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The Potassium, Sodium, Magnesium, Calcium and Phosphate Nutrition of Sugarbeet (*Beta vulgaris*) Grown on Soils Containing Incorporated Straw

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Abstract: Between 1990 and 1992, a series of three experiments compared the effects of incorporating or removing straw from a total of five preceding cereal crops on the nutrient concentration, uptake and processing quality of sugarbeet. Incorporated straw increased K concentrations in tops and roots and increased total K uptake by *c* 40 kg ha^{-1}. Conversely, incorporated straw reduced Na concentrations and reduced total Na uptake by *c* 10 kg ha^{-1}. Straw incorporation had little effect on root processing quality, because whilst K impurities increased in the straw incorporated treatments, Na impurities were reduced. Generally, any effects of straw disposal method on concentration and uptake of phosphorus, calcium and magnesium were small and of little agronomic or economic significance. In the absence of regular soil analysis it is recommended that when straw has been incorporated that K fertiliser rates for beet are reduced by *c* 20 kg ha^{-1}. This is less than the allowance made for cereals. Also, contrary to the current cereal recommendation, there was no evidence for reducing P inputs when straw had been incorporated.

Key words: sugarbeet, straw incorporation, potassium, sodium, processing quality, fertilisers.

INTRODUCTION

Sugarbeet in the UK is produced on *c* 170 000 ha of land and 90% of the beet crop is grown after a winter or spring sown cereal crop. In 20% of fields the straw is disposed of by incorporation, whilst on the remaining 80% of fields the straw is baled and removed. Previous studies (Allison *et al* 1992; Allison and Hetschkun 1995) have compared the effects of incorporating or removing cereal straw on the N nutrition of beet crops. There is little information, however, on how straw disposal affects the availability of other nutrients to the beet crop. Patterson (1960) showed there was no interaction between potassium (K) fertiliser input and straw disposal method. Conversely, Short (1973) showed that when straw was removed there was an increase in root yield when extra K was applied. However, when the straw was incorporated root yields were reduced when extra K fertiliser was applied. Neither of these studies investigated the effects of straw disposal method on nutrient uptake or processing quality.

Apart from N, cereal straw contains variable concentrations of crop nutrients. Barley straw contains, on average, 4·4 g calcium (Ca) kg^{-1}, 1·0 g phosphorus (P) kg^{-1}, 12·9 g K kg^{-1} and 2·4 g sodium (Na) kg^{-1} (ARC 1976). An average crop of barley will produce about 4 t ha^{-1} of straw. This will contain about 18 kg Ca, 4 kg P, 52 kg K and 10 kg Na. Removal of this straw exports these nutrients from the field. Conversely, straw incorporation returns the nutrients to the soil.

Correct recommendation and application of basal nutrients is essential for three main reasons: first, inadequate supplies of nutrients can limit growth, yield and economic performance of the beet crop; second, oversupply of nutrients, particularly K and Na can reduce the processing quality of the roots; third, fertilisers contribute *c* 20% of the variable costs of beet production (Nix 1995) and it is important that variable costs are

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minimised to maintain competitiveness. Current fertiliser recommendations for cereals make allowances for differences in straw disposal method: K and P fertiliser inputs are smaller when the straw from previous cereal crops has been incorporated (MAFF 1994). No such allowances are made for the beet crop (Jaggard *et al* 1995). The recommendations for beet rely on soil analyses to measure soil fertility, and it is estimated that approximately two thirds of the beet growing area is soil sampled before the beet crop is grown. Using soil analysis should compensate for changes in soil fertility due to straw disposal method. However, in the absence of soil analysis changes in soil fertility may not be detected. This would lead to the risk of incorrect fertiliser recommendations.

This paper describes a study to investigate the consequences of either removing or incorporating cereal straw on the P, K, Na, Ca and Mg nutrition of sugarbeet and suggests a change to current fertiliser recommendations.

MATERIALS AND METHODS

The experiments reported here were originally designed to study the effect of straw disposal method on the N nutrition of beet (Allison *et al* 1992; Allison and Hetschkun 1995). In this paper, however, the data have been re-analysed to investigate the effect of straw disposal method on the K, Na, Mg, Ca and P nutrition of sugarbeet. The experiments were done on three fields at Broom's Barn and started with sugarbeet crops that followed winter barley crops where the straw was either incorporated or removed. However, the effect of just 1 year's straw disposal method on sugarbeet will not be discussed: effects were small, inconsistent and complicated by the use of farmyard manure (FYM) in some experiments. The straw treatments were then maintained for one complete rotation and straw from crops of spring barley, winter oats, winter wheat and winter barley were either removed or incorporated. A second beet crop was then grown and tested the effect of a total of 5 years' straw disposal method.

Only the essential details of the experiments are given below: more information can be found in Allison *et al* (1992) and Allison and Hetschkun (1995).

Experimental design and treatments

All experiments had four blocks, each with two main plots where the straw was either removed (except for stubble which was *c* 15 cm high) or incorporated. The main plots were split into six subplots which tested the effects of N fertiliser. Before the straw was incorporated it was chopped into 5 cm lengths. The chopped straw was then incorporated to a depth of *c* 12 cm with one pass of a power harrow. Rates of cereal straw addition varied between 8 and 10 t DM ha^{-1}. The straw was removed from all other areas in each field. In all the experiments the minimum subplot size was 2·5 m wide and 12 m long. No discard areas were left between blocks, main plots or subplots.

In the autumn preceding the beet crop, nutrients were applied to the entire experimental area. The rates of P, K and Mg application were determined after soil analysis (MAFF 1986) of composite soil samples from each field. The ADAS indices for all fields were P (2), K (2), Mg (1). The beet crop received *c* 50 kg P ha^{-1}, 120 kg K ha^{-1}, 53 kg Mg ha^{-1} and 160 kg Na ha^{-1}. The preceding winter wheat crops also received 35 kg P ha^{-1} and 110 kg K ha^{-1}. The other cereal crops did not receive any P, K or Mg fertiliser. Nutrients were ploughed down to a depth of 25 cm and the soil was consolidated by a furrow press. Apart from the different N application rates (0–180 kg N ha^{-1} applied as ammonium nitrate) all beet crops were managed according to current recommendations and irrigated so that soil limiting deficits were not exceeded (Jaggard *et al* 1995).

Sugarbeet harvest and analysis

In the autumn of each year, a minimum of 30 m of row was removed from each plot. Adequate discards were left at the sides and ends of each plot. The sugarbeet was lifted by hand and topped at the lowest leaf scar. The roots from each plot were washed, weighed and a representative, macerated subsample of root material (brei) was obtained. A weighed, representative subsample of the tops from each plot was also obtained. The top and brei samples were dried to constant weight at 85°C and then milled <1 mm.

Samples (0·5 g) of the milled tops and roots were digested in nitric acid (10 ml, 690 g $litre^{-1}$). The samples and acid were placed in Teflon containers, sealed and digested using a pressure-controlled microwave digestion system (Floyd RMS 150, Floyd Inc, SC, USA). The digested samples were analysed for K, Na, Mg and Ca content with a Varian SpectrAA 300P atomic absorption spectrometer using conditions suggested by the manufacturer (Varian Techtron Pty, Victoria, Australia). The P content of the plant material was measured using an automated, colorimetric method using ammonium molybdate.

Statistical analysis

Analyses of variance were produced for all plant variates for each experiment on its own and as combined analysis. Results are quoted as different if the probability of them occurring by chance was less than 5% ($P < 0{\cdot}05$).

TABLE 1
Effect of incorporating straw (+St) or removing straw (−St) on top, root and total dry matter yield of beet and top, root and total uptake of Na and K[a]

Experiment		Dry matter ($t\ ha^{-1}$)				Sodium ($kg\ Na\ ha^{-1}$)				Potassium ($kg\ K\ ha^{-1}$)			
		−St	*+St*	*SED*	*P*	*−St*	*+St*	*SED*	*P*	*−St*	*+St*	*SED*	*P*
1	Tops	5·6	5·8	0·35	0·730	99·5	98·3	8·13	0·893	164·9	194·0	12·23	0·098
	Roots	16·8	17·4	0·19	0·043	7·4	8·1	1·21	0·627	101·6	113·1	1·14	0·002
	Total	22·4	23·2	0·52	0·234	106·9	106·3	9·15	0·956	266·6	307·7	11·77	0·041
2	Tops	4·8	4·6	0·18	0·372	79·1	53·5	2·60	0·002	131·8	149·2	2·57	0·006
	Roots	15·1	13·9	0·21	0·009	6·1	4·1	0·37	0·012	95·1	92·2	1·06	0·072
	Total	19·9	18·5	0·32	0·020	85·2	57·6	2·49	0·002	226·9	241·5	2·37	0·009
3	Tops	5·2	5·6	0·24	0·195	74·9	71·2	6·06	0·587	153·2	198·7	10·20	0·021
	Roots	15·8	16·2	0·38	0·363	6·7	5·4	0·58	0·118	86·8	100·2	3·27	0·027
	Total	20·9	21·7	0·38	0·127	81·5	76·6	5·60	0·444	240·0	298·9	12·09	0·017
Mean	Tops	5·2	5·3	0·16	0·473	84·5	74·3	3·49	0·017	150·0	180·6	5·38	0·001
	Roots	15·9	15·8	0·16	0·652	6·7	5·8	0·46	0·089	94·5	101·9	1·21	0·001
	Total	21·1	21·1	0·24	0·862	91·2	80·2	3·67	0·015	244·5	282·5	5·68	0·001

[a] Results have been averaged over N treatments. Results for individual experiments are based upon 3 degrees of freedom and mean results are based on 9 degrees of freedom. *P* is the probability of treatment differences occurring by chance.

RESULTS AND DISCUSSION

Total DM yields ranged from 18·5 to 23·2 t ha^{-1} (Table 1), and these values are typical for irrigated, hand harvested crops (Scott and Jaggard 1993). Straw disposal method had little consistent effect on top, root or total DM yield, although incorporated straw reduced root DM yield by 1·2 t ha^{-1} in Experiment 2 (Table 1). In all experiments, incorporated straw significantly increased the K content of the roots and tops, with the mean K content of the tops increased by 19% and the roots by 8% (Table 2). The concentrations of K in tops and roots were similar to those quoted by Draycott (1972), and indicated that all crops were adequately supplied with K. Total K uptake ranged from 227 to 308 kg ha^{-1}. Averaged over all three experiments, incorporated straw increased total K uptake by *c* 40 kg ha^{-1}. The concentration of Na in top and root DM were also similar to literature values (Draycott 1972). The effects of straw disposal method on Na con-

TABLE 2
Effect of incorporating straw (+St) or removing straw (−St) on the concentration of Na and K in beet top and root dry matter[a]

Experiment		Sodium ($g\ Na\ kg^{-1}$)				Potassium ($g\ K\ kg^{-1}$)			
		−St	*+St*	*SED*	*P*	*−St*	*+St*	*SED*	*P*
1	Tops	17·2	16·9	1·170	0·795	29·4	34·0	0·535	0·003
	Roots	0·44	0·45	0·067	0·836	6·07	6·48	0·107	0·030
2	Tops	16·3	11·6	0·600	0·004	27·6	33·5	1·080	0·013
	Roots	0·40	0·29	0·029	0·029	6·29	6·67	0·105	0·037
3	Tops	14·5	12·8	1·26	0·257	29·9	36·1	1·750	0·037
	Roots	0·42	0·33	0·035	0·080	5·49	6·18	0·090	0·005
Mean	Tops	16·0	13·7	0·61	0·005	28·9	34·5	0·071	0·001
	Roots	0·42	0·36	0·027	0·043	5·95	6·44	0·058	0·001

[a] Results have been averaged over N treatments. Results for individual experiments are based upon 3 degrees of freedom and mean results are based on 9 degrees of freedom. *P* is the probability of treatment differences occurring by chance.

centration and uptake were less consistent than for K. On average, incorporated straw reduced the Na content of tops and roots by 14% and Na uptake by 12% (Table 2). Over the three experiments, total Na uptake was as variable as K uptake and ranged from 52 to 100 kg ha^{-1}. Straw incorporation reduced Na uptake by 10 kg ha^{-1}. For both K and Na uptake, the effect of straw disposal method was most noticeable in the tops, this accounting for 80–90% of the difference in total K and Na uptake.

Incorporated straw significantly reduced Na impurities in experiments 2 and 3 and reduced Na impurities by *c* 16% when averaged over all three experiments (Table 3). Conversely, K impurity concentrations were significantly increased in all three experiments an average of 8% by incorporated straw. These results are similar to those obtained in recent straw disposal experiments at ADAS Terrington (Hayward 1993). In these studies, a beet crop was grown in 1992 on a silty textured soil that had been straw incorporated for ten years or where the straw had been removed (in 1991) or burnt (1981–1990). Potassium impurity concentrations increased by *c* 10% where straw had been incorporated (Cormack W pers comm).

The net effect of straw disposal method on sugar loss was assessed using the 'New Braunschweig Formula' (Märländer *et al* 1996)

$$\text{surcrose lost in molasses} = 0{\cdot}12\ (\mathrm{K} + \mathrm{Na}) + 0{\cdot}24\alpha\text{-amino N} + 1{\cdot}08$$

Surcrose losses were estimated to be 1·78% and 1·81% in straw removed or straw incorporated plots, respectively. These effects are small, and are not likely to be of economic significance. Since K and Na both have osmoregulatory roles within the plant, and are to a certain extent interchangeable, whilst incorporated straw increases K impurities, Na impurities are decreased with no overall effect on processing quality. However, in soils that contain much plant available K, the increase in K uptake will not be compensated for by a pro rata decrease in Na uptake. In these circumstances beet processing quality may be reduced (Last *et al* 1985). These results suggest that if straw in incorporated, K fertiliser inputs will need to be reduced to minimise impairment of root quality.

Concentrations and uptakes of P, Ca and Mg

Compared to Na and K the effects of straw disposal method on the concentration and uptake of P, Ca and Mg were small and inconsistent in both series (data not shown). When averaged over all three sites and both occasions the concentrations of P, Ca and Mg in the tops were 2·36, 8·27 and 1·63 g kg^{-1}, respectively, and the concentrations in the roots were 0·73, 1·87 and 0·97 g kg^{-1}, respectively. Total uptakes of P, Ca and Mg were 23, 71 and 23 kg ha^{-1}. From a beet processing viewpoint, P, Ca and Mg are relatively unimportant since they do not interfere with the crystallisation of sucrose or contribute to the production of low-value molasses (Harvey and Dutton 1993). Therefore, there is no evidence to suggest that when straw is incorporated P inputs to beet should be reduced. This is unlike the situation in cereals (MAFF 1994).

Modifications to K fertiliser inputs when straw is incorporated

Current fertiliser recommendations aim to increase K fertility in low fertility soils (ADAS Index 0 or 1), maintain soil fertility in soils with ADAS index 2 or 3 or reduce it if the indices are 4 or above (Jaggard *et al* 1995). On fields where the soils are sampled regularly, increases in K supply will be matched with reductions in K input. However, this will not be the case where there is no regular soil sampling policy.

TABLE 3
Effect of incorporating straw (+St) or removing straw (−St) on the concentration of Na and K impurities within beet roots[a]

Experiment	*Sodium (mg Na Kg^{-1} sugar)*				*Potassium (mg K kg^{-1} sugar)*			
	−St	*+St*	*SED*	*P*	*−St*	*+St*	*SED*	*P*
1	626	618	28·8	0·783	7790	8340	175·3	0·051
2	519	376	8·72	0·001	7650	8150	122·7	0·028
3	459	360	24·2	0·026	7380	8210	61·6	0·001
Mean	535	451	12·86	0·001	7610	8230	74·2	0·001

[a] Results have been averaged over N treatments. Results for individual experiments are based upon 3 degrees of freedom and mean results are based on 9 degrees of freedom. *P* is the probability of treatment differences occurring by chance.

In these experiments, incorporated straw increased K uptake by an average of 40 kg K ha^{-1} relative to where the straw was removed. Assuming that this increase in uptake was mainly due to the K released from the previous barley crop (which contained *c* 90 kg K ha^{-1}), the efficiency of K transfer was *c* 45–50%. Using average straw yield data (Nix 1995) and typical K contents (ARC 1976; Withers 1991) it is suggested that, in the absence of soil analysis, K fertiliser input to beet should be reduced by 20 kg K ha^{-1} when there has been a history of straw incorporation. This estimate assumes that the K supply in the unincorporated soil was adequate, and that the excess K uptake observed in the straw incorporated plots was due to luxury consumption. Due to the experimental design that assumption cannot be fully tested by the present work. However, sugar and dry matter yields were not markedly increased by straw disposal method (Allison and Hetschkun 1995) and therefore it is likely that no crops were K limited.

CONCLUSIONS

Incorporating straw has been shown to increase the uptake of K by beet and to increase the amount of extractable K in the soil. In the absence of soil analysis, it is recommended that K inputs to beet are reduced *c* 20 kg ha^{-1} when straw has been incorporated. Ideally, soil sampling should be used at least once per rotation to ensure correct K inputs. In these experiments there was no evidence that straw incorporation had an agronomically significant effect on the P, Ca and Mg nutrition of beet.

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