BBRO 04/14: Effects of sodium and triazole fungicides on yield and quality on soils of different K index

Summary

1. Experiments testing interactions between the concentration of exchangeable potassium (K) in the soil and crop responses to sodium (Na) fertiliser were done on the long-term K plots with a wide range of long-established differences in soil K. Experiments were on a silty clay loam at Rothamsted in 2004 and 2005 and a sandy loam at Woburn in 2005. Ancillary treatments at Rothamsted tested responses to triazole fungicides.

2. The yield response curves to exchangeable soil K obtained in these two years were identical to those obtained in experiments on the same plots in the previous four years. Maximum yields were achieved at exchangeable soil K concentrations of 100 - 120 mg/kg at Rothamsted and 120 - 160 mg/kg at Woburn, both of which are toward lower end of Soil K Index 2. The difference could be attributed to the lower concentrations of soil Na and lower concentrations of exchangeable K in the subsoil at Woburn.

3. High sugar yields depend on the full interception and utilisation of the energy in sunlight. To achieve this, leaf canopies need to expand rapidly, especially during the early months of growth. Leaf expansion is driven by suitable temperatures and adequate supplies of nitrogen and water, but also requires turgor (the force that drives cell expansion) to be maintained within the leaf tissues. This, in turn, requires high concentrations of K and Na (the two main osmotic solutes) to be maintained within the shoot.

4. Total uptakes of 300-400 kg K/ha and 150-250 kg Na/ha were required to achieve maximum sugar yields, much of which was taken up during the early months of growth. Sugar beet took up less Na when large amounts of soil K were available - even when extra Na was supplied as a spring fertiliser. This clearly demonstrates that sugar beet use K in preference to Na and only use Na when K supplies are inadequate.

5. Three-quarters of the K and 95% of the Na remained in the shoot. Their concentrations in tissue water were calculated to examine their relative contributions to the overall osmotic status of the shoot.

6. Plants maintained a stable physiological concentration of K of *ca* 200 mM K/kg tissue water within the shoot when the soil contained an adequate supply of K. They also maintained a minimum concentration of around 100 mM of Na/kg tissue-water, but this required a minimum of 15 mg of Na/kg to be present in the soil. To achieve maximum yields crops therefore needed to maintain an overall optimal shoot concentration of the two solutes of about 300 mM/kg of tissue-water.

7. Crops were able to maintain this optimal concentration of shoot K and Na when concentrations of exchangeable K in the soil were around 120 mg/kg (*i.e.* at the lower end of the K Index 2- range) provided the soil concentrations of Na was above 15 mg/kg. Under these conditions they did not respond to NaCl fertiliser.

8. A higher concentration of exchangeable soil K (*ca* 180-200 mg/kg) was needed to maintain an optimal concentration of shoot K and Na on Na-deficient soils. Crops grown on soils with less exchangeable K respond more readily to NaCl fertiliser, especially if the soils also contain less than 15 mg of Na/kg.

9. The whole 6-year series of experiments on the Rothamsted and Woburn long-term K plots has shown that we do not need to radically alter the advice that is given on K fertiliser use. The final 2-years' experiments indicate that there is scope to target the use of Na fertilisers to help save on input costs.

10. The effects of triazole fungicides effects on yield, nutrient content and beet quality were generally small. This may have been because harvesting schedules required the beet to be lifted in September whereas there might have been more conclusive responses had autumn growth been prolonged to allow fungicidal responses to become more pronounced.

BBRO 04/14: Effects of sodium and triazole fungicides on yield and quality on soils of different K index

Introduction

Sugar beet take up and utilise large quantities of potassium (K) and sodium (Na) - uptakes of 300-400 kg K/ha and over 100 kg Na/ha are common. Potassium and sodium have similar effects on the growth and productivity of sugar beet and have been generally thought to be interchangeable when used as fertilisers. Many plant use K and Na ions as solutes to maintain tissue osmotic and turgor potentials for growth. Most use K because they cannot tolerate high concentrations of Na but sugar beet, being a derived halophyte, can readily use sodium. In sugar beet, the concentrations of K and Na in the shoot are particularly important during the early growth for the rapid expansion of the leaf canopy to maximise radiation interception [1]. Unlike K, sodium is not particularly mobile within the plant and is largely retained by the shoot and very little is translocated to the storage root. The concentrations of K and Na are more important in the shoot than the storage root because, in the latter, the sucrose accumulated during the growth acts as the primary osmotic solute. However, recent BBRO-funded experiments on the K requirement of sugar beet, done on plots at Rothamsted with long-established differences in exchangeable soil K, showed that sugar beets use K as the main shoot osmoticum in preference to Na and use Na only when insufficient K is available [2].

For maximum yield to be achieved, sugar-beet soils need to be at K Index 2 or above (i.e. contain 120-240 mg of exchangeable K/kg). The most recent Representative Soil Sampling Survey for England & Wales for 1997-2001 showed that less than one-fifth of UK arable soils contain less than satisfactory levels of exchangeable K. But comparable British Sugar field surveys [3] showed that almost three-quarters of the UK sugar-beet acreage received Na fertilizer at an average rate of 150 kg Na/ha, usually in addition to applications of K in fertiliser and manures. This implies that Na may be being used indiscriminately on sugar-beet crops that neither require nor are able to use it.

In the project reported here, Rothamsted Research's long-term K experiments were used to define the levels of soil and crop K at which sugar beet yields ceased to respond to applied Na. The tissue-water concentrations of K and Na in the shoot and storage root were measured to obtain a clearer understanding of physiological interactions between K and Na. An ancillary objective was to examine the effects of triazole fungicides on beet quality. By

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[1] Milford, GFJ (2006). *Plant structure and crop physiology. In: Sugar Beet (Ed. AE Draycott)* pp. 30-49. Blackwell Publishing: Oxford.

[2] BBRO Project 00/25: *Establishing the potassium requirements of modern high-yielding sugar beet crops for yield and quality.*

[3] BBRO Project 02/05 (extension): *Validating the use of factory tarehouse data for grower advisory packages.*

physiologically delaying canopy senescence, triazole fungicides could alter the distribution of N and K between tops and roots late in the season and so alter the concentrations of K and amino-N in the harvested beet.

The experiments

The 2-year series of experiments reported here was done as a continuation of an earlier 4-year series that used the long-term K plots on a silty clay loam on Sawyers III field at Rothamsted to examine the K requirements of modern sugar-beet crops [2]. The field has two blocks of 20 plots with long-established differences in exchangeable soil K ranging from 40-400 mg K/kg. This allows crop responses to well-established differences in soil K to be studied under uniform growing conditions at a single site - this makes it a unique facility. Alternating each block between sugar beet and a cereal break allowed a sugar beet experiment to be done each year.

In the 2004 and 2005 experiments, each large 24 x 9m plot was sub-divided into four sub-plots to test responses to freshly-applied Na, with and without a triazole fungicide, at each level of soil K. The Na was applied as none or 150 kg NaCl/ha mixed into the soil during the spring cultivations. The triazole fungicide (Punch, carbendazim + flusilazole) was applied at the recommended rate (234 g ai/ha) in early August to control late-season foliar diseases. The Na and fungicide treatments were alternated between the sub-plots in the two years.

The sub-plots were large enough for 3 m^2 area of crop to be lifted from each sub-plot by hand immediately prior to machine harvest to measure the distribution of dry matter, the tissue water content, and the uptakes and distribution of nitrogen (N), K and Na between the shoot and storage root. A larger area of each sub-plot (13.5 m^2) was lifted with a modified Garford 3-row harvester and passed through a stationary mobile tarehouse. Frozen brei samples were analysed for sugar and amino-N, K and Na impurities in a tarehouse laboratory at the National Institute of Agricultural Botany.

A smaller experiment was done on 36 long-term K plots on a sandy loam at Woburn with a similar range of exchangeable soil K. The plots were too small (3 x 3m) to sub-divide so the Na treatments (nil *vs* 150 kg Na/ha) were applied to paired plots with similar levels of exchangeable soil K. The effect of the triazole fungicide was not tested. The plots were lifted by hand and analysed in the same way as the hand-lifted plots at Rothamsted.

The 2004 experiment at Woburn was severely grazed by deer and abandoned at an early stage, but the 12 plots were included in the 2005 experiment.

Effects of soil K and Na fertiliser on yield and beet quality

Sugar yield and soil K. When the experiments on sugar-beet on these long-term K plots started in 2000, the concentrations of exchangeable K in the soil ranged from 40 to 530 mg/kg at Rothamsted and from 40 to 650 mg/kg at Woburn. These concentrations decreased during the ensuing 6-year series of experiments, because no fresh K was applied to replace that removed in the harvested beet. The decrease was greater in plots at the upper end of the exchangeable soil K range than in the low-K plots. In the present experiments involving Na, the concentrations of exchangeable K in the Rothamsted plots ranged from 40 to 390 mg/kg in 2004 and from 50 to 280 mg/kg in 2005 and, at Woburn in 2005, from 30 to 280 mg/kg. These measurements of exchangeable soil K were made, as is usual, on the upper 23 cm of soil. Deeper sampling showed that the subsoil also contained large but variable concentrations of K which were, in situations such as the low K plots at Rothamsted, greater than those in the topsoil. The concentrations of exchangeable K in the subsoil were always greater at Rothamsted than at Woburn (Table 1). This is probably because the low clay content of the sandy loam soil at Woburn limits the amount of K that could be retained and the soil's free drainage allows it to be more readily leached out of the profile.

Table 1. *Concentrations of exchangeable K (mg/kg) within the soil profiles of low, medium and high K plots of the long-term K experiments on a silty clay loam at Rothamsted and a sandy loam at Woburn between 2001 and 2003*

	Soil depth cm	2001	2002	2003
		Rothamsted		
Low	0-30	55	67	50
	30-60	76	162	67
	60-90	116	119	88
Medium	0-30	81	211	181
	30-60	89	112	107
	60-90	124	114	101
High	0-30	372	500	451
	30-60	140	130	179
	60-90	246	115	104
		Woburn		
Low	0-30	41	35	33
	30-60	30	31	27
	60-90	31	30	25
Medium	0-30	153	174	84
	30-60	90	139	112
	60-90	78	103	55
High	0-30	366	272	217
	30-60	87	135	177
	60-90	58	77	106

Figure 1 combines the data for the responses of sugar yield to differences in exchangeable soil K from all six experiments done on the long-term K plots at Rothamsted and all five of those done at Woburn between 2000 and 2006. The data relate only to the crops that received no fresh K or Na fertiliser. Maximum yields in the experiments done in the first 4 years ranged from 57 to 72 t/ha of clean beet and from 7.8 to 11.2 t/ha of sugar. In the last 2 year's experiments relating to the current Na/fungicide project, the maximum yields were 55 t/ha of clean beet and 10.3 t/ha of sugar, respectively, at Rothamsted in 2004 and 64 t/ha and 10.2 t/ha in 2005, and 73 t/ha of clean beet and 13.7 t/ha of sugar at Woburn in 2005.

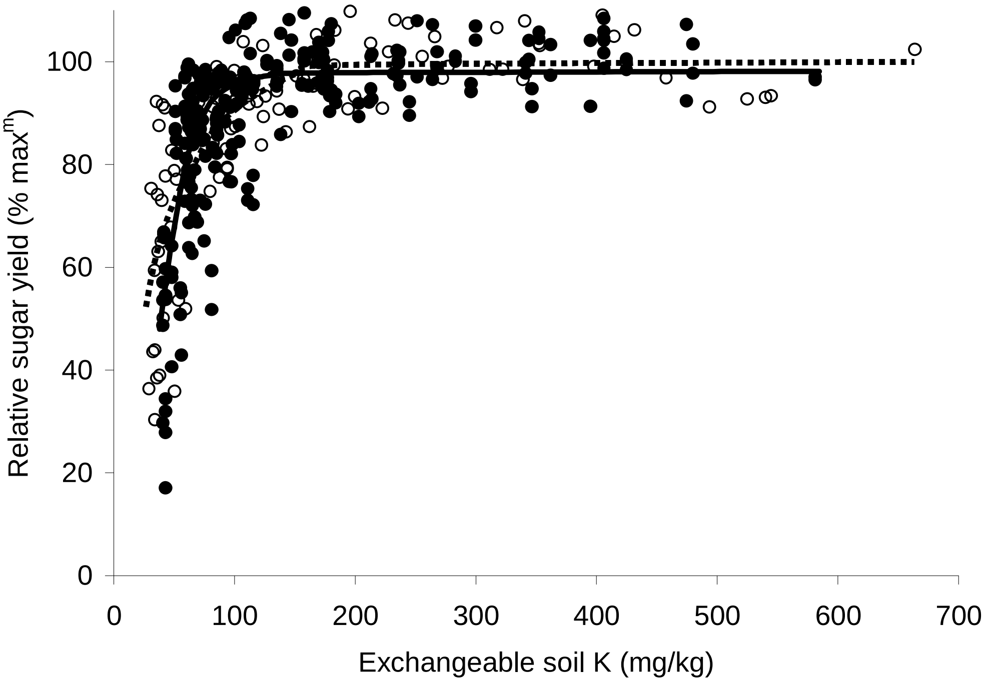

Fig. 1. *Relationships between sugar yield (expressed as a percentage of the maximum) and the concentration of exchangeable K in the soil from sugar-beet experiments between 2000 and 2005 onplots with long-established differences in soil K on a silty clay loam at Rothamsted (closed symbols and solid curve) and a sandy loam at Woburn (open symbols and dashed curve)*

Variations in yield responses between sites and seasons were minimised by expressing individual plot means as a percentage of the maximum for the experiment. The yield response curves obtained in this way were consistent across seasons at each site but, as the fitted curves show, there were slight differences between sites. The concentration of exchangeable soil K needed to achieve 95% of the maximum sugar yield (i.e. the critical concentration) was derived from the fitted regression for each curve. They were 98 ± 10.2 mg/kg for the silty clay loam at Rothamsted and 125 ± 11.2 mg/kg for the sandy loam at Woburn. Maximum yields were achieved at exchangeable soil K concentrations of 100 - 120 mg/kg at Rothamsted and 120 – 160 mg/kg at Woburn, both of which are toward the lower end of Soil K Index 2.

Responses to Na. The concentrations of exchangeable K in the soil cannot be replicated exactly in the field - even under the highly-controlled conditions of these long-term K experiments. In order to examine the interactions between soil K and applied Na on yield and beet quality, an element of replication was achieved by grouping plots within broad categories of Soil K Index. This allowed split-plot analyses of variance to be done on the Rothamsted data and paired-plot analyses on the Woburn data.

The 2005 Woburn experiment involved 36 experimental plots, 24 of which had never received Na fertiliser and had a soil concentration of about 7 mg Na /kg. The other 12 plots had been used in the 2004 experiment that was abandoned. At the start of the experiment, these plots had received a large application of Na and much of it remained in 2005, increasing the soil Na concentration to 27 mg/kg. These ancillary plots received no fresh NaCl but, even so, provided a useful contrast to the low soil Na plots.

The yields of clean beet and sugar, the fresh-weight percentage of sugar and the concentration of beet K relative to sugar were all increased by higher concentrations of exchangeable soil K in all experiments. The concentration of beet Na relative to sugar was decreased but that of amino-N was not affected (Tables 2 & 3). Clean beet and sugar yields were significantly increased by the spring applications of salt at low Soil K Index at Woburn in 2005, but not in either experiment at Rothamsted. The treatment increased the concentration of Na in the beet relative to sugar in all three experiments, but had no effect on beet K or amino-N.

Uptake and utilisation of K and Na

Crop uptakes of K. Uptakes of K by the crop increased asymptotically with increasing concentration of exchangeable K in the soil. They were at their maximum when the concentrations of exchangeable K were above 200 mg/kg. Maximum uptakes were around 300 kg K/ha at Rothamsted in 2004 and 350 and 400 kg/ha, respectively, at Woburn and Rothamsted in 2005 (Fig. 2*a*). At harvest, 75% of the K was in the shoot and 25% in the storage root, and the distribution was not affected by soil type or growing conditions (Fig. 2*b*). Sugar beet crops take up most of their K during the early months of rapid leaf expansion with uptake being largely complete by mid August. An uptake of 5 kg K/ha/day is generally considered essential to maintain maximum rates of growth. In the experiment at Rothamsted in 2002, the uptakes of K were measured in crops grown on soils with low, medium and high levels of exchangeable K. Soils at K Index 2 could sustain an uptake of 6.0 kg K/ha/day during early growth, and soils at K Index 4 an uptake of 7.3 kg K/ha/day, but soils at K Index 0 or 1 could only sustain a clearly inadequate rate of 2.1 kg K/ha/day (Fig. 3).

Table 2. *Effect of Na fertiliser on yield and beet quality at different levels of exchangeable soil K on a silty clay loam at Rothamsted in 2004 and 2005*

Soil K Index	Mean exchangeable soil K (mg/kg)	Without applied Na	Response to applied Na	Without applied Na	Response to applied Na
		2004 (Soil Na = 16 mg/kg)			
		Clean beet (t/ha)		Sugar (t/ha)	
0	66	45.7	-0.5	7.35	- 0.03
1	114	56.8	- 2.6	9.43	- 0.34
2	264	53.7	+ 4.2	8.95	+ 0.63
LSD (*P* = 0.05)		4.3	5.1	0.78	0.90
		***	ns	***	ns
		% Sugar		Amino-N (mg/100g sugar)	
0	66	16.03	+ 0.11	50.7	- 1.1
1	114	16.55	+ 0.22	53.5	- 3.1
2	264	16.67	- 0.47	51.2	- 1.8
LSD (*P* = 0.05)		0.29	0.36	2.6	3.6
		**	ns	ns	ns
		Beet K (mg/100g sugar)		Beet Na (mg/100g sugar)	
0	66	727	- 38	116	+ 22
1	114	906	+ 37	82	+ 11
2	264	1131	- 73	51	+ 18
LSD (*P* = 0.05)		57	78	14	16
		***	ns	***	***
		2005 (Soil Na = 14 mg/kg)			
		Clean beet (t/ha)		Sugar (t/ha)	
0	67	53.8	- 0.3	8.37	+ 0.15
1	97	58.4	- 1.5	9.43	- 0.06
2	202	63.1	- 0.9	10.13	+ 0.30
LSD (*P* = 0.05)		4.0	5.0	0.66	0.65
		**	ns	***	ns
		% Sugar		Amino-N (mg/100g sugar)	
0	67	15.54	+ 0.32	43.9	- 0.1
1	97	15.61	+ 0.31	46.3	+ 0.9
2	202	16.06	+ 0.22	43.5	- 1.6
LSD (*P* = 0.05)		0.32	0.32	4.9	7.7
		*	ns	ns	ns
		Beet K (mg/100g sugar)		Beet Na (mg/100g sugar)	
0	67	576	- 45	88	+ 22
1	97	775	+12	70	+ 11
2	202	1000	+4	52	+ 7
LSD (*P* = 0.05)		52	33	16	11
		***	*	***	***

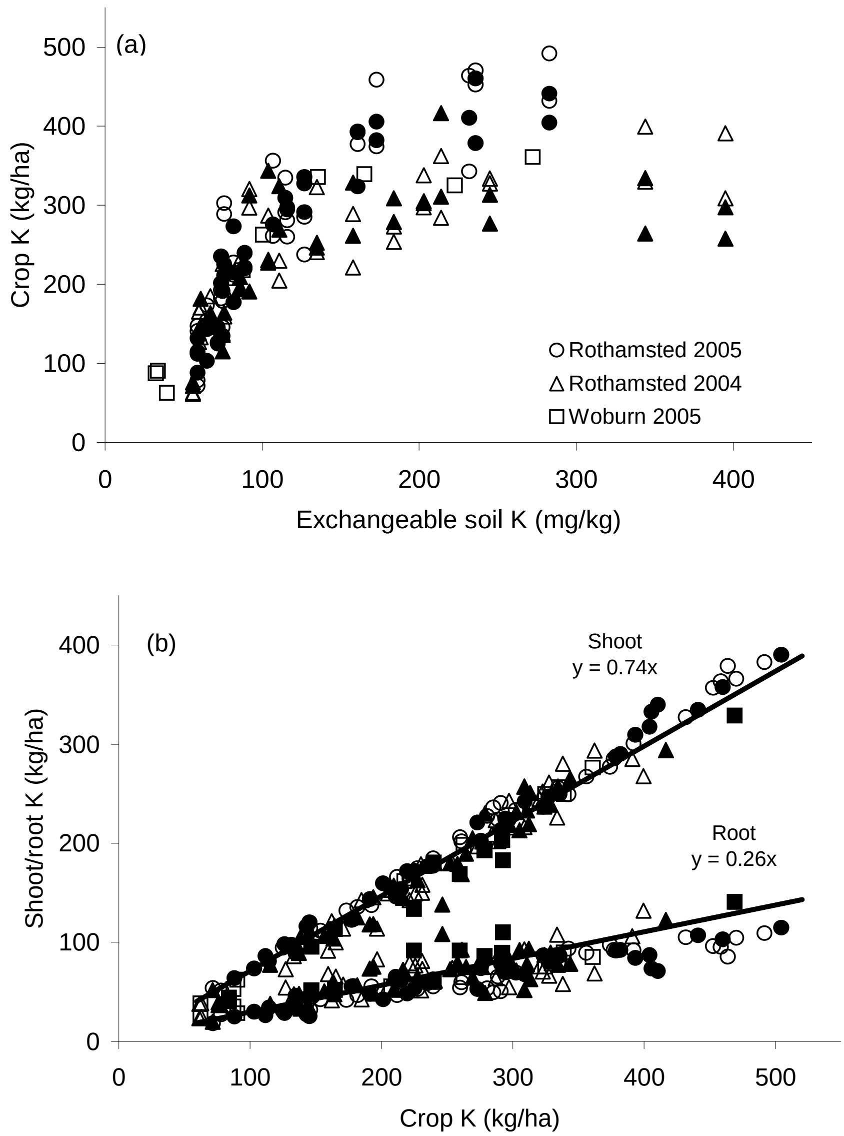

Fig. 2. *Uptakes (a) and distribution (b) of potassium in sugar-beet grown at different levels of exchangeable soil K and with none (open symbols) or 150 kg NaCl/ha (closed symbols) on a silty clay loam at Rothamsted in 2004 (triangles) and 2005 (circles), and a sandy loam at Woburn in 2005 (squares).*

Crop uptakes of Na. The average Na content of the Rothamsted soil was 16-18 mg Na/kg and that of the 24 main experimental plots at Woburn was 6 mg Na/kg. The soils of the 12 ancillary plots at Woburn that had Na residues from treatments applied in the previous year contained 26 mg Na/kg. Sugar beet took up little Na when large amounts of exchangeable K were available in the soil, even when given extra Na as a spring fertiliser. In the Rothamsted experiments, sugar beet took up 150-250 kg Na/ha when soil concentrations of exchangeable K were below 120 mg/kg, decreasing to 50-100 kg Na/ha at soil K concentrations above 200 mg/kg (Fig 4*a*). A similar response was obtained in the Woburn experiment when NaCl fertiliser was applied to the low soil Na plots in spring or the beet had access to large amounts of residual Na from the previous year. However, when little Na was present in the soil

Table 3. *Effect of higher levels of soil Na and Na fertiliser on yield and beet quality at different levels of exchangeable soil K on a sandy loam at Woburn in 2005.*

Soil K Index	Mean exchangeable soil K mg/kg	Yield without Na on soil with 7 mg Na/kg	Response to applied Na on soil with 7 mg Na/kg	Response to an increase in soil Na to 27 mg Na/kg	Yield without Na on soil with 7 mg Na/kg	Response to applying Na on soil with 7 mg Na/kg	Response to increasing soil Na to 27 mg Na/kg
		Clean beet (t/ha)			Sugar (t/ha)		
0	41	45.7	+16.2	+16.8	7.65	+2.25	+3.30
1	88	62.0	+7.1	+8.9	11.14	+1.23	+1.44
2	169	69.7	+3.8	+7.5	12.88	+0.15	+1.17
LSD (*P* = 0.05)		7.2 ***	10.2 **	8.4 ***	1.49 ***	2.11 *	2.02 **
		% Sugar			Amino-N (mg/100g sugar)		
0	41	16.71	+0.53	+0.85	34.0	-1.3	+6.3
1	88	17.94	+0.02	-0.21	50.3	-9.3	-10.6
2	169	18.48	-0.77	-0.30	45.2	+5.6	-12.7
LSD (*P* = 0.05)		1.05 *	1.76 ns	1.7 ns	8.3 *	11.7 ns	26.1 ns
		Beet K (mg/100g sugar)			Beet Na (mg/100g sugar)		
0	41	369	+66	+14	64	+112	+8
1	88	495	+111	+33	38	+48	+31
2	169	607	+240	+44	25	+60	+25
LSD (*P* = 0.05)		127 ***	180 **	25 **	66 ns	94 **	40 ns

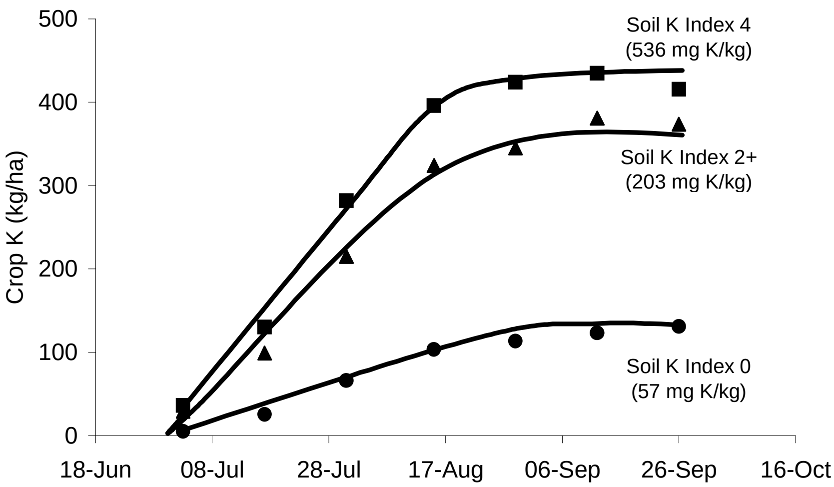

Fig. 3. *The patterns of K uptake by sugar beet crops grown on soils of different K Index on a silty clay loam at Rothamsted in 2002*

and no NaCl fertiliser was applied the sugar beet took up less than 50 kg of Na/ha, irrespective of how much exchangeable K there was in the soil. Like potassium, much of the crop's Na is taken up during the early months of leaf expansion but, unlike K, most of it is retained by the shoot and very little is present in the storage root (Fig. 4*b*).

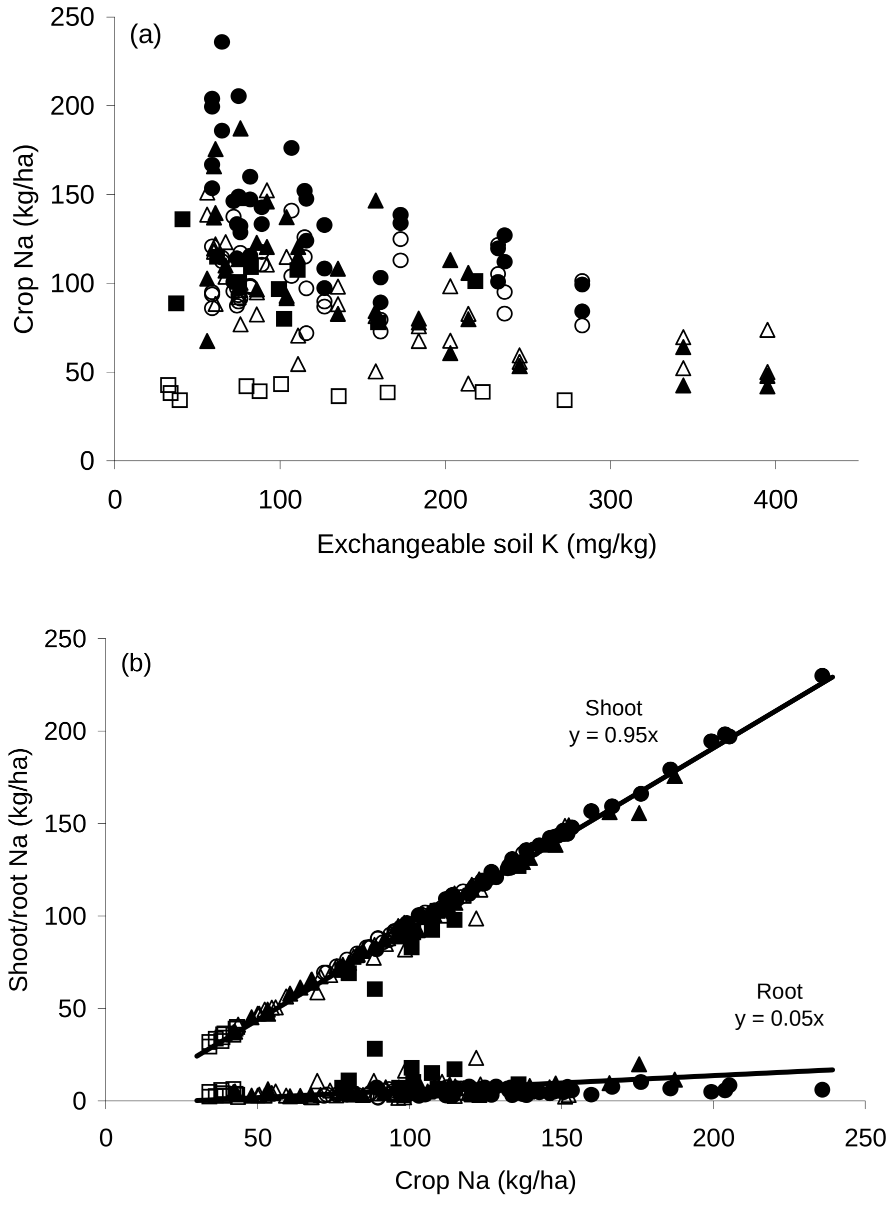

Fig. 4. *Uptake (a) and distribution (b) of sodium in sugar-beet grown at different levels of exchangeable soil K and with none (open symbols) or 150 kg NaCl/ha (closed symbols) on a silty clay loam at Rothamsted in 2004 (triangles) and 2005 (circles), and on a sandy loam at Woburn in 2005 (squares).*

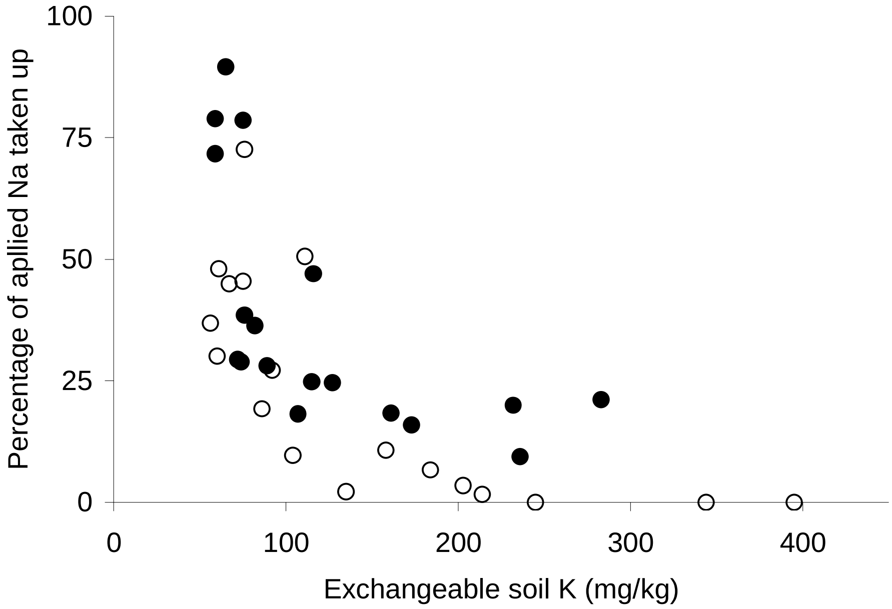

Fig. 5. *The proportion of fertiliser Na taken up by sugar beet crops at different levels of exchangeable soil K on a silty clay loam at Rothamsted in 2004 (open symbols) and 2005 (closed symbols)*

K and Na concentrations in plant tissue-water

Potassium and sodium are the main osmotic solutes within plant tissues. It is sensible, therefore, to seek to explain interactions between soil K and fertiliser Na in terms of their physiological effects on the relative concentrations of K and Na in tissue water rather than in dry matter[4]. Previous BBRO projects[2,3] considered the implications of interactions between exchangeable soil K and the concentrations of K in beet (storage root) tissue water. This report concentrates on the interactions between soil K, soil Na and applied Na on K and Na in the shoot because that is where the Na in the plant is primarily located (Fig. 4b).

The concentrations of K in shoot tissue-water increase asymptotically with the concentration of exchangeable K in the soil. They vary much less between sites and seasons than the actual quantities of K (kg/ha) that are present (Fig. 2). Concentrations are at their maximum (250 mM K/kg of tissue-water) when concentrations of exchangeable K in the soil are above 200 mg/kg (*i.e.* at the upper end of the Soil K Index 2 range).

Shoots can also accumulate high concentrations of Na in their tissue-water. When soil concentrations of exchangeable K are below 100 mg/kg (Soil Index

[4] **Leigh RA & Johnston AE** (1983). Concentrations of potassium in the dry matter and tissue water of field-grown spring barley and their relationships to yield. *Journal of Agricultural Science, Cambridge* **101**, 741-748.

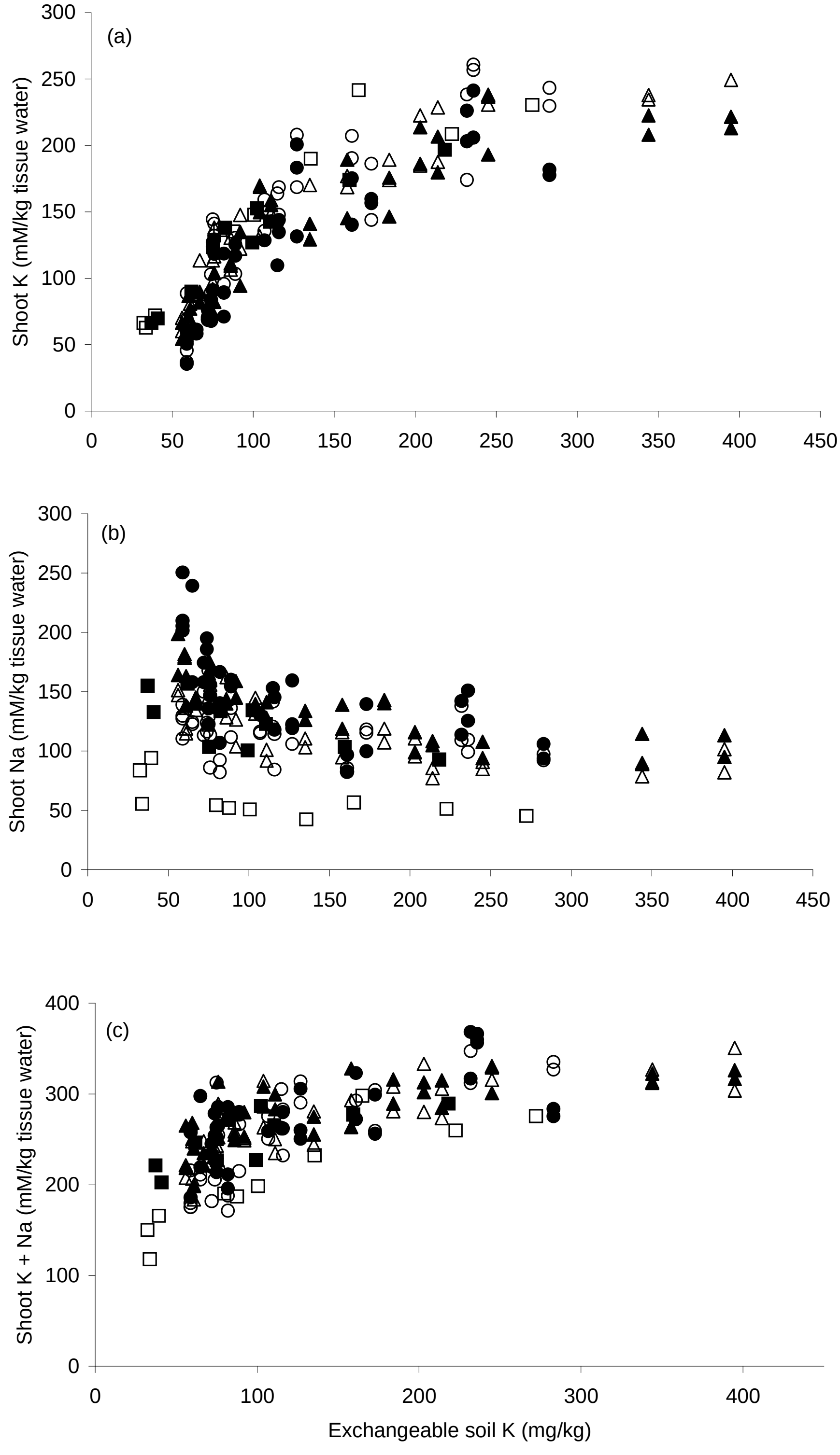

Fig. 6. *Tissue-water concentrations of (a) potassium, (b) sodium and (c) potassium plus sodium in the shoots of sugar beet grown with different levels of exchangeable soil K on a silty clay loam at Rothamsted in 2004 (circles) and 2005 (triangles) and a sandy loam at Woburn in 2005 (squares), and with (closed symbols) and without (open symbols) spring applications of 150 kg NaCl fertiliser/ha.*

0-1) shoots may contain more than 200 mM Na/kg of tissue water, but concentrations progressively decrease to about 100 mM/kg when adequate levels of soil K are available (Fig. 6b). This clearly demonstrates that sugar beet use K in preference to Na to maintain the osmotic status of the shoot, and use Na only when K supplies are inadequate.

However, the shoots of sugar beet still require a certain amount of Na, even when K is plentiful. They normally maintain a minimum concentration of about 100 mM Na/kg tissue-water, and this probably represents the critical requirement to function properly. Whether crops can achieve this critical concentration depends on the concentration of Na in the soil. Sugar beets grown on the main experimental plots at Woburn with only 6 mg soil Na/kg and without NaCl fertiliser, for instance, could only maintain shoot concentrations of around 50 mM Na/kg tissue-water.

The question is, therefore, what critical concentration of soil Na is required to maintain adequate concentrations of this nutrient in the shoot? Data from the whole 6-year series of experiments on the long-term K plots at Rothamsted and Woburn were used to help define this. The concentrations of Na in shoot tissue water in each experiment were plotted against the concentration of exchangeable soil K (as in Fig. 6*a*) and the minimum concentrations of shoot Na established when adequate levels of exchangeable K present in the soil were calculated from the asymptotes of the curves. These minimum concentrations of shoot Na are plotted against the concentrations of Na in the soil which ranged from 12 to 16 mg/kg at Rothamsted and from 5 to 26 mg/kg at Woburn (Fig. 7).

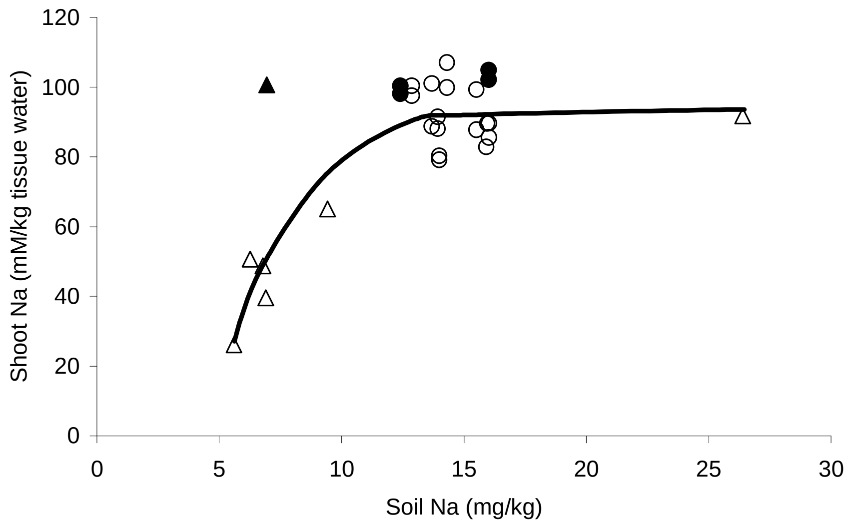

Fig.7. T*he minimum concentrations of Na in shoot tissue water established at different levels of soil Na when soil K is adequate in sugar beet grown with (closed symbols) or without (open symbols) 150kg/ha of spring-applied NaCl in experiments on a silty clay loam at Rothamsted (circles) or a sandy loam at Woburn (triangles) between 2000 and 2005*

The curve shows that, when no Na fertilisers were applied, sugar-beet plants established an optimal concentration of Na in the shoot of 90-100 mM Na/kg of tissue water only when a minimum of 15 mg/kg of Na was present in the soil. Shoots of plants grown on the main experimental plots at Woburn in 2005 with only 6 mg Na/kg in the soil maintained concentrations of only 25 to 60 mM Na/kg of tissue-water. Applying NaCl as a spring fertiliser increased these sub-optimal concentrations back to the optimum. It is worth noting, however, that this only required 150 kg NaCl/ha, whereas current advice would be to apply twice this amount on such a deficient sandy loam. Rothamsted's silty clay loam contained sufficient Na to maintain an optimal shoot tissue-water concentration of Na. Therefore, applying salt did not improve shoot Na concentrations or yield at this site.

Effect of triazole fungicides

Triazole fungicides physiologically delay canopy senescence during the autumn. They were applied to sub-plots in the Rothamsted experiments to test whether they also altered the accumulation of translocated shoot K and N in the harvested beet. Table 4 shows responses to the fungicide averaged over the different levels of soil K and the Na treatments. The fungicide had few effects on yield, the N, K and Na content of the crop or beet quality, apart from a small decrease in the amount of K in the beet in 2004 and a small increase in clean beet yield and decrease in the N content of the beet in 2005. The experiments were harvested toward the end of September in both years, so there could have been greater effects had the beet been harvested late.

Table 4. *Effect of triazole fungicide on yield, nutrient uptake and beet quality at Rothamsted in 2004 and 2005*

	2004				2005			
	Without fungicide	Response to fungicide	LSD (*P* =0.05)		Without fungicide	Response to fungicide	LSD (*P* =0.05)	
Clean beet (t/ha)	52.5	-0.5	2.3	ns	56.8	+2.4	2.0	*
Sugar (% F Wt)	16.42	+0.08	0.10	ns	15.97	-0.05	0.20	ns
Sugar (t/ha)	8.64	-0.04	0.40	ns	9.31	+0.13	0.24	ns
Beet K (mg/100g sugar)	938	-9	29	ns	765	+13	29	ns
Beet Na (mg/100g sugar)	92.3	-1.7	6.0	ns	77.4	-0.8	6.8	ns
Amino-N (mg/100g sugar)	51.3	-1.7	2.0	ns	45.7	-2.5	3.1	ns
Crop K (kg/ha)	240	-3	15	ns	267	+3	17	ns
Beet K (kg/ha)	72	-6	5	*	62	+2	4	ns
Crop Na (kg/ha)	94.9	-4.6	9.4	ns	121.3	+1.7	8.7	ns
Beet Na (kg/ha)	5.7	+0.1	1.7	ns	5.0	-0.1	0.8	ns
Crop N (kg/ha)	143	-6	10	ns	190	-8	12	ns
Beet N (kg/ha)	44.9	+0.2	2.9	ns	50.9	-2.2	1.8	*
Beet amino-N (kg/ha)	4.4	-0.1	0.3	ns	4.2	-0.2	0.3	ns

The implications for fertiliser practice

Sodium fertilizers have been widely promoted to UK sugar-beet growers on the grounds that Na and K are largely interchangeable in their functions within the plant, and Na fertilisers are cheaper than K fertilisers - or have been until recently. There are reasons to suspect that Na may now be being applied indiscriminately to sugar-beet crops that do not require, or are unable to use it. In the current project, we have used our physiological understanding of how sugar beet use K and Na to rationally define the critical levels of exchangeable soil K for yield and the conditions under which the crop is most likely to respond to applied salt.

To achieve high yields, sugar beet crops need to fully intercept and utilise the energy in sunlight. The rapid expansion of the leaf canopy is essential for this, especially during the early months of growth. Leaf expansion is primarily driven by suitable temperatures and adequate supplies of nitrogen and water. Rapid expansion also requires turgor (the force that drives cell expansion) to be maintained within the leaf tissues and this, in turn, requires shoots to maintain high concentrations of K and Na, the two main osmotic solutes [1].

The recent series of BBRO-funded experiments on the long-term K plots at Rothamsted Research, of which this project was part, showed that sugar beets need to maintain an optimum physiological concentration of about 200 mM K/kg of tissue water in their shoots to achieve rapid leaf expansion and high yield. For this, there needs to be a minimum concentration of 200 mg/kg of exchangeable K in the soil (i.e. for soils to be at Soil K Index 2 or above). The implications of this for grower advice are considered more fully in the reports on BBRO projects 00/25 and 02/05 [2,3].

Plants also need to maintain a minimum physiological tissue-water concentration of about 100 mM of Na/kg in their shoots, and the present project showed that this requires a minimum concentration of 15 mg of Na/kg in the soil. The overall optimal concentration of osmotic solutes (K plus Na) in the shoot is therefore around 300 mM/kg of tissue-water. Provided the soil contains sufficient Na, sugar-beet can maintain this overall concentration if the concentration of exchangeable K in the soil is above 120 mg/kg (*i.e.* at the lower end of the K Index 2- range). At this soil K concentration, they do not respond to NaCl fertiliser. However, soils need to contain slightly higher concentrations of exchangeable K (*ca* 180-200 mg/kg) on Na-deficient soils if non-limiting concentrations of osmotic solutes are to be maintained within the shoot. There are greater responses to NaCl fertiliser if this level of soil K is not present, especially if the soils also contain less than 15 mg/kg of Na.

The most recent Representative Soil Sampling Survey for England & Wales (for the period 1997-2001) showed that only one-fifth of the arable soils contained less than satisfactory levels of exchangeable K. British Sugar's factory measurements of the concentrations of K in the tissue-water of delivered beet indicate that the situation is similar for UK sugar-beet fields. On the other hand, recent British Sugar surveys show that almost three-quarters of UK sugar-beet crops receive Na fertilizer at an average rate of 150 kg Na/ha, usually in addition to build-up or maintenance dressings of K. Clay and organic soils, for instance, probably contain sufficient readily-exchangeable K to meet the crop's needs yet salt is applied to half of the crops grown on clay soils and a quarter of those grown on peat/organic soils. Although earlier work in these BBRO potassium projects has shown that we do not need to radically alter our advice on K fertiliser use, the current project suggests there is scope to better target the use of Na to help save on input costs.

On the basis of the current work, we conservatively estimate that approximately one-fifth of the national acreage that currently receives Na might not need it. The average cost of applying Na to sugar-beet at a rate of about 375 kg agricultural salt/ha is about £21/ha, nationally costing about £2.4 million per annum. Potential £0.5 million per annum of this could be saved with better-targeted advice.

Recent data from Rothamsted's potassium experiments and British Sugar Crop Surveys provided circumstantial evidence that triazole fungicides may alter the distribution N and K at harvest and so affect beet quality. For instance, in the Rothamsted experiments, less K was partitioned to the storage root in the two years in which a triazole fungicide was applied to control late-season diseases than in intervening years when no fungicide was used. Similarly, British Sugar's Crop Survey data show that beet sampled from fields that had been treated with triazole fungicides generally had lower concentrations of K (and amino-N) than beet taken from untreated fields. Attempts to quantify changes in the distributions of K and N by direct measurement in the current experiments were not entirely successful. The effects of triazole fungicides effects on yield, nutrient content and beet quality were generally small. This may have been because harvesting schedules required the beet to be lifted in September whereas there might have been more conclusive responses had autumn growth been prolonged to allow fungicidal responses to become more pronounced.