Time of application and chemical form of potassium, phosphorus, magnesium and sodium fertilizers and effects on the growth, yield and quality of sugarbeet (*Beta vulgaris*)

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SUMMARY

Between 1985 and 1988, 14 field experiments at different sites in the UK assessed the effect of applying P, K, Na and Mg in autumn, early spring, late spring or as a split application in both autumn and late spring on the growth, yield and processing quality of sugarbeet. Supplementary experiments compared Kaynitro and Chilean nitrate of soda. None of the treatments had any effect on plant population densities, and any differences in sugar yield could be explained by the leaching of Na. The effects on processing quality were inconsistent and unlikely to be of agronomic or economic significance. Generally, Kaynitro and Chilean nitrate of soda performed no better than the other fertilizers so it is unlikely that their extra cost would be justified. Apart from Na, the timing of nutrient application appeared to be unimportant, even on soils of low fertility. However, Na, being very mobile, was best applied in spring.

INTRODUCTION

Recommendations for application of K, P, Na and Mg fertilizer for the sugarbeet crop have to take many factors into account (Jaggard *et al.* 1989). K and Na, when broadcast shortly before drilling, may reduce the number of seedlings due to osmotic stress. Applications made after ploughing and when the soil is wet, particularly on silts and clays, result in compaction problems and reduce crop performance. Conversely, applying fertilizers in the autumn to light-textured soils risks some loss of nutrient, particularly Na, from over-winter leaching. For this reason it is now recommended that the heavier textured, nutrient-rich soils receive their fertilizer before ploughing in November or December. The sandier, less fertile soils should, however, receive their fertilizer in January or February either before ploughing, or after ploughing if low-ground-pressure vehicles are used for application. On sandy soils which contain very little P, K or Mg, it is recommended that fertilizer is applied after ploughing and only 1 or 2 weeks before the crop is sown. Unfortunately, the recommendations for these nutrients are, in part, based upon conflicting evidence. For instance, Webber (1961) and Adams (1961) obtained beneficial responses to seedbed K and P, as opposed to Russell (1956) and Draycott *et al.* (1976) who found pre-ploughing application of the two nutrients to be superior. Draycott & Bugg (1982) and Armstrong & Jaggard (1990) found little yield difference between applying Na pre-ploughing or in the seedbed, as long as the later application did not interfere with germination. Thus there is an overriding need to consider soil nutrient status and the mobility of each nutrient within the soil.

In the mid 1980s, British Sugar plc and Imperial Chemical Industries plc conducted a survey amongst a representative sample of 300 sugarbeet growers. Crop husbandry details throughout the season and the resulting crop yield were recorded. Generally there was a benefit from applying P and K in spring rather than autumn. However, British Sugar's Crop Survey, performed at the same time, showed no evidence of yield differences due to timing of fertilizer application, but did show that even fields with impoverished, sandy soils were receiving fertilizer dressings during autumn, contrary to recommended practice.

To try to reconcile these conflicting data it was decided to conduct a new series of experiments, using modern varieties and management techniques, to

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study the interaction of soil type, time of fertilizer application and weather patterns on the yield and processing quality of sugarbeet in England.

MATERIALS AND METHODS

The experiments were started in autumn 1985 and, with the exception of Broom's Barn, were located on soils where sugarbeet might be expected to respond to added fertilizer. Year 1 experiments commenced in autumn 1985 with soil sampling that preceded the application of the first fertilizer treatment, and ceased with beet harvest in winter 1986. Likewise, Year 2 started in autumn 1986 and Year 3 in autumn 1987; site and management details are given in Table 1. At the start of each experiment, five replicate topsoil samples were taken; these were then air-dried, sieved < 2 mm and analysed for exchangeable K and Mg and extractable P using standard methods (MAFF/ADAS 1986).

The experiments tested the effect of time of basal K, Mg, P and Na fertilizer application on the yield and processing quality of the subsequent beet crop. The K, P and Mg fertilizers were applied at rates dependent upon the results of the soil analyses (Jaggard *et al.* 1989) as muriate of potash (KCl), triple superphosphate (mainly $Ca(H_2PO_4)_2.H_2O$) and kieserite ($MgSO_4.H_2O$). Na was always applied as agricultural salt (NaCl) at a fixed rate of 150 kg Na/ha. All fertilizers were broadcast by hand, either in the autumn, early spring, pre-sowing or as a split application (two thirds in the autumn and one third in spring). Application dates are listed in Table 1. N, as ammonium nitrate (NH_4NO_3), was applied twice; 30 kg N/ha as soon as the beet crop was drilled, and a top-dressing of 90 kg N/ha *c.* 6 weeks later, at full establishment of the crop.

In each year some subsidiary treatments assessed the benefits of alternative strategies for applying basal and nitrogen fertilizers to the crop. At Broom's Barn every experiment tested, as one application in the autumn, the entire P, K, Na and Mg fertilizer requirement for the 5-year rotation. In Years 2 and 3, on selected sites, a treatment tested an early spring fertilizer application which supplied all the P, Na and Mg but only 66 kg K/ha; the remainder of the K (20 kg/ha) was applied as 'Kaynitro' (25% N and 16% K), which replaced the NH_4NO_3 at drilling. In Year 3, on selected sites, a further treatment supplied all the basal fertilizer in early spring together with 50 kg Na/ha as Chilean nitrate of soda (16% N and 26% Na) at drilling, again replacing the NH_4NO_3.

At all sites each treatment was allocated at random to each of the six replicate blocks. At Broom's Barn the plots were six rows (3 m) wide × 12 m long. At all other sites the plot dimensions were 12 rows (6 m) wide × 12 m long. In all experiments commercial seed was sown *c.* 3 cm deep and 18 cm apart. Standard management was used throughout to keep the crop as weed, disease and pest free as possible. The crops at Broom's Barn were irrigated when limiting soil moisture deficits were exceeded (Jaggard *et al.* 1989). The other crops were unirrigated.

In October or November a sample area from within each plot (8 m long × four rows wide) was harvested. The plants within this area were lifted and topped manually at the level of the lowest leaf scar and then counted. A representative sample of 20 tops was weighed, subsampled and dried to constant weight at 85 °C to determine dry matter yield. The roots were washed, weighed and sugar percentage and impurity concentrations were determined on a representative subsample of the macerated root using standard methods (Carruthers & Oldfield 1961).

RESULTS AND DISCUSSION

Plant population density

Maximum sugar yields are attained when plant population densities are > 75000 plants/ha at final harvest (Draycott & Webb 1971; Draycott *et al.* 1974; Jaggard *et al.* 1989). This population density was exceeded at all sites in all years except at Tattersett in Year 1. Time of fertilizer application had no significant effect on plant population density. However, at Broom's Barn in Year 2 a reduction in plant population density resulted from the late spring application, but this was not statistically significant. This application was only 3 days before drilling and had the spring of 1987 not been wetter than average, significant reductions in plant populations could have resulted.

Fertilizers may affect germination and seedling growth (and thereby final population density) in two main ways; one detrimental, the other beneficial. Firstly, large salt concentrations reduce water imbibition by the germinating seed. Holmes *et al.* (1973) found that K and Na fertilizers, when applied to the seedbed in large amounts, could reduce plant populations by up to 30%. Farley (1972) reported that with large amounts of NaCl applied to the seedbed, plant populations were reduced by *c.* 20%. Draycott *et al.* (1976) in 12 field experiments noted that autumn applications of K and Na resulted in slightly larger plant population densities than spring applications. The reduction from the spring application was due mainly to the effects of Na and was most noticeable in dry years. More recent work by Durrant & Mash (1989) showed that steeping seed in KNO_3 solution could reduce the thermal time needed for hypocotyl growth. Radicle growth was always slowed even at small concentrations. The optimal concentration of KNO_3 was *c.* 4 mM. Holmes *et al.* (1973) also showed that a February, or a split winter/seedbed application, was better than a sole winter application (when leaching of nutrients from the seedbed occurred) or a

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Table 1. *Experimental field details, P, K, Na and Mg fertilizer application dates and husbandry practice dates for sugarbeet crops harvested in 1986 (Year 1), 1987 (Year 2) and 1988 (Year 3)*

	Site details									Dates of husbandry practices					
	Ordnance Survey grid		ADAS index for			Total amount of nutrient applied (kg/ha)			Fertilizer application			Beet details		
Year/site	reference	Soil texture	P	K	Mg	P	K	Mg	Autumn	Early spring	Late spring	Ploughing	Sowing	Harvest
Year 1														
Broom's Barn	TL 754655	Sandy loam	2	2	2	20	60	0	1.11.85	14.3.86	11.4.86	12.11.85	30.4.86	15.10.86
East Harling	TM 003869	Loamy sand	2	0	0	20	160	100	29.11.85	26.2.86	14.3.86	11.3.85	10.4.86	13.10.86
Tattersett	TF 856299	Loamy sand	3	0	0	20	160	100	4.12.85	20.2.86	18.3.86	10.3.86	26.4.86	10.11.86
Blakedown	SO 883774	Sandy loam	3	1	2	20	80	0	5.12.85	7.2.86	18.3.86	17.3.86	2.4.86	9.10.86
Year 2														
Broom's Barn	TL 756658	Sandy loam	2	2	2	20	60	0	4.12.86	18.2.87	14.4.87	16.11.86	17.4.87	20.10.87
Baumber	TF 217741	Sandy loam	0	1	0	40	80	100	17.11.86	11.2.87	10.3.87	11.2.87	14.4.87	12.10.87
Blakeshall	SO 831809	Sandy loam	4	1	1	0	80	50	9.12.86	10.2.87	20.3.87	12.2.87	21.4.87	21.10.87
East Harling	TM 006868	Sand	2	1	1	20	80	50	22.12.86	10.2.87	10.3.87	15.1.87	15.4.87	23.10.87
Tattersett	TF 862301	Loamy sand	2	1	1	20	80	50	22.12.86	8.1.87	16.3.87	3.2.87	18.4.87	10.11.87
Ripon	SE 345745	Sandy loam	2	0	3	20	160	0	19.12.86	18.1.87	10.3.87	8.1.87	20.4.87	28.10.87
Year 3														
Broom's Barn	TL 756652	Sandy loam	2	2	2	20	60	0	21.9.87	15.2.88	18.3.88	15.11.87	7.5.88	24.10.88
Baumber	TF 216733	Sandy loam	1	1	0	30	80	100	18.11.87	16.2.88	10.3.88	30.11.87	6.4.88	19.10.88
Hardingham	TG 030044	Loamy sand	5	1	1	0	80	50	22.11.87	12.2.88	14.3.88	4.2.88	7.4.88	14.10.88
Shereford	TF 894290	Sandy loam	3	1	2	20	80	0	18.11.87	20.2.88	12.3.88	22.11.87	7.4.88	14.11.88

Different sugarbeet cultivars were used in the experiments; it was assumed that all cultivars responded in a similar way to added fertilizers.

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Table 2. *Effect of time of P, K, Na and Mg fertilizer application on sugar yield (t/ha) for sugarbeet crops harvested in 1986 (Year 1), 1987 (Year 2) and 1988 (Year 3) on a range of soil types*

	Time of application				
Year/site	Autumn	Early spring	Late spring	Autumn/spring	S.E. (D.F.)
Year 1					
Broom's Barn	10·14	10·45	10·16	10·16	0·112 (19)
East Harling	10·29	10·95	11·14	10·68	0·378 (15)
Tattersett	10·44	10·18	10·68	10·66	0·277 (15)
Blakedown	9·07	9·24	8·75	9·14	0·233 (9)
Mean	9·99	10·20	10·18	10·16	0·134 (9)
Year 2					
Broom's Barn	9·73	9·92	9·49	9·78	0·132 (24)
Baumber	9·86	8·95	9·76	9·21	0·643 (15)
Blakeshall	9·73	9·19	9·89	9·97	0·131 (15)
East Harling	10·17	9·66	9·51	10·14	0·320 (20)
Tattersett	9·24	9·24	9·68	9·62	0·172 (15)
Ripon	8·43	8·02	8·12	8·30	0·231 (20)
Mean	9·53	9·16	9·41	9·50	0·113 (15)
Year 3					
Broom's Barn	9·90	10·14	10·14	9·85	0·096 (20)
Baumber	10·35	10·95	10·86	10·46	0·121 (25)
Hardingham	8·62	9·00	8·93	8·80	0·157 (25)
Shereford	10·59	11·05	10·93	11·10	0·112 (25)
Mean	9·86	10·28	10·22	10·05	0·066 (9)
Grand mean	9·75	9·78	9·86	9·85	0·073 (39)

sole seedbed application (when high salt concentration inhibited seedling growth).

A third factor affecting seedling germination and establishment is an adequate supply of phosphorus Draycott (1972) noted that P fertilizer applied to deficient soils increased seedling vigour and the chance of seedling survival after attack by pest or disease. However, Draycott was dealing with P-deficient soils, which are rare in UK arable agriculture today. All the present experiments were on soils containing > 10 mg/l Olsen-extractable phosphorus.

In the current experiments, plant population densities were nearly all satisfactory, which suggests that all treatments provided sufficient nutrients to maintain seedling vigour without causing osmotic stress.

Sugar yield and sugar concentration

There were no significant effects of fertilizer application time on sugar yield except at Blakeshall in Year 2 and Baumber and Shereford in Year 3 (Table 2). At Blakeshall, the fertilizer treatment which was ploughed down immediately after application in early spring did not produce as much sugar as the other treatments. At Baumber and Shereford in Year 3, application in autumn caused a reduction in sugar yield. In general, autumn application of all the basal fertilizer performed poorly in Year 3. Overall the yield loss was *c.* 0·4 t/ha of sugar.

The changes in sugar yield were caused mainly by changes in root sugar concentration rather than by changes in root yield. For instance at Blakeshall in Year 2, the early spring application reduced sugar concentration by *c.* 0·5% compared with the late spring application (Table 3). Similarly in Year 3, autumn application resulted in significantly smaller sugar concentrations than the spring applications. Sugar content was also increased significantly at Tattersett in Year 1, where the late spring application performed better than the early spring or autumn applications. A similar significant trend was observed for the Year 1 mean. Over all site/years the late spring application was superior, giving sugar concentrations 0·2% larger than either the autumn or early spring applications.

It is likely that the variations in yield between autumn and spring applications were due to differences in the availability of nutrients to the growing crop. These differences are probably caused by overwinter leaching of nutrients which will then only become available to the crop relatively late in the season. Of the nutrients applied, it is the movement of Na that can most easily explain the observed yield differences.

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Table 3. *Effect of time of P, K, Na and Mg fertilizer application on root sugar concentration (%) for sugarbeet crops harvested in 1986 (Year 1), 1987 (Year 2) and 1988 (Year 3) on a range of soil types*

	Time of application				
Year/site	Autumn	Early spring	Late spring	Autumn/spring	S.E. (D.F.)
Year 1					
Broom's Barn	18·4	18·5	18·5	18·3	0·09 (20)
East Harling	17·9	17·9	18·3	17·9	0·12 (15)
Tattersett	19·0	19·1	19·4	19·3	0·08 (15)
Blakedown	19·5	19·4	19·7	19·5	0·07 (9)
Mean	18·7	18·7	19·0	18·8	0·06 (9)
Year 2					
Broom's Barn	18·1	18·2	18·3	18·2	0·06 (24)
Baumber	17·7	17·7	17·9	17·8	0·09 (15)
Blakeshall	18·5	18·3	18·8	18·7	0·06 (15)
East Harling	17·3	17·3	17·1	17·3	0·12 (20)
Tattersett	17·6	17·7	17·8	17·7	0·09 (15)
Ripon	16·5	16·4	16·3	16·5	0·13 (20)
Mean	17·6	17·6	17·7	17·7	0·05 (15)
Year 3					
Broom's Barn	19·1	19·1	19·2	19·0	0·08 (20)
Baumber	18·3	18·5	18·6	18·4	0·07 (25)
Hardingham	19·4	19·7	19·7	19·6	0·09 (25)
Shereford	19·0	19·0	19·3	19·1	0·09 (25)
Mean	18·9	19·1	19·2	19·0	0·04 (9)
Grand mean	18·3	18·3	18·5	18·4	0·03 (39)

Table 4. *Effect of time of P, K, Na and Mg fertilizer application on the yield of sugarbeet (t beet/ha or t sugar/ha) for 140 field experiments on a range of soil types*

	Nutrients tested	Soil type	No. of experiments	Time of application: Pre-ploughing	Seedbed
Russell (1956)	P, K	Heavy	(5)	6·88 t sugar/ha	6·65 t sugar/ha
		Light	(7)	4·93 t sugar/ha	4·68 t sugar/ha
		Varied	(18)	38·5 t beet/ha	36·7 t beet/ha
Adams (1961)	P, K	Varied	(29)	5·80 t sugar/ha	6·07 t sugar/ha
Webber (1961)	P, K	Light	(7)	5·70 t sugar/ha	5·91 t sugar/ha
Holmes *et al.* (1973)	Na, K	Loams	(10)	5·36 t sugar/ha	5·51 t sugar/ha
Draycott *et al.* (1975)	Mg	Loamy sand/ sandy loam	(10)	6·76 t sugar/ha	6·29 t sugar/ha
Draycott *et al.* (1976)	Na, K	Varied	(12)	6·85 t sugar/ha	6·50 t sugar/ha
Last & Draycott (1977)	Na	Loams	(5)	7·39 t sugar/ha	7·57 t sugar/ha
Clare & Harrod (1978)	P, K	Sandy clay loam	(3)	9·35 t sugar/ha	9·44 t sugar/ha
Draycott & Bugg (1982)	Na	Sandy loams	(11)	6·41 t sugar/ha	6·48 t sugar/ha
		Clay loams	(8)	5·96 t sugar/ha	5·92 t sugar/ha
		Silts	(3)	7·93 t sugar/ha	7·98 t sugar/ha
		Organic	(9)	6·80 t sugar/ha	6·72 t sugar/ha
Armstrong & Jaggard (1990)	Na	Sandy loam	(3)	68·4 t beet/ha	68·4 t beet/ha

The relative mobility of the Na ion (compared with K for instance) is well documented. Williams (1976), reporting studies at Woburn on a similar soil to these experiments, found that average concentrations of nutrient in drainage water under arable cropping during 1970–75 were: 11 mg Na/l, 5 mg K/l, 8 mg

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Table 5. *Effect of time of P, K, Na and Mg fertilizer application on potassium impurities within roots at harvest (mg K/100 g sugar) for sugarbeet crops harvested in 1986 (Year 1), 1987 (Year 2) and 1988 (Year 3) on a range of soil types*

	Time of application				
Year/site	Autumn	Early spring	Late spring	Autumn/spring	S.E. (D.F.)
Year 1					
Broom's Barn	839	865	873	864	11·7 (20)
East Harling	1077	1072	1038	1041	14·8 (15)
Tattersett	870	865	867	870	11·8 (15)
Blakedown	762	805	783	767	10·5 (9)
Mean	887	902	890	886	8·1 (9)
Year 2					
Broom's Barn	775	817	820	801	19·7 (24)
Baumber	839	856	915	874	23·8 (15)
Blakeshall	882	859	896	881	8·6 (15)
East Harling	954	972	1015	971	14·9 (20)
Tattersett	821	825	830	837	13·4 (15)
Ripon	1124	1122	1150	1106	16·4 (20)
Mean	899	909	938	912	6·2 (15)
Year 3					
Broom's Barn	896	941	927	921	11·8 (24)
Baumber	814	843	838	836	11·7 (25)
Hardingham	804	825	816	818	8·9 (25)
Shereford	722	726	733	713	10·8 (25)
Mean	809	834	829	822	4·2 (9)
Grand mean	870	885	893	879	4·2 (39)

Mg/l and 0·2 mg P/l. A similar (unpublished) study performed at Broom's Barn on a clay loam soil in 1984–87 gave average nutrient concentrations of: 17 mg Na/l, 0·25 mg K/l, 170 mg Ca/l, 3·1 mg Mg/l and 0·06 mg P/l.

Tinker (1967) demonstrated from theoretical and experimental results that Na applied in fertilizers was leached rapidly from the soil. Two years' winter rainfall was sufficient to remove most of the applied Na. The autumn application in a wet year may have resulted in insufficient Na within the soil profile. Tinker (1970) described Na leaching as a simple process analogous to chromatography. Using this analogy, an estimate was made of the depth to which Na moved between the autumn application and sowing in each year. This was done using weather data from the nearest meteorological station and soil data from NO_3^- leaching studies performed on similar soil types. In Year 1 autumn-applied Na probably moved *c.* 18 cm through the soil; in Year 2, 24 cm and in Year 3, 34 cm. An important component of the chromatography analogy is 'D', the ratio between the amount of a nutrient held 'exchangeably' and the amount moving freely within the soil solution. Tinker (1970) estimated that for Na 'D' has a value ranging from 1 to 4. The value of 'D' for K (and other nutrients) is an order of magnitude larger. Therefore these other nutrients do not leach as readily. The effect of Na movement will be more serious at any site when the land has been ploughed soon after fertilizer application. This occurred at Broom's Barn in Year 1, where the Na could have been inverted to plough depth (*c.* 25 cm) and then leached a further 18 cm. In Year 2, the autumn applications were either made to the ploughed surface or were made a sufficiently long time before ploughing for the nutrient to be mixed into the soil and not buried. In Year 3, ploughing at Baumber and Shereford took place soon after fertilizer application and the Na in this fertilizer could well have been *c.* 55 cm deep when the crop was sown in 1988. This probably explains why yields from an autumn application at these sites in Year 3 were less than from those in spring.

Sugarbeet will root to 1·5–2 m depth, therefore in all three years most of the applied Na should have been available to the crops. However, Na leached from the plough layer will not become available until later in spring. Draycott & Farley (1971) showed that the major effect of Na fertilizers was to increase leaf area. Milford *et al.* (1977) demonstrated that this increase was a compensatory adjustment by the plant to accommodate the extra Na without changing water

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Table 6. *Effect of time of P, K, Na and Mg fertilizer application on α-amino-N impurities within roots at harvest (mg N/100 g sugar) for sugarbeet crops harvested in 1986 (Year 1), 1987 (Year 2) and 1988 (Year 3) on a range of soil types*

Year/site	Time of application: Autumn	Early spring	Late spring	Autumn/spring	S.E. (D.F.)
Year 1					
Broom's Barn	80	79	76	80	3·5 (20)
East Harling	64	61	59	59	2·7 (15)
Tattersett	110	100	94	103	4·1 (15)
Blakedown	74	71	67	69	4·9 (9)
Mean	82·0	77·8	74·1	77·8	1·30 (9)
Year 2					
Broom's Barn	65	62	60	64	2·1 (24)
Baumber	67	63	56	59	2·8 (15)
Blakeshall	29	32	25	34	3·4 (15)
East Harling	113	106	110	105	4·1 (20)
Tattersett	130	122	119	123	6·7 (15)
Ripon	123	131	113	116	7·8 (20)
Mean	87·9	86·0	80·4	83·6	1·66 (15)
Year 3					
Broom's Barn	61	51	77	86	13·3 (20)
Baumber	136	124	116	130	5·3 (25)
Hardingham	42	38	30	35	1·5 (25)
Shereford	48	41	39	43	2·2 (25)
Mean	71·9	63·5	65·5	73·8	4·68 (9)
Grand mean	81·6	77·2	74·3	79·1	1·55 (39)

or turgor potential. Insufficient Na in the soil may therefore reduce leaf area. Since yield is directly related to the amount of light intercepted by the foliage (Jaggard & Clark 1990) it is likely that, in Year 3, a lack of available Na may have impaired leaf expansion in the important May/June period, thus reducing photosynthetic area and yield.

The results from 140 field experiments testing the effect of time of application of basal fertilizer on beet yield varied from each other (Table 4). Russell (1956), and Draycott *et al.* (1975, 1976) obtained some benefit from application in autumn before ploughing. Conversely, Adams (1961), Webber (1961), Holmes *et al.* (1973), Last & Draycott (1977) and Clare & Harrod (1978) showed small benefits from seedbed applications. In the remaining studies there was essentially no difference between treatments. For the purpose of this paper, the data from those experiments testing times of application of Na were re-analysed with respect to winter (October–March) rainfall. Rainfall data for each experiment were obtained from the nearest ARCMET site (generally < 40 km away). There was a slight tendency for the spring treatment to perform better when there was more winter rainfall than average. The weakness of this relationship may be explained by the fact that whilst Na may leach in winter this is unlikely for K, and a sufficiency of K can compensate for any lack of Na (Adams 1961; Holmes *et al.* 1961). A further complication is that the beneficial effect of Na may be negated by crop damage due to osmotic stress following application to the seedbed.

Processing quality

The effects of K impurities (Table 5) were always small, and were inconsistent in Year 1. In Years 2 and 3 the autumn application produced the smallest concentration on a per unit of sugar basis, in seven of the ten experiments. When averaged over sites, this effect was significant in Years 2 and 3. Conversely, the late spring applications resulted in the smallest concentrations of α-amino-N (Table 6). The effect was small, and was seldom significant in individual experiments, but it was significant when averaged overall. Na is also an important impurity in beet roots; the time of application had no consistent effect on its concentration and the results are not presented here.

The relationship between soil supply of K and Na and their accumulation as impurities is not straightforward. Simon *et al.* (1966) found that an excess of soil K did not adversely affect root quality. Similar

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Table 7. *Effect of Kaynitro and Chilean nitrate of soda on sugar yield (t/ha), sugar content (%), α-amino-N (mg N/100 g sugar) and K impurities (mg K/100 g sugar) as compared to the standard late spring application for sugarbeet harvested in 1987 (Year 2) and 1988 (Year 3) on a range of soil types*

Year/site	Treatment	Sugar yield (t/ha)	Sugar content (%)	α-amino-N (mg/100 g sugar)	K impurities (mg/100 g sugar)
Year 2					
East Harling	Late spring	9·51	17·1	110	1015
	Kaynitro	9·73	17·1	111	988
	S.E. (20 D.F.)	0·320	0·12	4·1	14·9
Ripon	Late spring	8·12	16·6	113	1150
	Kaynitro	8·35	16·6	122	1094
	S.E. (20 D.F.)	0·231	0·13	7·8	16·4
Year 3					
Baumber	Late spring	10·86	18·6	116	838
	Kaynitro	10·50	18·5	118	867
	Chilean nitrate	10·80	18·6	109	838
	S.E. (25 D.F.)	0·121	0·07	5·3	11·7
Hardingham	Late spring	8·93	19·7	30	816
	Kaynitro	8·86	19·6	35	809
	Chilean nitrate	9·14	19·7	34	820
	S.E. (25 D.F.)	0·157	0·09	1·5	8·9
Shereford	Late spring	10·93	19·3	39	733
	Kaynitro	10·91	19·2	41	741
	Chilean nitrate	11·35	19·4	42	730
	S.E. (25 D.F.)	0·112	0·09	2·2	10·8

results were obtained by McDonnell *et al.* (1966), who found that large dressings of K fertilizer had little overall effect on processing quality. Draycott *et al.* (1970) tested a wide range of application rates of Na and K fertilizers. Increasing the amount of both increased the quantities of K and Na within the root, but only by small amounts. Amino-N content was reduced with increased amounts of fertilizer. The current experiments gave similar results, time of application increasing one quality component while decreasing another. Overall, these changes are unlikely to be of agronomic or industrial significance. Regression analysis of the data showed that the largest source of variation in K and α-amino-N impurities was the effect of site and year rather than treatment. For instance, for K impurities the variance ratio for site was 352, for year 45, the year/site interaction was 47, and for application time it was 6·7. Similarly for α-amino-N the variance ratios were: site 234, year 52, year/site interaction 151 and application time 5·9.

Supplementary treatments

Rotational manuring, the extra treatment at Broom's Barn, had no effect on plant population density, yield or processing quality of the sugarbeet crop. Biscoe (1990), who compared rotational and annual manuring treatments in beet and the following three cereal crops, found that the beet benefited from a rotational manuring system but this was offset by yield losses by the cereal crops. Johnston & Goulding (1988) suggested that, with a rotational manuring policy, it may be best to apply the K before the most sensitive crop. From a management point of view, a rotational manuring policy may offer some advantages, particularly the reduced cost of spreading fertilizers. In practice, this advantage is seldom realized because the large application rates usually require more than one pass of the spreader.

Table 7 compares the effect of the standard late spring input with that of Kaynitro and Chilean nitrate of soda. Relative to the late spring application neither Kaynitro nor Chilean nitrate of soda affected plant population density; effects on sugar yield were small. Chilean nitrate did, however, increase yield at Shereford in Year 3 by *c.* 0·4 t/ha. The effects of these two fertilizers on processing quality were generally small and inconsistent. Chilean nitrate slightly increased Na impurities in Year 3 at Hardingham and Shereford, and α-amino nitrogen impurities also at Hardingham. These experiments show that there is little benefit from applying Kaynitro or Chilean nitrate of soda and any benefit is unlikely to recoup the extra cost of their use.

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CONCLUSIONS

If treatments testing fertilizer timing are to have an effect on yield, they are likely to do so in conditions where the potential nutrient uptake and yield are large.

The average yield from the three years of experimental work was *c*. 40% larger than the average national yield. It is likely, therefore, that if the treatments were going to affect crop growth, differences should have been apparent in these experiments. Generally this was not the case; even on the least fertile soils the timing of basal fertilizer application had little influence on the crop. Nevertheless, there was a tendency for yield to be decreased after autumn application when during the following winter a combination of heavy rainfall and cultivation practice could have leached some nutrients out of the plough layer. On the soil types where this is a risk it is probably safest to apply the basal fertilizer either a few weeks before ploughing during late winter, or to apply it to the surface after ploughing using a vehicle which exerts only low ground-pressure. The results suggest that it is best to avoid applying the fertilizer then ploughing it down. Yield differences only occurred in soils with K indices of 1 or less following the wet winter of 1987/88. These conditions should not be too commonplace in the UK: in 1987 the British Sugar Crop Survey showed that 4% of the crop was grown on soils with a K index of zero, 40% with index 1, 43% at index 2 and 13% at index 3 and above. Even with the bias towards low indices in the experiments, the treatments which applied Na or K in the seedbed, either as a basal dressing or as a nitrogenous fertilizer, gave no significant yield advantage. These treatments also risk exposing the seeds and seedlings to osmotic stress.

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