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Sodium and potassium relationships in sugar beet

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SUMMARY

Three field experiments with sugar beet grown on a light calcareous soil tested a wide range of amounts of sodium and potassium fertilizer with either magnesium or nitrogen. Both sodium and potassium increased sugar yield and there was a large negative interaction between them. Magnesium also increased sugar yield, but the larger dressing of nitrogen decreased it. Sodium, potassium and nitrogen fertilizers also affected the concentration of impurities in the root juice at harvest.

Plant samples were also analysed in August when the crop usually contains most sodium. Sodium fertilizer greatly increased the sodium and decreased the potassium concentration in the dry matter of the tops but the composition of the roots changed little. Potassium dressings slightly increased potassium in the tops but did not affect the root composition.

Exchangeable sodium in the top soil of plots given sodium fertilizer decreased rapidly early in the season, but increased again from August, probably because sodium was taken up rapidly early in the summer and returned later in dead leaves. Soil potassium decreased throughout the season on plots where potassium was applied, but did not change on plots without potassium fertilizer; this is explained by fixation and release from non-exchangeable forms.

On this soil there was no reason to regard sodium in its effect on yield, other than as a replacement for potassium, but its behaviour in the soil and effect on the composition of the plant was quite different.

INTRODUCTION

Many experiments have shown that potassium and sodium fertilizers can greatly increase yield of sugar beet, and that these elements may be partly interchangeable (Adams, 1961*a*, *b*; Holmes *et al.* 1961; Tinker, 1965). These two, together with nitrogen, are the most important fertilizers for sugar beet in Great Britain. All three elements occur in the soluble fraction of the root and greatly impede the making of white sugar during the processing of the roots. Carruthers & Oldfield (1961) showed an inverse relationship between the concentration of these three elements and the percentage of sugar to total solids in the root juice (termed the 'Juice Purity', Draycott & Cooke, 1967).

The concentration of sodium, potassium and α-amino nitrogen is often measured in the root juice during analysis of beet from fertilizer experiments (e.g. Tinker, 1965), but the total amounts of these elements in the plant and their distribution has received much less attention. Adams (1961*c*) reported experiments done by J. B. Hale in 1943, in which beet from experiments with sodium and potassium fertilizers were harvested and analysed at intervals throughout the season, and Goodman (1963) gave results for the composition of beet at three centres.

The experiments reported by Adams were on a heavy soil at Rothamsted and potassium did not increase yield. Because of this, and also because of the much larger root yields obtained now, it was decided to investigate cation relationships again on a light soil where larger effects were expected. Magnesium was tested in the first year, for Jorritsma (1956) found that magnesium improved juice purity, possibly by decreasing sodium or potassium uptake by the plants. The results of the first experiment, and of experiments on farmers' fields in the same year (Tinker, 1967*a*) showed that magnesium had very small effects on juice purity unless the plants were severely magnesium deficient. Therefore, in 1964 and 1965 magnesium was replaced by nitrogen which has a large effect on juice purity (Tinker, 1965).

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Very large dressings of sodium and potassium were tested to investigate interactions and antagonisms under extreme conditions; they may be compared with the usual recommendation of 1·6 cwt/acre sodium and 1·0 cwt/acre potassium. The two nitrogen dressings were designed to span the usual recommendation of 1·0 cwt/acre.

EXPERIMENTAL

Three field experiments were done between 1963 and 1965 on Broom's Barn farm. The 1964 experiment was on the Moulton Series, a coarse sandy loam over sand and chalk; in 1963 and 1965 the experiments were on Ashley Variant, a gravelly sandy loam over sandy clay loam. Table 1 contains soil analyses.

In 1963 the experiment tested 0, 0·4, 1·2 and 2·0 cwt/acre sodium as sodium sulphate; 0, 0·8, 1·6 and 2·4 cwt/acre potassium as potassium sulphate and 0, 0·32, 0·80 and 1·28 cwt/acre magnesium as kieserite in a factorial design with one replicate. All plots received 1 cwt/acre nitrogen as urea and 0·5 cwt/acre P_2O_5 as triple superphosphate. In 1964 and 1965, the treatments were 0, 1, 2 and 3 cwt/acre sodium as sodium chloride, 0, 1·1, 2·2 and 3·3 cwt/acre potassium as potassium chloride and 0·8 and 1·4 cwt/acre nitrogen as 'Nitro-chalk', in factorial combination. All plots received 0·5 cwt/acre P_2O_5 as triple superphosphate and a spray of 20 lb/acre borax in June.

Plot size was 0·0167 acre in 1963 and 1964 and 0·01 acre in 1965. The harvested area was 0·007 acre in 1963 and 1964 and 0·004 acre in 1965. All the experiments were harvested during late November or early December; tops and roots were weighed and roots analysed for sugar percentage, sodium, potassium and α-amino nitrogen (Tinker, 1965). In addition, separate plant samples were taken in late August before many leaves had senesced (as Adams (1961*c*) found most sodium in the crop then). The samples consisted of twelve beet from each plot in 1963 and 1965 and eight in 1964. Leaves and petioles were wiped clean and roots washed; all parts were weighed and subsampled to measure dry matter and for chemical analysis.

Soil samples were taken at intervals during the 1964 and 1965 experiments to interpret the plant composition effects. These were taken at 0–6 in in 1964 and 0–9 in and 9–18 in in 1965. A sample was also taken from each experimental area before the fertilizers were applied.

RESULTS AND DISCUSSION

Yield effects

Table 2 shows the mean effects of the four elements. Results are given as means of 1964 and 1965 for potassium, sodium and nitrogen and for 1963 only for magnesium. The effects of sodium and potassium in 1963 (when the dressings differed slightly from the other years) were very similar to those in 1964 and 1965. Both sodium and potassium increased root yields and sugar yields significantly. There were no significant differences between mean yields with different amounts of sodium and potassium. Sugar yield was significantly increased by magnesium in 1963, though few beet had magnesium-deficiency symptoms (Tinker (1967*a*) found that responses were usually small when fewer than 10% of the plants showed symptoms). Additional nitrogen increased top yield, decreased sugar yield but did not affect root yield.

Of the impurities (sodium, potassium and α-amino nitrogen) in the beet juice, sodium and potassium fertilizers slightly increased the concentration of the first two but decreased the α-amino nitrogen concentration. Nitrogen fertilizer increased the concentration of all the impurities, especially α-amino nitrogen, whereas magnesium had no effect on the concentration of any.

Table 3 shows the sugar yields for all combinations of sodium and potassium in the 1964 and 1965 experiments. Additional amounts of potassium always increased yield where sodium was withheld or the smallest dressing given. The smallest dressing of sodium always increased yield, even with the largest amount of potassium. Large dressings of sodium decreased yields slightly, perhaps by damaging seedlings.

Garner (1952) and Tinker (1965) reported that there is usually an additional response to sodium even in the presence of large amounts of potassium and this agrees with our results. However, this does not necessarily imply a specific function for sodium, as suggested by Lehr (1953). In our experiments

Table 1. *Analysis of soils from the experimental sites*

	Exchangeable K	Exchangeable Na (m-equiv./100 g soil)	Exchangeable Mg	Exchange capacity	pH	Organic matter (%)	Clay content (%)
1963	0·179	0·104	0·33	10·7	7·8	1·40	10·5
1964	0·200	0·065	0·27	12·5	7·6	1·69	11·0
1965	0·230	0·076	0·33	10·7	7·8	1·39	11·5

Table 2. *Yields and concentrations of impurities in the roots for each nutrient averaged over all other nutrients*

Treatments... (cwt/acre)	Sodium					Potassium				
	0	1	2	3	S.E.	0	1·1	2·2	3·3	S.E.
			1964–5					1964–5		
Washed beet (ton/acre)	21·2	21·8	21·4	21·8	±0·31	20·8	21·9	21·6	21·8	±0·31
Sugar yield (cwt/acre)	73·1	74·8	74·5	76·3	±0·95	71·6	75·8	75·3	76·0	±0·95
Potassium (%)	0·15	0·15	0·16	0·16	±0·003	0·14	0·15	0·16	0·16	±0·003
Sodium (%)	0·018	0·020	0·020	0·022	±0·0003	0·021	0·019	0·019	0·020	±0·0003
α-amino N (%)	0·034	0·033	0·031	0·030	±0·0002	0·034	0·032	0·030	0·032	±0·0002

Treatments... (cwt/acre)	Magnesium					Nitrogen		
	0	0·32	0·80	1·28	S.E.	0·8	1·4	S.E.
			1963				1964–5	
Washed beet (ton/acre)	20·8	21·4	21·3	21·6	±0·24	21·7	21·4	±0·22
Sugar yield (cwt/acre)	70·2	72·3	72·2	72·9	±0·83	76·1	73·2	±0·67
Potassium (%)	0·16	0·15	0·15	0·16	±0·006	0·15	0·16	±0·002
Sodium (%)	0·014	0·013	0·014	0·014	±0·0008	0·019	0·020	±0·0002
α-amino N (%)	0·017	0·017	0·017	0·017	±0·0012	0·025	0·038	±0·0001

Table 3. *Mean yield of sugar (cwt/acre) in* 1964–5 *with combinations of sodium and potassium fertilizers averaged over levels of nitrogen*

Potassium (cwt/acre K)	Sodium (cwt/acre Na)			
	0	1	2	3
0	65·6	74·0	73·4	73·4
1·1	74·2	77·4	75·2	76·3
2·2	74·8	78·4	77·1	75·7
3·3	77·6	79·0	72·3	74·4

S.E. ±1·90

there was an additional response from the largest potassium dressing, and still more potassium may have increased yield further. As the yield responses given by increments of either sodium or potassium are comparable in size, they could be explained by simply assuming sodium to be a replacement for potassium.

Plant composition

Fig. 1 shows the mean effects of the fertilizers on the concentration of nutrients in the roots, petioles and leaves at the end of August. The large amounts of sodium and potassium applied and the small exchange capacity of the soil were expected to cause large changes in plant composition, but most changes were small. The concentration of sodium in the leaves and in the petioles was increased greatly by sodium fertilizer and decreased by potassium (Adams, 1961*c*). Sodium fertilizer increased sodium in the roots and, as also found by Adams (1961*c*), potassium fertilizer increased but sodium decreased the potassium concentration in leaves and petioles, but the effects on the roots were small. Magnesium fertilizer had little effect on the sodium and potassium concentration in the plant parts; nitrogen fertilizer decreased the concentration of sodium and potassium in the leaves and petioles but had little effect on the roots.

The concentrations of sodium and potassium in leaves and roots with all combinations of these elements as fertilizers (Table 4) emphasize the large changes caused by sodium fertilizer; potassium had relatively little effect. Sodium dressings either decreased or did not affect potassium concentration, supporting Adams's (1961*c*) conclusion that sodium did not assist potassium uptake. An increased supply of potassium often decreases sodium percentage, (e.g. ap Griffith & Walters, 1966), but changed sodium little in these experiments.

The K/Na ratio was much larger in roots than in the foliage; sodium was thus relatively concentrated in the foliage, the reverse of the situation in plants that do not respond to sodium fertilizer, in which the element enters the root in appreciable amounts but not the leaves (Huffaker & Wallace, 1959; Wybenga, 1957). The relative stability of the root composition agrees with the small changes found in the root juice sodium and potassium concentrations at harvest (Table 2).

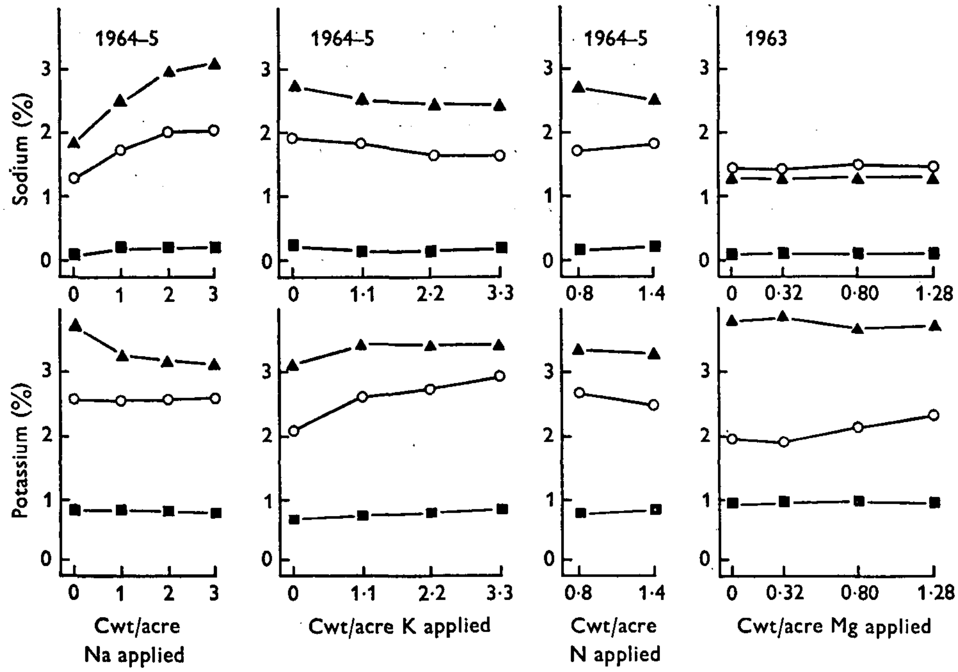

Fig. 1. Mean effect of fertilizers on sodium and potassium concentration in dry matter of sugar beet harvested at the end of August. ▲—▲, Leaves; ○—○, petioles; ■—■, roots.

A pot experiment with soil from the experiment site showed how sodium affects the concentrations of other cations in the leaves of sugar beet (Table 5). There was an inverse relationship between sodium and calcium, as found by Nightingale & Smith (1966) for alfalfa, and a smaller effect on magnesium concentration. Field experiments have also shown that magnesium-deficiency symptoms in sugar beet are enhanced more by sodium fertilizers than potassium fertilizers (Tinker, 1967*a*). A pot experiment with a range of soils (Tinker, 1966) gave no indication that the uptake of sodium was affected by the supply of other cations in the soil.

Lehr (1942) emphasized the cation balance in fodder beet leaves and related it to yield. The mean composition of leaves in our experiments would place them in the 'moderate yield' class of Lehr, though it is uncertain whether his results with plants in pots are applicable to field crops. It would be difficult to get a composition corresponding to his 'maximum yield' class with any practicable fertilizer dressing in our experiments. Further work on the factors limiting composition changes of soil-grown beet may prove valuable in explaining the function of sodium in sugar beet nutrition.

Soil composition

Soil samples were taken at intervals in 1964 and 1965 from plots receiving either none or the largest amounts of sodium and potassium. Fig. 2 shows a very rapid decrease in exchangeable sodium during spring and summer, followed by a rapid increase to approximately the initial value by late November. We assume that this represents uptake by the plants with subsequent release into the soil, either through the roots, or more probably by rainwash and litter, following senescence of the leaves and petioles (which contain most of the sodium) and the eventual return of the leaves and petioles at harvest. Adams (1961*c*) found that the sodium in the crop decreased after August.

Assuming 6 in of soil over 1 acre weighs 2000000 lb, the gain in top-soil sodium on plots receiving the large dressing of sodium between plant sampling and the end of the year was 145 lb/acre sodium on average. This corresponds reasonably well with the sodium (125 lb/acre) in the leaves and petioles, which were returned to the soil between September and December. Similar calculations for plots not receiving sodium gives 50 lb/acre returned to the soil and 80 lb/acre in the leaves and petioles. There was evidence of uptake of sodium from the soil below 18 in, for more sodium was found in the beet than was removed from the top 18 in of soil during the summer; this is possible because Coulter & Draycott (1966) showed that sugar beet roots extend to at least 4 feet in this soil. Release from non-exchangeable forms seems unlikely (Tinker, 1966).

Table 4. *Mean effects in 1964–5 of combinations of sodium and potassium fertilizer on the concentration of sodium and potassium in the leaves and roots as percentages of the dry matter*

Potassium (cwt/acre K)	Sodium (cwt/acre Na) 0	1	2	3
	Concentration of sodium in leaves			
0	1·85	2·64	3·14	3·16
1·1	1·73	2·26	2·95	3·20
2·2	1·85	2·46	2·82	2·85
3·3	2·00	2·75	3·02	3·22
		±0·19		

Potassium (cwt/acre K)	Sodium (cwt/acre Na) 0	1	2	3
	Concentration of potassium in leaves			
0	3·70	2·90	3·05	2·90
1·1	3·71	3·50	3·33	3·25
2·2	3·66	3·38	3·10	3·20
3·3	3·87	3·37	3·22	3·22
		±0·21		

Potassium (cwt/acre K)	Sodium (cwt/acre Na) 0	1	2	3
	Concentration of sodium in roots			
0	0·15	0·22	0·27	0·22
1·1	0·11	0·18	0·19	0·26
2·2	0·12	0·18	0·20	0·19
3·3	0·10	0·21	0·21	0·19
		±0·048		

Potassium (cwt/acre K)	Sodium (cwt/acre Na) 0	1	2	3
	Concentration of potassium in roots			
0	0·74	0·70	0·79	0·71
1·1	0·77	0·80	0·84	0·77
2·2	0·77	0·85	0·77	0·77
3·3	0·88	0·94	0·87	0·85
		±0·073		

Table 5. *Cation concentration in tops (leaf plus petiole) of sugar beet grown for 3 months in pots in the greenhouse, with added sodium*

Sodium content of soil (m-equiv/100 g soil)	K	Na	Ca	Mg	Total
	(m-equiv/100 g dry matter)				
0·08	32	11	130	51	224
0·25	32	41	126	50	249
0·42	32	56	110	44	242
0·76	28	96	105	47	276
1·45	34	170	77	37	318
2·82	33	235	70	37	375
5·58	44	233	55	42	374
22·08	32	348	28	45	453

The final rapid decrease in soil sodium in winter followed ploughing, and subsequent leaching gradually removed the added sodium over a period of 2 years.

The amount of sodium supplied to soil in rain varies with season, distance from the sea and direction from which the rain comes. Table 6 shows the rainfall at Broom's Barn and the amount of sodium it contained for the years 1965–7. On average the annual total was 6 lb/acre and there was little variation from year to year. Between March and November in 1965, 4·4 lb/acre sodium fell on the plots in rain. It is therefore unlikely that this source of supply of sodium affected the relationships found

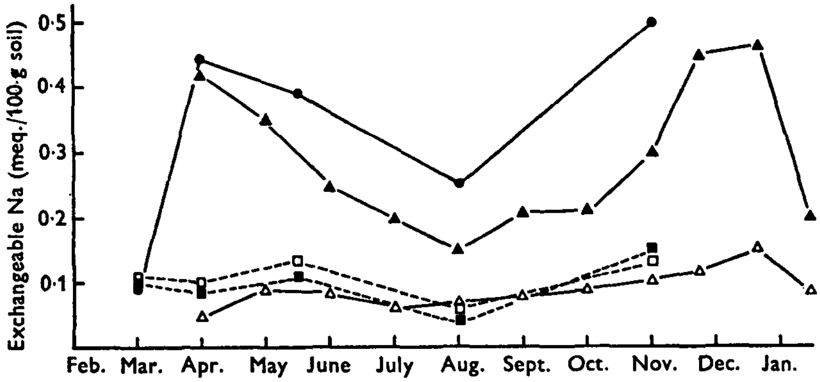

Fig. 2. Exchangeable soil sodium in plots with and without sodium applications, 1964 and 1965. △—△, Without sodium, 0–6 in, 1964; ■--■, without sodium, 0–9 in, 1965; □--□, without sodium, 9–18 in, 1965; ▲—▲, 3 cwt/acre sodium, 0–6 in, 1964; ●—●, 3 cwt/ acre sodium, 0–9 in, 1965.

Table 6. *Sodium in rainfall at Broom's Barn*, 1965–7

Year	Rainfall (in)	Sodium (lb/acre)
1965	27·25	6·6
1966	22·12	6·2
1967	23·48	5·1

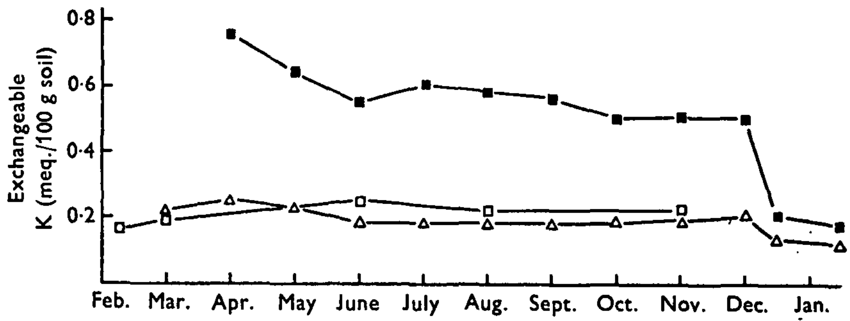

Fig. 3. Exchangeable soil potassium in plots with and without potassium applications, 1964 and 1965. △—△, Without potassium, 0–6 in, 1964; □—□, without potassium, 0–9 in, 1965; ■—■, 3·3 cwt/acre potassium, 0–6 in, 1964.

between sodium uptake by the crop and depletion of exchangeable sodium in the soil.

The results for exchangeable potassium and sodium in the soil differed greatly (Fig. 3); potassium changed little in plots not given it, and plant uptake of about 160 lb/acre in 1964 decreased exchangeable potassium in the top soil by only 50 lb/acre. There was little indication of release of potassium from the beet tops in November. The uptake on plots given the large dressing of potassium was 220 lb/acre, which agreed well with the decrease in exchangeable soil potassium of about 200 lb/acre. Again there was no clear indication of the return of potassium to the soil, which may be partly because less potassium than sodium is leached from the leaves (Tukey, Tukey & Wittwer, 1958). The stability of exchangeable soil potassium may reflect the transfer of potassium to and from a non-exchangeable pool with an equilibrium level of about 0·2 m-equiv./100 g soil.

Although effects on the sugar yield could be explained by assuming sodium to be a replacement for potassium, the plant composition results and soil analyses do not allow such an explanation. The early uptake, and early loss of sodium found by Adams (1961*c*), in agreement with soil analyses reported here, may be because it is more available to plants and more mobile than potassium (Tinker, 1967*b*). This may explain the occasional finding that sodium gives a yield greater than any obtainable with potassium alone.

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