates were included in a multiple regression with the responses (0·6–0·0) cwt N/acre and (1·2–0·6) cwt N/acre as dependent variates. The independent variates were: % infection with virus yellows; soil N %; sowing date; growing period; summer rainfall (April–September); winter rainfall (November–March). The responses were deviations from seasonal averages; Series V was excluded from the investigation. The combined regression on all six variates never accounted for any significant part of the variation in response.

Simple correlations of each variate with the two response variates were also examined. Of the 48 values only two and five reached significance at the 5 and 10% points respectively, no more than could be expected to occur by chance. Taking the four series together, the most consistent values of r were those for growing period and response (0·6 – 0·0) cwt N/acre; however, Holmes & Adams (1966) found no evidence that harvest or sowing date affected response to compound fertilizers.

The slight correlation of N response with winter rainfall is of interest in view of the much closer relationship (r = 0·71) found for the period 1933–51 by Boyd *et al.* (1957).

With Last & Tinker (1968), we have found no simple means of predicting the nitrogen requirement of a beet crop. Indeed, had there been a simple explanation for differences in response from site to site and year to year, it would probably have been noticed long ago by farmers and advisers.

Current manurial practice

Surveys of fertilizer practice show that many growers apply much more N fertilizer than they need. The average dressing (cwt N/acre) was 1·07 in 1957,

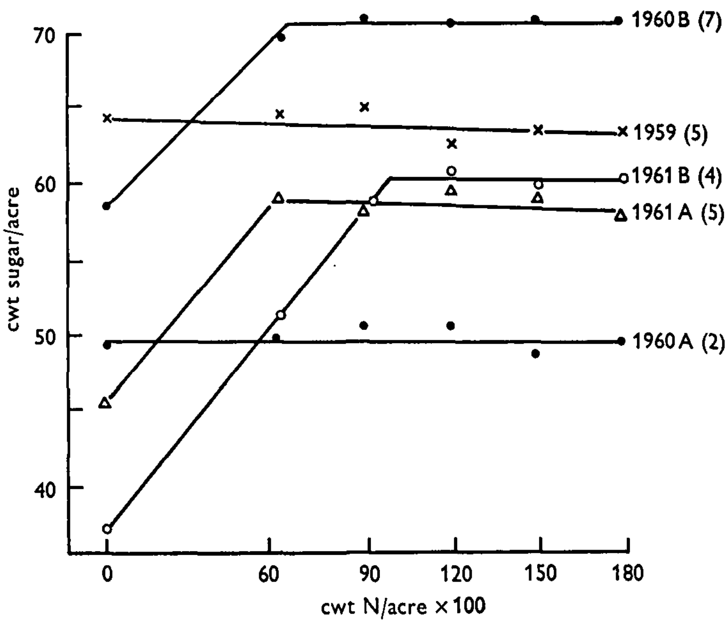

Fig. 1. Effect of N on sugar yield (cwt/acre)—Series II. For explanation see text.

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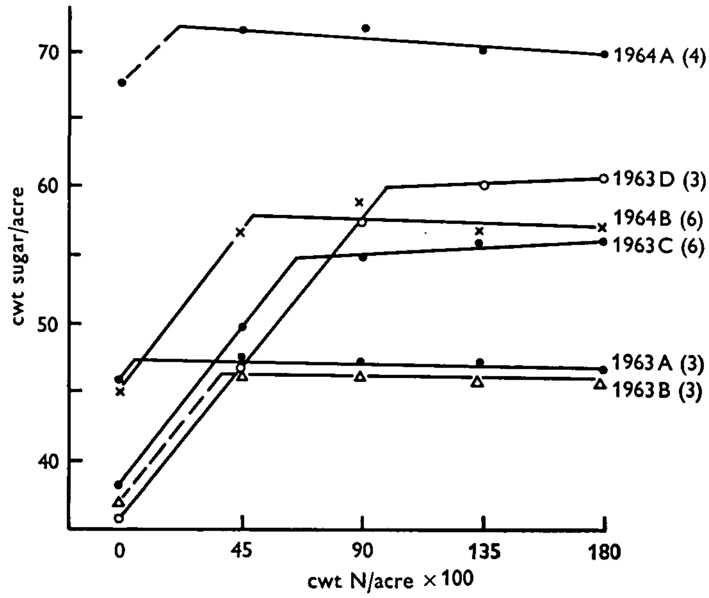

Fig. 2. Effect of N on sugar yield (cwt/acre)—Series IV. For explanation see text.

1·23 in 1962 and 1·28 in 1966. These figures do not include N in farmyard manure, used on about one-fifth of the sugar beet acreage in 1966. For districts with mineral soils the range of average dressings in 1966 was from 1·12 cwt N/acre on the silt soils of Holland (Lincolnshire) to 1·49 cwt N/acre in N.W. Norfolk; less nitrogen was used on fen peat soils. (Batey *et al.* 1967).

In all districts, the amounts given on different farms differ considerably. In England and Wales as a whole, about one-quarter of those farming on mineral soils used more than 1·5 cwt N/acre and one-quarter used less than 1·0 cwt N/acre.

Optimal N dressings

On the average of all sites the transition from the steeply rising portion of the response curve to the almost horizontal portion occurred at 0·6–0·8 cwt N/acre. For several reasons the recommended optimum should be greater than this: in particular, losses from applying too little fertilizer are much greater than those from applying too much; also, the form of the response curve in the transition portion is unknown. Although, as we have shown, crop requirements are likely to differ relatively little from year to year and from place to place, it would be prudent to insure against the exceptional season or field. Also, some allowance should be made for the inevitable unevenness of fertilizer distribution. We therefore recommend a dressing of 1·0 cwt N/acre for sugar beet grown after one or more cereal crops on mineral soils.

Although the results in our paper confirm much previous work, they call for some change in current thinking on the form of the response curve and hence on what loss growers can expect by giving dressings greater or less than the optimum. The penalty from over-manuring is small; on the average, dressings greater than the optimum decreased yield by only 0·12 cwt of sugar, worth less than £0·25/acre, per 0·1 cwt N/acre; the cost of this dressing (equivalent to one-fifth cwt sugar) was about £0·45/acre at 1968 subsidized prices, giving a total loss of about £0·7 per 0·1 cwt N/acre. Seasonal differences in the amount of loss are likely to be small.

There is only slight evidence that sugar beet grown on the heavier Chalky Boulder Clay soils (Hanslope and Stretham Series), and on sands and loamy sands poor in organic matter in Eastern England, requires more N, but because overmanuring costs little, growers on these soils should apply about 0·25 cwt N/acre more than the general average; crop increases from applying more than this are unlikely to be profitable.

By contrast, substantial losses of crop can be expected from undermanuring. An average dressing of 0·5 cwt N/acre would have been sufficient in three of the ten seasons, but in each of the other seven seasons would have given several cwt sugar/acre less than the optimum; as there are also between-site differences to be taken into account, the losses of an individual grower giving this amount could have been even larger.

There was some evidence that after potatoes (and

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probably therefore after other heavily-manured crops, and after crops that enrich the soil in nitrogen) rather less than the recommended amount of N was needed. However, as nitrogen responses are rather unpredictable, and losses from underestimating N requirements could far outweigh possible savings from using less fertilizer, it would be unwise to decrease the dressing by more than 0·20 cwt N/acre.

In addition to the published summaries included in the references, detailed results, including site characteristics, were tabulated in annual reports and their appendices presented to the Sugar Beet Research and Education Committee; in order from 1957 to 1966, these are Committee Papers nos. 489, 528, 569, 626, 673, 730, 788, 847, 905 and 945. The reports are unpublished but may be consulted on application to Dr R. Hull, Head of Broom's Barn Experimental Station, Higham, Bury St Edmunds, Suffolk.

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