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Comparisons of liquid and solid fertilizers and anhydrous ammonia for sugar beet

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SUMMARY

Six field experiments (1963–8) in eastern England compared solid fertilizer with liquid fertilizer or anhydrous ammonia for sugar beet. Two glasshouse experiments investigated the interaction between depth of placement of fertilizer and soil moisture.

Yields of sugar were the same from broadcast solid and sprayed liquid in all the experiments, but nitrogen uptake by the crop was less from liquid than from solid. Three experiments tested placement of liquid 4 in to the side and either 2 or 6 in below the seed. Plants with deep-placed fertilizer consistently out-yielded those with shallow-placed fertilizer, but yields were never significantly different from broadcast solid fertilizer. Dry-matter yields of sugar beet grown in containers indoors showed that the crop responded to deep placement when the surface soil was watered infrequently.

With anhydrous ammonia injected during seed-bed preparation, sugar yield and nitrogen uptake were the same as with solid fertilizer in the seed bed, and were greater than with anhydrous ammonia injected in the ploughed land during early spring. A side-band injection of anhydrous ammonia before singling gave a crop containing as much nitrogen at harvest as, but less sugar than, nitrogen applied in the seed bed.

INTRODUCTION

Most British sugar-beet crops receive dressings of the three major nutrients, N, P and K. Conventionally these are applied as a granular compound fertilizer broadcast on the soil at some stage during seed-bed preparation, although P and K are sometimes applied during the previous autumn (Adams, 1961). Recent advances in technology offer alternatives to solid fertilizers; N P K compounds are obtainable as concentrated aqueous solutions ('liquid' fertilizers) and N can be bought cheaply as anhydrous ammonia.

Liquid fertilizer can be sprayed on the soil surface or injected into the soil through tines. Fertilizer can be injected accurately in a band at the required distance from and depth below the seed or young plant. Experiments with potatoes (Holliday & Draycott, 1968) showed some yield advantage in dry seasons from placing fertilizers deeply. The question arises whether similar placement would increase sugar-beet yields.

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Early sowing is important to achieve maximum yield of sugar (Hull & Webb, 1967) and as the usual methods of applying fertilizers may delay sowing, other methods would have advantages provided yields were not decreased. Nitrogen applied as ammonium forms is not lost by leaching and cold soil slows nitrification (Sabey *et al.* 1956). Thus nitrogen applied as aqueous or anhydrous ammonia early in the spring may not be lost very readily (Sohn & Peech, 1958).

Fertilizer injection therefore offers several possibilities for sugar beet. Complete liquid fertilizer could be applied to the plough furrow very early in the spring or, with suitable equipment, when drilling the seed. With split applications, P and K could be applied during autumn or winter and the nitrogen as aqueous or anhydrous ammonia, early in the spring, at sowing or after the young plants have emerged.

The above considerations led to the two groups of experiments reported in this paper. The first group, at the Leeds University Farm, included experiments in both glasshouse and field, and mainly investigated depth of fertilizer placement.

The second, at Broom's Barn Experimental Station, tested placement of and timing of nitrogen dressings, and compared anhydrous ammonia with other forms of fertilizer nitrogen.

EXPERIMENTAL

Field experiments

Locations and soils

The 1963–5 experiments were on the Leeds University Farm near Tadcaster in the West Riding of Yorkshire. In 1963 the experiment was on the Wothersome Series, a heavy loam overlying sandy clay loam; in 1964 and 1965 experiments were on the Barkston Series, a medium loam over magnesium limestone. The parent material of both soils is boulder clay derived mainly from Permian sediments.

The 1966–8 experiments were at Broom's Barn Experimental Station, near Bury St Edmunds in West Suffolk, in 1966 on Stretham Series (a clay loam over chalky boulder clay) and in 1967 and 1968 mainly on the Moulton Series (a sandy loam over sand and chalk). The parent material of both soils is calcareous drift of variable depth.

Treatments and design

1963–5. Three methods of applying compound (N:P:K) fertilizer were tested: (1) solid broadcast by hand on the cultivated soil before seed-bed preparation; (2) liquid injected 4 in to the side and 2 in below the level of the seed (shallow placement); (3) liquid injected 4 in to the side and 6 in below the level of the seed (deep placement).

In 1963 the liquid was injected when the rows of seedlings were just visible; in 1964 and 1965 simultaneously with sowing. All three methods were tested at about 1·00 and 2·00 cwt/acre N in the compound (the exact amounts, averaged over the 3 years, were 1·04 and 2·13 cwt/acre N); the composition of the compound is given below. Plots without fertilizer were also included. There were four randomized blocks of the treatments in 1963 and 1964 and six blocks in 1965.

1966–8. Six methods of applying nitrogen fertilizer were tested: (1) solid broadcast by hand on the cultivated soil before seed-bed preparation; (2) anhydrous ammonia injected early in spring on the ploughed soil (average date—5 March); (3) anhydrous ammonia injected in the cultivated soil before seed-bed preparation; (4) anhydrous ammonia injected as a side-dressing before singling the plants (28 May); (5) liquid (24 % N) sprayed on the cultivated soil before seed-bed preparation; (6) liquid compound (N:P:K) sprayed on the cultivated soil before seed-bed preparation.

All the preseed-bed preparation treatments were applied at the beginning of April. The ammonia was always injected 6 in deep. All six methods were tested at one rate only (1·00 cwt/acre N) and there were four randomized blocks in each year. A basal dressing of agricultural salt or kainit and 5 cwt/acre of a 0:20:20 compound was applied to all plots except that the 0:20:20 compound was omitted where the liquid compound was used. (Fertilizer analyses are given in abbreviated form, thus 0:20:20 implies a fertilizer containing no N, 20 % P_2O_5, 20 % K_2O.)

In all the experiments (1963–8) tractor-mounted machinery was used; it was calibrated to apply the required amounts of liquid fertilizers and anhydrous ammonia by weight. Errors in the amounts applied did not exceed ± 5 %.

Composition of the fertilizers tested

In the first group of experiments the solid was a compound granular fertilizer composed of ammonium sulphate, single superphosphate and muriate of potash. The liquid was a compound composed of urea, diammonium phosphate and muriate of potash. In 1963 the nutrient ratio was 7:3:10 (%N:%P_2O_5:%K_2O); in 1964 and 1965 all the plots received 5 cwt/acre agricultural salt and the nutrient ratio used was 2:1:1.

In the second group the solid was 'Nitro-chalk' (21 % N); the anhydrous ammonia contained 82 % N and the nitrogen liquid spray was a mixture of equal parts by weight of urea and ammonium nitrate and contained 24 % N. The liquid compound was made from the same constituents as in the first group of experiments.

Varieties, plot size and harvesting

The variety of sugar beet was Sharpe's Klein E, except in 1963 when it was Hilleshog N. The rubbed and graded seed was precision-sown and hand-singled to a final population of about 30 000/acre.

The plots in 1963–5 were 0·01 acre, of which 0·0056 was harvested; in 1966–8, 0·012 acre, of which 0·0052 was harvested. In 1963 and 1964 harvesting was by machine and in 1965–8 by hand. The roots were counted into sacks and the tops weighed in the field. Roots were analysed for percentage sugar and juice purity, and samples of both tops and roots were dried.

Glasshouse experiments

Plant containers

Two experiments with sugar beet were made in an unheated glasshouse, one in each of the years 1963 and 1964. The plant containers were steel cylinders 3 ft tall by 10 in diameter and open at both ends. The containers stood in troughs of water

3 in deep; sand was packed into the containers 2 ft deep and watered to field capacity. Two layers of soil each about 4 in deep were added above the sand and separated by a disk of wax 1·5 mm thick. The disks, made from a molten mixture of paraffin wax and petroleum jelly (1:1 by weight), prevented water and nutrients moving between layers but roots grew through it easily. Similar techniques were described by Crist & Weaver (1924), Hendrickson & Veihmeyer (1931), Taylor & Gardner (1960) and Stone & Mulkey (1961). Sugar-beet seeds were planted in the surface soil in spring and by early autumn the roots were comparable in size and shape to roots grown in the field. The wax disk did not restrict the roots.

Treatments and design

Solid fertilizer of the same composition as that used in the field experiments was tested and at the same amount of N (cwt/acre) 1·00 or 2·00 (0·64 or 1·28 N gm/container) in the upper layer; 1·00 or 2·00 in the lower layer; no fertilizer in either layer. These five fertilizer treatments were in factorial combination with two watering treatments, which were started when the sugar beet were established. There were four replicates. The upper soil layer was either given small amounts of water often (about every other day, depending on weather) or large amounts at longer intervals (about every 10 days), but all received the same total quantity. The lower soil layer and the sand in all the containers were kept uniformly moist by adding water to the troughs regularly.

RESULTS

Field experiments

1963–5. Table 1 shows the yield of roots in the first three experiments was increased by all three methods of application. The broadcast solid and the shallow liquid injection gave similar yields with each amount of fertilizer. Liquid injected deeply gave slightly more yield than liquid injected shallowly with the smaller dressing and increased yield further with the larger. These small increases in yield from deep placement were consistent but not statistically significant.

All the fertilizers increased yield of sugar beet tops, and the larger dressing gave significantly more than the smaller. Deep injection gave the largest yield but not significantly more than either of the other methods of application. Percentage sugar in the roots was decreased significantly by fertilizer but the effect was independent of the application method, consequently the yields of sugar from the three methods paralleled the yields of roots—shallow placement gave the smallest yield and deep placement the largest, but the difference was not statistically significant. Fertilizer decreased juice

Table 1. *Average effects of methods and rates of application on yield of roots, tops and sugar, sugar content and juice purity*

	Yield of roots 1963–5 (ton/acre)				Yield of tops 1963–5 (ton/acre)				Sugar 1963–4 (%)				Yield of sugar 1963–4 (cwt/acre)				Juice purity 1963–4 (%)			
Rate (cwt/acre N in compound) ...	0	1·00	2·00	Mean	0	1·00	2·00	Mean	0	1·00	2·00	Mean	0	1·00	2·00	Mean	0	1·00	2·00	Mean
Solid broadcast	12·4	14·4	14·4	13·7	10·6	14·2	15·8	13·5	17·8	17·0	17·1	17·3	39·9	47·4	48·5	45·3	92·6	92·4	91·9	92·3
Liquid placed shallowly	12·5	14·2	14·2	13·6	10·6	13·1	15·5	13·1	17·8	17·1	16·8	17·3	39·9	45·6	48·1	44·5	92·9	92·4	91·7	92·3
Liquid placed deeply	12·5	14·8	15·6	14·3	10·3	14·8	16·6	13·9	17·7	17·1	16·8	17·2	40·0	47·4	51·1	46·2	92·7	92·1	91·5	92·1
S.E. (Body of table)		±0·64				±0·82				±0·18				±2·4				±0·18		
Mean	12·5	14·5	14·7	—	10·5	14·0	16·0	—	17·8	17·1	16·9	—	39·9	46·8	49·2	—	92·7	92·3	91·7	—
S.E. (Means)		±0·37				±0·47				±0·10				±1·4				±0·10		

purity but usually independently of the application methods, although in one year (1963) placed fertilizer decreased purity more than broadcast fertilizer.

In the first 2 years an additional treatment tested liquid of the same composition and at the same amount as used in the two liquid placement treatments. The liquid was sprayed on the partially-worked seed bed, for a direct comparison with the broadcast solid. Applied in this way the average sugar yield from sprayed liquid was 48·7 and from broadcast solid 48·6 cwt/acre.

Each year the plants were counted immediately before the crop was singled to about 30000 plants/acre. In two of the three experiments placement significantly decreased the number of plants in the braird. Averaged over the three experiments the populations (1000/acre) were: solid broadcast, 143·1; liquid shallow placement, 118·7; liquid deep placement, 129·2. The quantities of fertilizer tested had no consistent effect on the number of seedlings established.

1966–8. Table 2 shows the average yields, quality of the roots and plant population for the three experiments. 'Nitro-chalk' in the seed bed yielded most roots but not significantly more than the liquids or the anhydrous ammonia injected immediately before seed-bed preparation. Anhydrous ammonia injected as a side-band before singling yielded significantly less roots than 'Nitro-chalk' every year; the early spring injection yielded significantly less in 2 out of 3 years.

Percentage sugar was least with 'Nitro-chalk' and largest with the liquid sprays, but the effects were small and inconsistent. Sugar yield was significantly less from side-banded anhydrous ammonia than from 'Nitro-chalk' in the seed bed. The liquid sprays and the other ammonia treatments gave yields not significantly less than 'Nitro-chalk' and not significantly more than side-banded anhydrous ammonia. Yields of tops did not differ on average but yield from ammonia in the early spring was significantly less than from 'Nitro-chalk' in 2 out of 3 years. The number of roots at harvest was similar for all treatments, as was the purity of the root juice.

In all three experiments the side-bands of anhydrous ammonia were 4 in to the side of the roots of plants and 6 in below the soil surface. The injection tines caused slight mechanical damage to the plants, so in 1964 and 1965 an additional treatment tested side-band placement of ammonia midway between the rows, i.e. 10 in to the side of the rows. The average sugar yield was 54·2 cwt/acre when placement was 4 in from the rows and 52·8 cwt/acre when placement was 10 in from the rows.

Samples of roots and tops from the three experiments were dried and analysed for nitrogen by a Kjeldahl method. Table 3 shows the concentration of nitrogen in tops and roots, nitrogen removed by the crop and the relative efficiencies of the treatments taking solid fertilizer as 100%.

Solid and anhydrous ammonia injected as a side dressing gave the largest nitrogen concentrations in both tops and roots. Sugar beet grown with anhydrous ammonia injected during early spring, and with the liquid N P K spray, had the smallest

Table 2. *Average effects of methods and forms of fertilizer application on yield of roots, tops and sugar percentage sugar, juice purity and plant population*, 1966–8

	Yield of roots (ton/acre)	Yield of tops (ton/acre)	Sugar (%)	Yield of sugar (cwt/acre)	Juice purity (%)	Plant population (1000/acre)
Solid (Nitro-chalk) broadcast in the seed bed	18·9	10·4	16·7	63·3	93·59	33·6
Anhydrous ammonia injected in early spring	17·7	9·2	17·0	60·3	94·41	34·5
Anhydrous ammonia injected in the seed bed	18·2	10·6	17·0	62·0	94·15	34·0
Anhydrous ammonia as a side-dressing	17·2	10·2	16·9	57·4	94·35	34·5
Liquid (N) sprayed in the seed bed	18·1	10·0	17·1	61·9	94·45	34·2
Liquid (N P K) sprayed in the seed bed	17·8	9·3	17·2	60·8	94·64	33·7
S.E.	±0·48	±0·69	±0·14	±1·60	—	±0·12

Table 3. *Average effects of methods and forms of fertilizer application on nitrogen concentration in tops and roots and on nitrogen recovery by the crop*, 1966–8

	Nitrogen concentration (%)		Nitrogen removed in the crop	
	Tops	Roots	(cwt/acre)	(as % of solid)
Solid (Nitro-chalk) broadcast in the seed bed	2·68	0·82	1·52	100
Anhydrous ammonia injected in early spring	2·53	0·71	1·32	87
Anhydrous ammonia injected in the seed bed	2·60	0·74	1·44	95
Anhydrous ammonia as a side-dressing	2·74	0·75	1·41	93
Liquid (N) sprayed in the seed bed	2·59	0·71	1·38	91
Liquid (N P K) sprayed in the seed bed	2·47	0·69	1·28	85

nitrogen concentrations. The total nitrogen removed in the crop was 1·52 cwt/acre (0·52 more than applied) with the solid fertilizer treatment. Less nitrogen was removed in the crop with each of the other treatments; anhydrous ammonia injected during early spring and liquid N P K spray were least effective.

Glasshouse experiments

Figure 1 shows the dry matter of the sugar beet grown in containers in 1963 and 1964. In 1963 yield from frequent and infrequent watering did not differ significantly when fertilizer was not given, suggesting the method of watering had little effect on yield. Fertilizer in the upper or in the lower layer gave similar yields with frequent watering, suggesting that it was equally available to the crop from the two layers. When the containers were watered infrequently there was again no significant difference in yield, but the larger amount of fertilizer gave slightly more yield when in the lower layer, presumably because the nutrients were more available than those in the upper layer.

In 1964, with frequent watering, fertilizer in the upper and lower layers again yielded similarly. With infrequent watering, fertilizer in the lower layer gave significantly more dry matter than fertilizer in the upper layer. This suggests that sugar beet in the field, where the surface layers of soil are liable to dry periodically, will probably respond more to fertilizer placed deeply than to fertilizer in the surface soil.

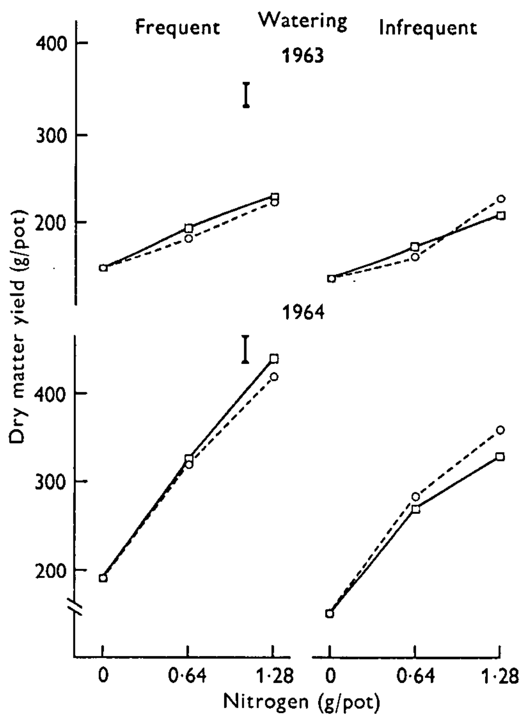

Fig. 1. Total dry-matter yield of sugar beet in glasshouse experiments 1963–4. □——□, Fertilizer in upper soil layer; ○– – –○, fertilizer in lower soil layer. I L.S.D. at $P = 0{\cdot}05$.

DISCUSSION

Few experiments have been reported during the last 20 years comparing broadcast solid fertilizer with similar nutrients band-placed for sugar beet. Prummel (1957) in Holland and Werkhoven & Miller (1960) in the United States reported some yield increase from placement of N and P. Shotten (1962) in England found a distinct advantage from placement, but Cooke (1949) concluded that placement had little value. Our placement experiments using liquid compound fertilizer gave similar results to Cooke's; in no experiment did placement 4 in to the side and 2 in below the seed give yields significantly different from broadcasting. Seedling population was smaller with placement than with broadcasting fertilizer (Cooke, 1949; Prummel, 1957). This was not important in our experiments where plots were singled to a uniform population, but in crops sown to a stand this effect of placement would be undesirable.

The theoretical advantages of deep placement were discussed by Cooke (1967) and by Holliday & Draycott (1968). Yield increases from deep placement with various crops have been described by Kohnke & Bertrand (1956), Jamison & Thornton (1960) and Larson *et al.* (1960). In our field experiments sugar beet gave a small, consistent but non-significant response to deep placement. Deep placement for sugar beet is of doubtful value in Britain where long, dry periods are few; also broadcast application is much simpler. However, glasshouse experiments confirmed that sugar beet gives a significant response to deep-placed nutrients which may be of value in climates drier than our own.

Five of the field experiments compared broadcast solid fertilizer with the same quantity of N P K as a liquid spray; there was no significant difference between the yields from these two treatments in any experiment. In three experiments the amount of N in the crop was measured and plants given liquid fertilizer contained slightly less N, possibly because N was lost to the atmosphere. Part of the N in the liquid was in the form of urea, and Gasser (1964) has shown on calcareous soils some N can be lost in this way; also Nowakowski (1961) and Widdowson & Penny (1964) report that liquids give slightly less yield than solids.

Yield of sugar and nitrogen recovery were similar from anhydrous ammonia injected a few days before sowing and from solid fertilizer. Observations on the colour of the leaves from July onwards indicated that less nitrogen was available from ammonia injected during early spring in the ploughed land than from other applications (van Burg *et al.* 1967). This was confirmed by nitrogen analyses on the crop at harvest and the yield was also less. These observations suggest that some of the ammonia applied early had been lost. The side-band application also gave less yield than the seed-bed treatment but the nitrogen recovery was similar. This suggests that band placement ultimately supplied nitrogen to the plants, but not early enough for full growth. Sugar beet given nitrogen later in the season yield less well than plants given nitrogen in the seed bed (Last & Tinker, 1968).

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