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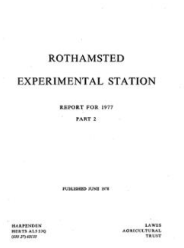

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Yields of Sugar Beet and Barley in Contrasting Crop Rotations at Broom's Barn, 1971–76

A. P. DRAYCOTT, M. J. DURRANT, R. HULL and D. J. WEBB

Introduction

An experiment started at Broom's Barn in 1965 compared yields of crops, particularly sugar beet, given phosphorus, potassium and sodium in amounts considered optimal for each crop in five contrasting rotations. Four amounts of nitrogen fertiliser were tested each time sugar beet was grown. The experiment was described in *Rothamsted Report for 1971*, Part 2, 149–154, together with the yields and nutrient balances for the first six years. This paper reports results of the second six years and draws conclusions for the whole 12 years of cropping.

Field details

The rotations were continued unchanged in 1971–76: Rotation I (RI)—sugar beet every year; Rotation II (RII)—once in three years with two barley crops; Rotation III (RIII) once in six years with five barley crops; Rotation IV (RIV)—once in three years with a two-year leys; and Rotation V (RV)—with beans and potatoes. The cultivars were the same except as follows: sugar beet was Bush Mono 1971–73 and Bush Mono 'G' 1974–76, barley was Julia and beans were Maris Bead, 1971–76. Table 1 lists the amounts of each element given to each crop and shows that some modifications were made following results of the first six years of cropping. The major differences were increased nitrogen to second and subsequent barley crops and to grass, and more potassium to beans, potatoes and grass. Three plots in the continuous sugar beet (RI) were given magnesium. Harvesting procedure and plant sampling were as before, except that dry matter determinations were made on crop samples from all plots.

TABLE 1

Amounts of each element applied (kg ha^{-1}), 1971–76

	N	P	K	Na	Mg
Sugar beet, RI	*	28	84	49	†
Sugar beet, RII–V	*	28	84	148	—
Barley—First year after sugar beet	75	38	42	—	—
Barley—Second and subsequent years after sugar beet	106	38	42	—	—
Beans	—	33	83	—	—
Potatoes	100	33	124	—	—
Grass—First year	75	38	104	—	—
Grass—After first cut	75	—	104	—	—
Grass—Second year	150	38	208	—	—
Grass—After first cut	75	—	104	—	—

* Sugar-beet plots split for 0, 63, 125 and 188 kg N ha^{-1}.
† Mg applied to three RI plots at 100 kg Mg ha^{-1} every year.

Pests and diseases. Until 1977, searches for viable cysts of *Heterodera schachtii* on RI plots revealed none. None was found on the roots of the plants examined in July 1975; further soil samples in November 1976 contained mainly *H. avenae*, some of *H. mani*

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TABLE 2

Numbers of some arthropods caught in pitfall traps in three rotations, 1973–75

	1973	1974	1975		1973	1974	1975		1973	1974	1975
BEETLE PESTS											
Atomaria linearis				*Agriotes* spp.				*Chaetocnema* spp.			
RI	924	454	418	RI	0	6	0	RI	2	3	0
RII	592	734	505	RII	8	1	2	RII	0	6	3
RIII	122	132	41	RIII	37	37	12	RIII	0	0	0
CARABID BEETLES											
Agonum dorsale				*Amara* spp.				*Bembidion femoratum*			
RI	28	53	33	RI	3	8	13	RI	140	109	54
RII	24	37	32	RII	5	10	5	RII	107	100	76
RIII	80	50	86	RIII	22	16	23	RIII	22	5	1
Bembidion lampros				*Bembidion quadrimaculatum*				*Bembidion tetracolum*			
RI	540	524	682	RI	8	30	2	RI	8	9	3
RII	352	507	542	RII	7	15	3	RII	14	2	0
RIII	282	186	403	RIII	2	1	5	RIII	7	0	3
Calathus spp.*				*Harpalus aeneus*				*Harpalus rufipes*			
RI	0	0	6	RI	20	23	23	RI	13	4	89
RII	0	0	9	RII	9	10	20	RII	11	2	79
RIII	0	1	47	RIII	13	16	13	RIII	14	9	39
Notiophilus biguttatus				*Pterostichus melanarius*				*Synuchus nivalis*			
RI	7	8	7	RI	266	53	588	RI	0	0	26
RII	11	5	6	RII	312	45	508	RII	0	0	45
RIII	34	20	23	RIII	518	257	1867	RIII	0	0	7
Trechus quadristriatus											
RI	10	51	54								
RII	23	42	47								
RIII	8	17	18								

OTHER BENEFICIAL ARTHROPODS (1975 only)

	Staphylinid beetles	Centipedes	Spiders
RI	1365	20	295
RII	537	12	268
RIII	1197	12	558

	Coccinellid adults	Coccinellid larvae	Hymenoptera
RI	14	68	349
RII	11	90	274
RIII	43	75	357

APHIDS

	Winged	Wingless
RI	302	52
RII	292	47
RIII	174	*c.* 2800

* Mainly *fuscipes*, a few *erratus* in 1975
Other carabids caught, but only in very small numbers, were: *Agonum muelleri, Asaphidion flavipes, Demetrias atricapillus, Loricera pilicornis, Nebria brevicollis, Pterostochus madidus, Stomis pumicatus.*

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type, *Globodera rostochiensis* (RV only) and also a few old and empty cysts of *H. schachtii* group (determined by Alan Stone, Nematology Department). In October 1977, however, numerous *H. schachtii* cysts were found on sugar-beet roots in three out of nine RI plots (one plot had a heavy infestation on all roots examined); isolated cysts were also found on one RV plot and one RII plot (each adjacent to a heavily-infested RI plot). Evidently the pest has been present in small numbers for some years but appears not to have affected yields significantly, except probably on the most heavily-infested plot in 1977. The nematode is undoubtedly present in other plots but in insufficient numbers to be readily detected or to affect yields adversely.

Aphanomyces cochlioides was found in an area of the experiment in 1971 but this was not restricted to continuous sugar-beet plots. In 1973 and in 1974, violet root rot (*Helicobasidium purpurem*) infected continuous sugar beet on some plots. Nitrogen fertiliser greatly decreased the symptoms even when the smallest dressing was given.

In 1973–75, pitfall traps (*Rothamsted Report for 1969*, Part 1, 312) were used to determine the activity of carabid beetles and other arthropods on the soil surface of three contrasting treatments, viz. sugar beet on RI, sugar beet on RII and barley after sugar beet on RIII. Trapping started soon after sugar beet sowing and ended at cereal harvest, the periods being 22/3–12/7/73, 2/4–9/7/74 and 29/4–5/8/75. Total catches for six traps (two per plot, on three plots per rotation) are given in Table 2.

The plots were small and it was likely that these creatures moved between plots. Differences in total catch observed between sugar beet and barley plots were considerable but may well be a result of differential preferences for degree of soil cover (Baker & Dunning, 1975) rather than of rotation. Effects most probably due to rotation can only be measured between RI and RII; they occurred with staphylinid beetles which were more numerous on RI than RII ($P = 0{\cdot}01$). Differences might have been expected with *Atomaria linearis* but this only occurred in 1973. On a field scale, this specific pest of sugar beet often causes crop failure in the absence of a rotation but the RI plots established as well as the RII, presumably because the intermingled small plots allowed dispersion and dilution of beetles.

Weeds. A survey of the weed populations in each of the rotations is in progress and will be reported in full at a later date. In brief, after nine crops the experimental area was sampled to assess the weed seed population and species composition. Soil from each phase of each rotation was kept moist in 3-cm-deep seed boxes in the glasshouse and the emerged weed seedlings were identified, counted and removed (always before flowering). Soil from the rotation of sugar beet, beans and potatoes (RV) contained more weed seeds than any other rotation, particularly of *Chenopodium album* L. and *Urtica urens* L. This was probably because no herbicides were used in the potato crop and good mechanical weed control was not achieved.

Yields

Mean effect of rotation. Table 3 shows that the effects of the rotations on sugar yields were usually small in the period 1971–76, as they were in the previous six years. The mean sugar yields in 1971–76 show that sugar beet in rotation with five barleys (RIII) were significantly less than the other four rotations. Yield of sugar was least in RIII in every year 1973–76. There was no other consistent difference between RI, RII, RIV and RV. The design of the experiment was such that crops in rotation with sugar beet were given nitrogen fertiliser. The only plots given no nitrogen fertiliser were some of those in RI which received no nitrogen since 1964. As discussed later, these plots cause a slight underestimate of the sugar yield on RI in Table 3.

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TABLE 3

Crop yields (mean all nitrogen treatments)

	1971	1972	1973	1974	1975	1976	Mean 1971–76
Sugar beet							
				Sugar, t ha^{-1}			
Rotation							
RI	6·29	6·17	6·85	3·48	4·83	3·99	5·27
RII	6·85	5·52	7·14	3·68	4·90	4·27	5·39
RIII	6·19	5·50	6·58	3·30	4·28	3·62	4·91
RIV	5·79	6·64	6·84	3·43	5·25	4·09	5·34
RV	6.61	5·15	7·04	3·60	4·61	3·91	5·15
SED	±0·354	±0·462	±0·251	±0·285	±0·299	±0·194	±0·068
Mean of all rotations	6·35	5·80	6·89	3·50	4·78	3·98	
			±0·075				
Barley grain Year after sugar beet				t ha^{-1} at 85% DM			
1	3·86	3·95	3·52	2·59	3·75	2·08	3·29
2	3·79	3·97	3·42	2·49	3·23	2·20	3·18
3	3·55	4·09	3·45	2·23	2·85	1·77	2·99
4	3·12	3·72	3·35	2·35	2·68	1·89	2·85
5	3·27	3·57	3·03	2·27	2·92	1·66	2·79
SED							±0·055
Bean grain				t ha^{-1} at 85% DM			
	1·75	1·77	2·98	1·33	0·63	0·69	1·53
Grass Year after sugar beet				Total DM t ha^{-1}			
1	5.32	2·91	7·34	3·50	0·96	1·22	3·54
2	10·01	9·78	10·45	10·21	11·39	6·72	9·76
Potato tubers				Fresh weight t ha^{-1}			
	32·6	28·8	30·2	23·9	10·0	9·1	22·4

As before, barley yields were always greatest after sugar beet and declined in successive crops. The decline continued in RIII throughout five years whereas in 1965–70 the yield decreased for three years and then remained the same. Bean yields were poor, particularly in the dry summers of the last three years and this soil appears to be unsuitable for the crop. Grass yields were greater in 1971–76 than 1965–70 due to increased fertiliser use but, without irrigation, yields were relatively poor. Potato tuber yields also suffered badly from water shortage in 1975 and 1976. The total amount of dry matter produced by each rotation during the six years was RI—66·3, RII—42·7, RIII—33·9, RIV—49·4 and RV—37·6 t ha^{-1}, less in all cases than in the previous six years. Yields in individual years have been discussed in *Rothamsted Reports for 1971–76*, 293, 287, 277, 67, 74 and 75 respectively.

Effect of nitrogen fertiliser on sugar yields. Figure 1 shows the mean effect of nitrogen fertiliser on sugar yield in each rotation. Between 63 and 125 kg N ha^{-1} were needed for maximum sugar yield in all five rotations. In RI and RIV, response appeared to be decreasing between 63 and 125 kg N ha^{-1} probably because of a large residue of nitrogen in the soil from previous beet (RI) or grass (RIV). In RII and RIII, response appeared

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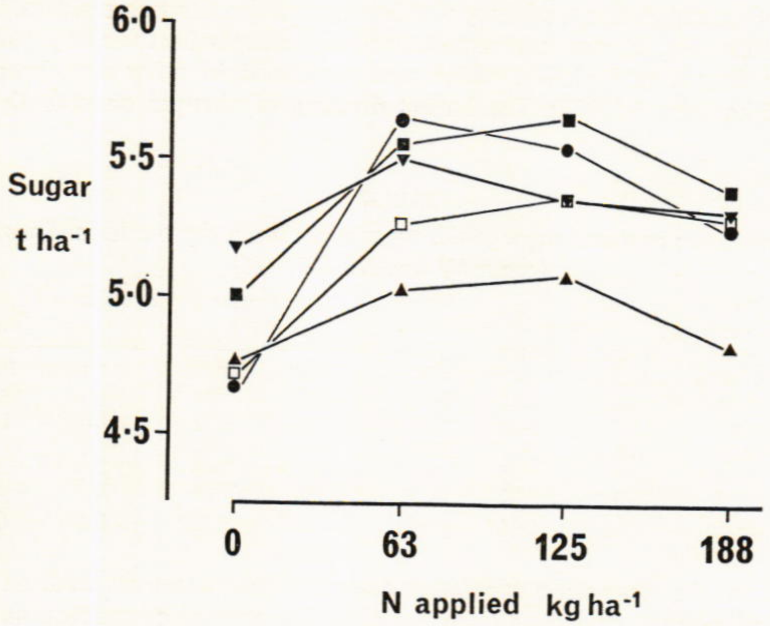

FIG. 1. Effect of nitrogen fertiliser on yield of sugar in five rotations. Mean 1971–76. ●, RI; ■, RII; ▲, RIII; ▼, RIV; □, RV.

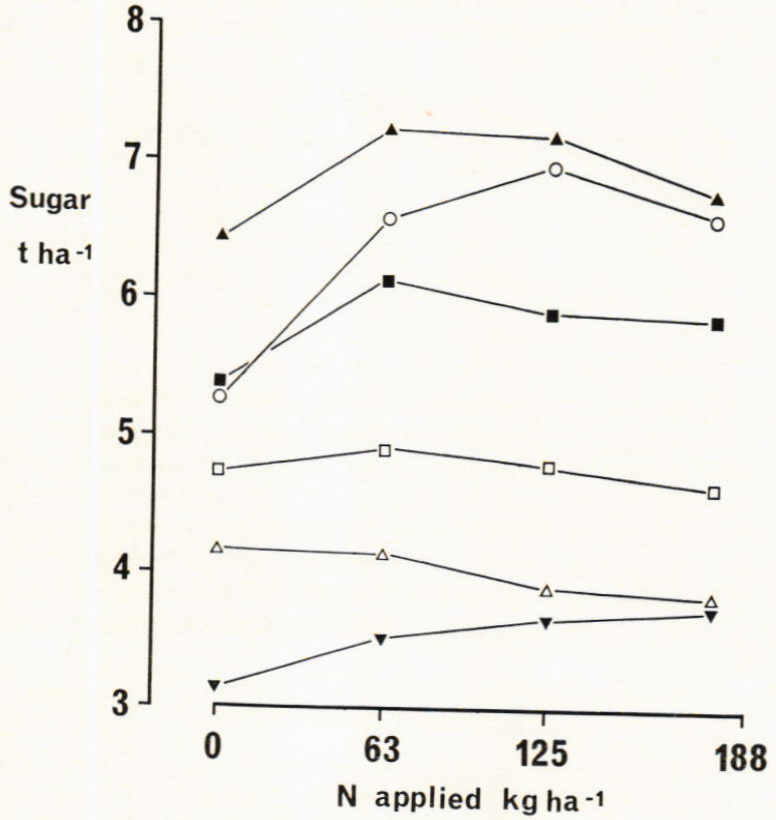

FIG. 2. Effect of nitrogen fertiliser on yield of sugar each year. Mean five rotations. ○, 1971; ■, 1972; ▲, 1973; ▼, 1974; □, 1975; △, 1976.

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to be increasing, suggesting the barley was leaving smaller nitrogen residues. On average of the rotations (Fig. 2), nitrogen requirement of the sugar beet varied greatly between years—from 0 kg N ha^{-1} (1976), which was confirmed in other experiments in that year, to 125 kg N ha^{-1} (1971). The largest dressing of nitrogen consistently decreased sugar yield.

TABLE 4

Effect of rotation on root and sugar yield, sugar percentage, dry matter and root impurities (mean N1 and N2 1971–76)

Rotation	Fresh root yield (t ha^{-1})	Sugar (%)	Sugar (t ha^{-1})	Fresh top yield (t ha^{-1})	Dry matter (t ha^{-1}) Tops	Dry matter (t ha^{-1}) Roots	α-amino N (meq per 100 g beet)	K (meq per 100 g beet)	Na (meq per 100 g beet)
RI	34·0	16·4	5·59	24·1	3·96	7·77	2·11	3·88	1·20
RII	33·5	16·7	5·60	21·6	3·61	7·72	1·74	4·02	0·87
RIII	30·7	16·4	5·05	20·9	3·46	7·06	1·87	4·04	0·70
RIV	33·0	16·4	5·45	20·9	4·01	7·63	2·20	4·35	0·94
RV	32·0	16·6	5·32	21·7	3·54	7·35	1·73	4·02	1·02
SED	±0·97	±0·15	±0·187	±0·99	±0·158	±0·252	±0·108	±0·082	±0·056

Table 4 shows the mean effect of rotation on several measurements made on sugar beet, omitting plots given 0 or 188 kg N ha^{-1}, i.e. of the crop given near-optimal nitrogen dressing. The results show that continuous sugar beet (RI) yielded at least as well as sugar beet in the other rotations. Yields of sugar in RIII were significantly smaller than the rest but the relatively small amounts of sodium found in the roots at harvest gave the first indication of a possible explanation—this is considered in more detail below.

TABLE 5

Effect of nitrogen given to sugar beet on barley grain yield, 1971–76

Years after sugar beet	N0	N1	N2	N3
	t ha^{-1} at 85% DM			
1	3·31	3·24	3·33	3·29
2	3·13	3·16	3·21	3·22
3	2·96	3·03	3·08	2·90
4	2·83	2·82	2·90	2·86
5	2·75	2·76	2·81	2·83
SED		±0·111		

Effect of residual nitrogen. Table 5 gives the yield of barley following the four nitrogen treatments for sugar beet. In the first year after sugar beet, 75 kg N ha^{-1} were given to barley and there was no response to residual nitrogen. Thus less than 75 kg N ha^{-1} could have been used. There was a suggestion that residues slightly improved the yields of the second and subsequent barley crops even though these received 106 kg N ha^{-1}. However, there was no justification for increasing this dressing when, as in common practice, 63–125 kg N ha^{-1} are given for the sugar beet. Similarly, if the sugar beet received at least 63 kg N ha^{-1}, the nitrogen dressings given for potatoes, grass and beans were adequate.

Nutrient balance for each rotation

The amounts of nutrients removed in the crops were determined from their yields and chemical analyses. The previous paper (Draycott, Durrant, Hull & Webb, 1972) described the effects of rotation on the total amount of each nutrient in sugar beet. Effects were similar in 1971–76 and results are not presented here. In the previous paper, however,

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nutrient removal by the different crops was not given, thus Table 6 shows mean values for six elements. On plots where magnesium was given, uptake in roots and tops was increased from 15 to 20 kg Mg ha^{-1}, but without effect on yield.

TABLE 6

Mean annual offtake by sugar-beet roots, barley and bean grain and straw, grass and potato tubers, 1971–76

	N	P	K	Na	Ca	Mg
			kg ha^{-1}			
Sugar beet	69	11	60	12	25	8
Barley	73	13	40	5	16	5
Beans	90	12	29	5	21	3
Grass—First year	101	14	144	13	31	5
Second year	145	27	264	19	54	11
Potatoes	81	12	95	1	1	4

Nutrient balances (amount applied − amount removed) for the second six years and for the whole 12-year period are shown in Table 7. Giving 125 kg N ha^{-1} to continuous sugar beet (RI) left a residue of nearly 50 kg N ha^{-1} year^{-1}. Phosphorus balance over the 12-year period was between 12 and 18 kg P ha^{-1} year^{-1} and potassium between 17 and 25 kg K ha^{-1}. Results of a nearby experiment (Draycott, Durrant & Webb, 1978) suggest that nutrient balances of this order for phosphorus would result in no limitation of yield of sugar beet or cereals through shortage of phosphorus. In the case of potassium, however, a large part of the 12-year balance came from the residue from kainit given in 1964 for the first crop. As the increase in residues was relatively small in 1966 and 1967, the amounts of potassium given to some crops was increased in 1968 and revised again in 1971. As shown in Table 7, this had the desired effect and left residues

TABLE 7

Nutrient balance for each rotation (125 kg N ha^{-1} applied to sugar beet)

1965–76 Rotation	Amount applied − Amount removed (kg ha^{-1})				
	N	P	K	Na	Mg
RI	+574	+183	+306	+485	−114*
RII	+249	+189	+213	+554	−82
RIII	+272	+204	+217	+318	−69
RIV	+354	+146	+270	+515	−98
RV	−220	+218	+281	+554	−71

* Plots given magnesium: +474.

1971–76 Rotation	N	P	K	Na	Mg
RI	+313	+99	+155	+207	−48*
RII	+172	+128	+43	+242	−37
RIII	+197	+142	+29	+116	−32
RIV	+291	+99	+168	+207	−49
RV	−27	+117	+209	+260	−30

* Plots given magnesium: +540.

of between 26 and 33 kg K ha^{-1} year^{-1} between 1971 and 1976 on RI, RIV and RV. The amount of potassium given to barley was not changed so residues of only 7 and 5 kg ha^{-1} year^{-1} were left on RII and RIII which, judging from the adjacent fertiliser experiment, would be insufficient to maintain the soil potassium status. Since potassium and sodium fertilisers are partially interchangeable (Durrant, Draycott & Boyd, 1974), it is necessary to consider these nutrients together. Table 7 shows that the sodium balance was smallest in RIII simply because it was given half as often. This suggests that as the

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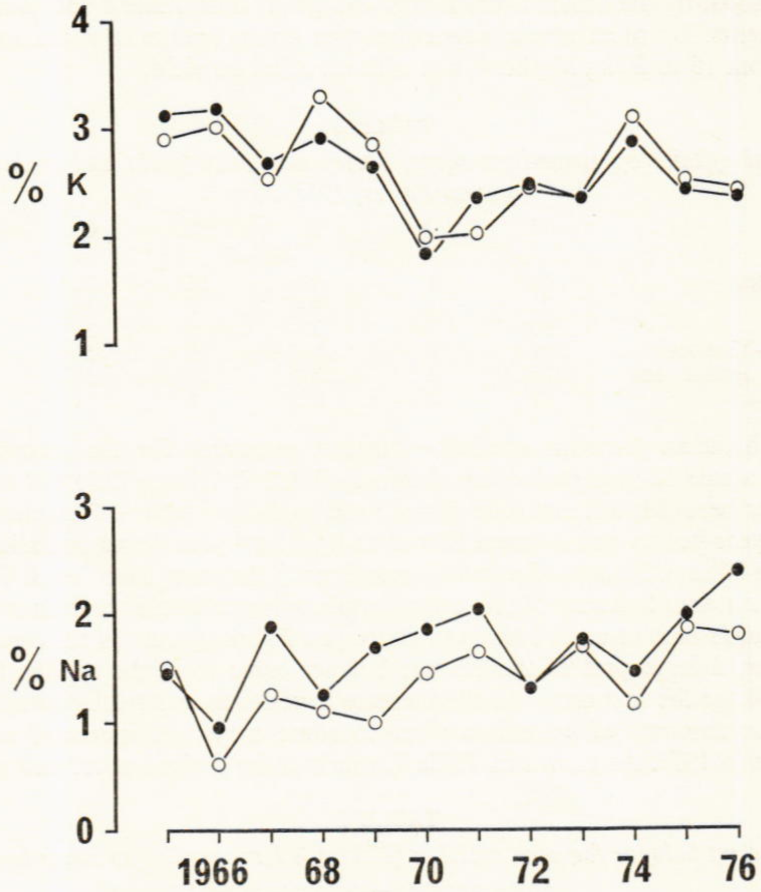

FIG. 3. Potassium and sodium concentration in dried sugar-beet tops, 1965–76. 125 kg N ha^{-1} given to sugar beet. ●, Mean RI, RII, RIV and RV; ○, RIII.

potassium balance was similar on RII and RIII, it was differences in the sodium balance which caused the differences in sugar yield between RII and RIII.

Further evidence that sodium balance was important was obtained from the trends in nutrient availability inferred from the analysis of dried sugar-beet tops as shown in Fig. 3. Generally, potassium concentration in tops was greater in the first years than more recently but there was no difference between RIII and the other rotations. As the experiment progressed, the amount of sodium in tops increased but there was usually less in tops from RIII than in those from other rotations.

Summary and conclusions

Results of the second six years of an experiment are reported in which yields of sugar beet were compared when grown in five contrasting rotations. The rotations remained unchanged in the second six years on the same plots but modifications were made in the fertiliser treatments following results of the first six years' cropping. More nitrogen was given to second and subsequent barley crops following sugar beet as yields of each successive barley crop were found to decline during the first six years and it was shown that part of the decline was due to increasing requirement of nitrogen. Grass was also given more nitrogen to improve its yield. More potassium was given to beans, potatoes

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and grass as this element was also shown to affect yields greatly on this soil. Three plots in the continuous sugar beet were given magnesium to determine whether it affected yield.

Mean sugar yields differed little between rotations as was found in the first six years. On average of the second six years, however, sugar beet in rotation with five barley crops yielded significantly less sugar than when grown in the other four rotations. The reason for this smaller yield of sugar in RIII was not fully explained but it seems likely that it was due in part to shortage of potassium and/or sodium. Potassium balance was least in RIII and from comparisons with a nearby experiment (described on pp. 15–30) sufficiently small to suggest that insufficient fertiliser was given to ensure no loss of yield through shortage of potassium. It is likely that sugar beet grown in rotation with two barley crops (RII) yielded similar amounts of sugar to sugar beet in RI, RIV and RV when the potassium balance over the six-year period was only slightly greater than in RIII and very similar to RIII over the 12-year period because sodium balance was greater on RII than RIII.

Yields of barley following sugar beet showed similar effects to those in the first six years with a gradual decline with each successive barley crop. The extra nitrogen given to second and subsequent barleys in 1971–76 thus did not prevent the decline.

Response to nitrogen by sugar beet varied greatly between years but not between rotations. For example, in 1976 the largest sugar yields were from plots given no nitrogen whereas in other years 125 kg N ha^{-1} were needed. Sugar beet following the crops which left a residue of nitrogen needed 0–63 kg N ha^{-1} to ensure no shortage whereas sugar beet following barley needed 0–125 kg N ha^{-1}.

Although the small plots of different crops with bare soil between them formed a favourable haunt for animals and birds which damaged all crops (especially sugar beet), pests and diseases in general did not affect yields to the extent anticipated at the start of the experiment. The appearance of a heavy *H. schachtii* infestation in the 13th year of continuous sugar beet on a sandy loam emphasises the need for a rotation, as demanded by the sugar factory contract. As a result of this infestation, the experiment will be greatly modified.

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