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The effects of subsoiling and deep incorporation of P and K fertilizers on the yield and nutrient uptake of barley, potatoes, wheat and sugar beet grown in rotation

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SUMMARY

A small-plot experiment on sandy loam soil at Woburn tested the effects of subsoiling by hand and of incorporating a large dressing of P and K fertilizer into the subsoil.

The treatments were applied once in 1973 and their effects were assessed from 1974 to 1977 on the yields of, and N, P, K uptakes by, barley, potatoes, wheat and sugar beet grown in rotation. All crops were present each year and all plots received annual seed-bed dressings of N, P and K appropriate to the crop. Dolomitic limestone was applied once in the rotation. The effects of the treatments on P soluble in 0·5 M-$NaHCO_3$ and exchangeable K in surface and subsoils were measured.

Subsoiling alone increased the 4-year mean yield of wheat by 21 %, of barley by 24 % and of sugar from sugar beet by 11 %. Mean yield of potatoes was unaffected.

Incorporating P and K into the subsoil increased the mean yield of potatoes by 16 % and further increased mean yield, in addition to the effect of subsoiling, of barley by 20 % and of sugar by 4 %. Mean yield of wheat was not further affected.

INTRODUCTION

On heavy land there is no detectable leaching of P into undisturbed subsoil from fertilizer applied to the topsoil for arable crops. On lighter soils there may be some leaching where large dressings are applied for several years. Substantial amounts of P applied in, or with farmyard manure (FYM) have been found to leach into the subsoil (Johnston, 1976).

K is more likely to leach than P; the extent depending on the amount of K applied and the number of exchange sites on which it can be held; in most mineral soils this depends on the amount and type of clay. In long-term experiments at Rothamsted and Woburn there has been considerable enrichment of the subsoil where much K has been applied, especially when in FYM (Johnston, 1971).

As a consequence of prolonged use of fertilizers and FYM and only partial removal of the P and K in harvested crops, residues of these nutrients accumulate in the topsoil, often with beneficial effects (Johnston, Warren & Penny, 1970; Johnston & Poulton, 1977). Because it was known that P had eached into the subsoils of some FYM-treated soils, but not into fertilizer-treated ones, it was conjectured that part of the extra yield of some crops measured on FYM-treated soils could have been caused by this subsoil enrichment.

Few field experiments have been reported on the effects of enriching a subsoil with nutrients and even fewer which distinguish between the effects of the nutrients and the subsoil disturbance necessary to incorporate them. Of those that do, most have incorporated nutrients behind subsoiling tines spaced widely apart (70–140 cm) which leaves vertical bands of enriched soil separated by much wider unenriched zones. Complete mixing of P by hand digging to a depth of 35 cm was reported by Daraselia (1968) and showed greater benefit from the nutrient than from the subsoil disturbance on the yields of tea in Russia. Robertson & Volk (1968) found no benefits in the U.S.A to maize, sorghum or bahia grass from mixing together the top 90 cm of soil either with or without P. Other experiments in the U.S.A. using subsoil-tine incorporation of NPK fertilizer showed an average increase from subsoiling of 14 % and from subsoil incorporation of fertilizer of 24 %, but results varied greatly with season and crop (Kohnke & Bertrand, 1956). Similar experiments reported by Rice & Morris

(1959) showed no benefits on sandy soils but some benefits from both repeated subsoiling and deep placement of fertilizer on heavier soil. Few experiments have been done on subsoil enrichment in the U.K. In East Anglia, Webb (1975), Draycott (1976) and Jaggard & Webb (1977) reported no benefit to sugar beet, winter wheat or spring barley from either tine-subsoiling alone or injecting liquid NPK behind the tine.

Most of the few subsoiling experiments in the U.K. have used widely separated tines. Russell (1956) reported on the effects of tine-subsoiling on a range of soil types and arable crops. Yields were increased on about 50% of the experiments, on most of the remainder yields were unaffected, a few showed small yield losses. Yield increases were sometimes large and varied with crop, soil type and season. Hull & Webb (1967) showed consistent, small increases in yield from tine-subsoiling on arable crops and lucerne. Tine-subsoiling was tested at Woburn in 1962 and 1963 (Rothamsted Experimental Station, 1962, 1963) on sites known to have plough pans, and caused 10–25% yield increases in spring barley but had little effect on yields of sugar beet, spring wheat or early potatoes. Hand digging the subsoil has been tested by Johnston & Warren (1964) at Woburn and by Fisher, Gooderham & Ingram (1975) and El-Karouri & Gooderham (1977) at Wye. At Woburn yields of sugar beet roots were increased by 11% by digging the subsoil whilst at Wye barley grain yields were increased by 14% and the dry matter from a ryegrass ley by 33%.

DESCRIPTION OF THE EXPERIMENT

Standard factors

The experiment was started in summer 1973 on sandy loam soil (Cottenham Series) (Catt, King & Weir, 1975) developed in drift over Lower Greensand, at Woburn. The site had been fallow in the three previous years and was chosen because it was likely to be free from soil-borne pathogens. Four crops were grown each year in the rotation, barley (Julia), potatoes (Pentland Crown), wheat (Cappelle-Desprez), sugar beet (Klein E). All crops received fertilizer applications to the seed bed in accordance with standard farm practice at Woburn. The amounts and composition (%N:%P_2O_5:%K_2O respectively) of the compound fertilizers used were:

Barley: 380 kg/ha of (20:14:14) except in 1974: 450 kg/ha of (20:15:15). Fertilizers were combine drilled.

Potatoes: 1860 kg/ha of (13:13:20) except in 1974 when 1940 kg was applied.

Wheat: 290 kg/ha of (0:20:20) combine drilled each year. 100 kg N/ha (except in 1976 when 75 kg N was applied), as 'Nitro-Chalk' 25% N, top-dressed in spring.

Sugar beet: 750 kg/ha of (0:14:28) in each year. 160 kg N/ha, as 'Nitro-Chalk' 25% N, in 1975 and 1977, 180 kg N in 1974, 140 kg N in 1976.

Dolomitic limestone, which supplied Mg and Ca, was applied at 5 t/ha to wheat stubble each autumn before sugar beet. The first application was made in autumn 1974.

After the treatments were applied the whole site was mouldboard ploughed to 25 cm depth. Thereafter all cultivations were done in accordance with standard farm practice which included mouldboard ploughing each autumn. Weedkillers and pesticides were applied as required except that weeds in sugar beet were controlled by hand hoeing. Details of cultivations and applications of chemicals are in the 'Yields of the Field Experiments' (Rothamsted Experimental Station, 1974, 1975, 1976 and 1977).

The plots were 4·3 m wide × 2·6 m long. There were 24 rows of the cereals sown 18 cm apart, 6 rows of potatoes planted 71 cm apart (within the rows the spacing was 30 cm) and 8 rows of sugar beet sown 64 cm apart. Yields were estimated from a central area; 16 rows of cereals, 4 rows of potatoes, 6 rows of sugar beet, all by 1·5 m length of row.

Treatments

Four treatments were applied between mid-August and early October in 1973 only: (i) none; (ii) subsoiled alone; (iii) subsoiled and PK incorporated into the subsoil; (iv) PK to topsoil.

All treatments were done by hand. Topsoil was defined as 0–23 cm (about plough depth) and subsoil as 23–46 cm depth. Subsoiling was done by spade after removing the topsoil which was later replaced. PK was incorporated as intimately as possible into the subsoil. Half the PK dressing was spread on the subsoil surface after removing the topsoil. Subsoil was then dug by spade partially inverting each spadeful, the remaining PK was then applied and the subsoil worked by forking with a twisting motion. The PK dressing for the topsoil was applied half before autumn ploughing in mid-October 1973, half shortly afterwards.

The test dressings of P and K were: 1930 kg P_2O_5/ha as superphosphate and 460 kg K_2O/ha as muriate of potash. These large amounts were intended to equalize readily-soluble P and K in top and subsoil. In May 1973 before fertilizer was applied analyses of the top (0–23 cm) and subsoils (30–46 cm) for bicarbonate-soluble P and exchangeable K showed that the site was acceptably uniform. Subsoil for this purpose was defined as 30–46 cm because ploughing had occasionally been deeper than 23 cm. The intermediate 23 to 30 cm zone was sampled and analysed but the values were not used in calculating quantities of test nutrients to be applied. The values were intermediate between those of top and subsoils.

The following were the mean values (mg/kg air dry soil) for the top and subsoil, respectively: $NaHCO_3$-soluble P, 81 and 56 (difference 25) exchangeable K, 110 and 80 (difference 30).

Exchangeable K in topsoil was increased to 160 mg/kg after applying muriate of potash in July, increasing the difference between top and subsoil to 80 mg/kg.

Application rates of test P and K were based on three assumptions. That the weight of subsoil (23–46 cm) is 3363 t/ha (based on Crowther, 1936). That 10% of phosphate fertilizer applied will remain bicarbonate soluble (Johnston, 1975). That 70% of potassium fertilizer will remain exchangeable (Warren & Johnston, 1962). Using these assumptions the amounts of P and K required were calculated to be 1930 kg P_2O_5/ha and 460 kg K_2O/ha.

Each treatment occurred once in a randomized block of four plots. The blocks were arranged in four groups of three so that each of the four crops was grown on a group of three blocks, the crops rotating annually.

RESULTS

Tables 1–4 give annual yields and means for the 4 years. The discussion that follows relates to mean values unless specific years are mentioned.

Effects on yield

Barley

Grain yields (Table 1) were increased from 3·38 to 4·25 t/ha by subsoiling alone and further increased to 4·94 t by incorporating P and K into the subsoil ('deep PK'). P and K added to the topsoil ('shallow PK') had no effect. Results were reasonably consistent over the 4 years but proportionately greatest in 1975 when deep PK doubled yield.

Straw yields (Table 1) were similarly affected by the treatments but the effects were rather less, i.e. grain:straw ratios were increased by subsoiling and by deep PK.

Potatoes

Yields of total tubers (Table 2) were increased from 45·4 to 52·5 t/ha by deep PK but were unaffected by subsoiling alone and only slightly increased by shallow PK. Deep PK was beneficial in all years. The effects of subsoiling alone and shallow PK varied between years. In 1977 both these treatments were beneficial, the effects of shallow PK exceeded those of deep PK in this year.

Wheat

Grain yields (Table 3) were increased from 4·32 to 5·18 t/ha by subsoiling but were not further affected by deep PK; shallow PK lessened yield. Results were reasonably consistent over the 4 years except in 1977 when deep PK gave a larger yield than subsoiling alone.

Straw yields (Table 3) were also increased by subsoiling but, in contrast to the effects on grain, deep PK was better than subsoiling.

Sugar beet

Root yields (Table 4) were increased from 29·2 to 32·1 t/ha by subsoiling and further increased to 33·5 t by deep PK; shallow PK had no effect. Subsoiling alone was beneficial in all years; deep PK showed additional benefit in 1974 and 1976 only.

The sugar percentage of the roots was little affected by the treatments, consequently the effects of treatments on the yield of sugar were similar to the effects on root yields.

The yield of tops was increased by subsoiling and

Table 1. *The effects of subsoiling and deep incorporation of P and K on the yield of barley, grain and straw*

Treatment	Year 1974	1975	1976	1977	Mean
	Grain (t/ha at 85% dry matter)				
None	4·89	2·30	3·43	2·90	3·38
Subsoiled alone	5·23	3·79	4·46	3·53	4·25
Subsoiled + PK	6·21	4·69	4·51	4·34	4·94
PK to topsoil	4·53	1·90	3·77	3·20	3·35
S.E. of a difference ±	1·075	0·240	0·261	0·338	0·302
	Straw (t/ha at 85% dry matter)				
None	4·91	3·54	3·16	4·08	3·92
Subsoiled alone	5·43	4·40	4·14	3·69	4·41
Subsoiled + PK	5·30	5·29	4·44	4·10	4·78
PK to topsoil	4·89	3·30	3·41	4·17	3·94
S.E. of a difference ±	0·700	0·180	0·203	0·391	0·322

Table 2. *The effects of subsoiling and deep incorporation of P and K on the yield of total tubers in potatoes (t/ha)*

Treatment	Year 1974	1975	1976	1977	Mean
None	68·8	33·8	41·3	37·8	45·4
Subsoiled alone	65·1	36·4	39·7	40·7	45·5
Subsoiled + PK	78·5	41·4	47·1	43·1	52·5
PK to topsoil	72·1	32·7	43·0	45·7	48·4
S.E. of a difference ±	1·37	3·89	2·34	2·17	2·00

further slightly increased by deep PK; shallow PK lessened yield. The effects of shallow PK were consistent in all years, those of subsoiling and deep PK varied and in 1976 both lessened yield of tops.

Effects on nutrient uptake and nutrient content

Nutrient uptake and % nutrient content in dry matter for each crop, grain only for the cereals, have been averaged over the 4 years and are in Table 5.

Table 3. *The effects of subsoiling and deep incorporation of P and K on the yield of wheat, grain and straw*

Treatment	Year 1974	1975	1976	1977	Mean
Grain (t/ha at 85% dry matter)					
None	5·56	4·23	3·48	4·03	4·32
Subsoiled alone	6·52	5·65	4·06	4·51	5·18
Subsoiled + PK	5·85	5·49	4·17	4·95	5·11
PK to topsoil	5·23	4·31	3·18	3·52	4·06
S.E. of a difference ±	0·867	0·333	0·281	0·367	0·182
Straw (t/ha at 85% dry matter)					
None	9·03	7·28	4·90	6·36	6·89
Subsoiled alone	10·84	8·39	5·64	6·51	7·84
Subsoiled + PK	11·04	8·72	6·34	6·73	8·21
PK to topsoil	10·89	6·61	4·33	5·94	6·94
S.E. of a difference ±	0·894	0·281	0·522	0·331	0·410

Barley

Uptake of N in grain was increased from 54 to 66 kg/ha by subsoiling alone and further increased to 74 kg by deep PK; shallow PK had no effect. Effects were consistent over the 4 years.

Uptake of both P and K was greater from subsoiling alone than from shallow PK but was largest from deep PK.

Nutrient contents were not significantly affected by any of the treatments; differences in uptakes were caused by the effects of treatments on yield.

Potatoes

Uptake of N in tubers was increased from 145 to 162 kg/ha by deep PK but only slightly increased by subsoiling alone and shallow PK. Effects were reasonably consistent over the 4 years except in 1977 when shallow PK gave the greatest increase.

Uptakes of P and K were not affected by subsoiling. Uptake of P was increased equally by deep and shallow PK; uptake of K was also increased by both these treatments but more by deep PK.

The treatments had little effect on mean nutrient contents other than P which was increased from 0·24 to 0·28% by deep PK and to 0·32% by shallow PK.

Table 4. *The effects of subsoiling and deep incorporation of P and K on the yield of sugar-beet roots (washed), sugar percentage of roots, total sugar and tops (fresh) (t/ha)*

Year		Treatment: None	Subsoiled alone	Subsoiled + PK	PK to topsoil	S.E. of a difference ±
1974	Roots	31·2	32·6	35·6	32·0	1·75
	% sugar	15·9	15·4	15·4	15·8	0·16
	Total sugar	4·95	5·03	5·49	5·07	0·283
	Tops	29·2	32·6	39·0	27·1	4·15
1975	Roots	14·5	17·1	17·3	15·2	1·00
	% sugar	15·6	15·5	15·7	15·5	0·20
	Total sugar	2·26	2·66	2·72	2·36	0·180
	Tops	10·0	12·4	11·4	9·6	0·75
1976	Roots	35·3	36·9	39·3	33·0	1·62
	% sugar	14·9	15·0	14·9	14·8	0·18
	Total sugar	5·25	5·54	5·86	4·88	0·241
	Tops	28·3	24·9	25·6	24·7	1·32
1977	Roots	35·8	42·0	41·8	38·2	3·30
	% sugar	16·9	17·0	16·7	16·8	0·37
	Total sugar	6·03	7·13	7·01	6·42	0·691
	Tops	25·8	32·1	30·8	25·4	3·41
Mean	Roots	29·2	32·1	33·5	29·6	0·88
	% sugar	15·8	15·7	15·6	15·7	0·11
	Total sugar	4·62	5·09	5·27	4·68	0·160
	Tops	23·3	25·5	26·7	21·7	1·97

Table 5. *The effects of subsoiling and deep incorporation of P and K on nutrient uptake (kg/ha) by, and nutrient content (% in dry matter) of barley, potatoes, wheat and sugar beet, mean* 1974–7

	Treatment								S.E. of a difference ±	
	None		Subsoiled alone		Subsoiled + PK		PK to topsoil			
Crop and element	Uptake	%	Uptake	%	Uptake	%	Uptake	%	Uptake	%
Barley grain only										
N	54	1·82	66	1·79	74	1·75	54	1·83	4·6	0·067
P	11·8	0·41	14·3	0·40	16·9	0·40	12·3	0·43	1·02	0·012
K	17	0·57	21	0·56	24	0·57	17	0·58	1·8	0·013
Potatoes										
N	145	1·68	150	1·67	162	1·58	149	1·61	6·6	0·037
P	21·6	0·24	21·3	0·24	29·4	0·28	30·5	0·32	2·23	0·010
K	218	2·51	216	2·41	267	2·54	245	2·60	14·5	0·065
Wheat grain only										
N	79	2·15	92	2·10	90	2·08	75	2·19	4·1	0·070
P	14·2	0·39	16·0	0·37	15·8	0·37	13·7	0·40	0·56	0·015
K	17	0·47	20	0·45	19·3	0·44	17	0·48	0·4	0·008
Sugar-beet roots										
N	65	1·01	68	0·97	71	0·97	64	1·00	1·7	0·021
P	10·2	0·15	11·0	0·15	13·8	0·18	11·7	0·17	1·16	0·012
K	63	0·96	69	0·97	75	1·00	68	1·03	2·5	0·031
Sugar-beet tops										
N	99	2·49	105	2·47	110	2·56	91	2·50	7·6	0·034
P	12·1	0·30	12·2	0·28	13·9	0·32	13·0	0·34	1·01	0·021
K	143	3·53	151	3·47	165	3·88	142	3·86	9·1	0·170

Wheat

Uptake of N in grain was increased from 79 to 92 kg/ha by subsoiling alone and similarly by deep PK but not by shallow PK. Effects were consistent over the 4 years.

Extra uptakes of P and K from subsoiling alone slightly exceeded those from deep PK and were substantially greater than from shallow PK.

Nutrient contents were not significantly affected by any of the treatments; as for barley, effects on uptakes were caused by differences in yield.

Sugar beet

Uptake of N in roots was increased from 65 to 68 kg/ha by subsoiling alone and further increased to 71 kg by deep PK; shallow PK had no effect. Effects were not consistent between years. In 1975 and 1977 increased N uptake by subsoiling alone, 5 and 9 kg/ha respectively, was as great as by deep PK, 4 and 9 kg/ha.

Uptake of P in roots was consistently increased by deep PK but not by subsoiling alone or shallow PK. Uptake of K was also increased by deep PK and to a smaller extent by subsoiling alone and shallow PK.

The treatments had little effect on nutrient contents in roots other than P which was increased from 0·15 to 0·17% by shallow PK and to 0·18% by deep PK.

Uptake of N in tops was increased from 99 to 105 kg/ha by subsoiling alone and further increased to 110 kg by deep PK; shallow PK lessened this to 91 kg. Effects were not consistent between years. In 1975 and 1977 the average increase in N uptake by subsoiling alone, 20 kg/ha, was greater than by deep PK, 12 kg/ha. P and K uptakes were both increased by deep PK. Subsoiling alone increased uptake of K but not P; shallow PK increased uptake of P but not K.

Nutrient contents in tops were all slightly increased by deep and shallow PK but not by subsoiling alone.

Effects on available nutrients in the soil

Top and subsoils, as previously defined for soil analysis, were sampled after 2 years cropping and again after 4 years (Table 6).

For P it was evident that the rate of fertilizer chosen had been too large for the intended aim of equalizing soluble P in the untreated topsoils and treated subsoils. At the rate applied, $NaHCO_3$-soluble P in the subsoil was increased by about 60 mg/kg, with no evidence of decline between the two sampling occasions. As a result the subsoil had about 30 mg/kg more soluble P than the untreated

Table 6. *The effects of subsoiling and deep incorporation of P and K on nutrient contents (mg/kg) of the soil*

	Nutrient					
	P soluble in 0·5 M-$NaHCO_3$			Exchangeable K		
Treatment	Before treatment	After 2 years	After 4 years	Before treatment	After 2 years	After 4 years
None						
Topsoil	81	86	87	160	137	154
Subsoil	56	60	52	80	91	105
Subsoiled alone						
Topsoil	81	83	82	160	135	153
Subsoil	56	58	53	80	84	98
Subsoiled +PK						
Topsoil	81	92	86	160	144	155
Subsoil	56	114	114	80	121	131
PK to topsoil						
Topsoil	81	124	114	160	167	185
Subsoil	56	69	64	80	103	121

topsoil. The same amount of P applied to the topsoil increased soluble P by about 40 mg/kg with evidence of only slight leaching down the soil profile. However the enriched subsoils contained about as much $NaHCO_3$-soluble P as the topsoils to which extra P was applied. Less P therefore became 'fixed' in non-bicarbonate-soluble form in the subsoil than in the topsoil.

For K the rate chosen was slightly too small to equalize top and subsoils leading to a treated subsoil with about 20 mg K/kg less than in the untreated topsoil. The same dressing of K applied to the topsoil increased exchangeable K there by about 30 mg/kg relative to untreated topsoils sampled at the same time. There was evidence for leaching of K from top to subsoil in all plots, at a rate of about 5 mg/kg per year in untreated soils and at 10 mg/kg where the large dressing had been applied to the topsoil.

DISCUSSION

The experiment had a limited objective, namely to determine whether there were benefits to crop yields from enriching subsoil at Woburn with P and K. Subsoiling alone was included, although there was no detectable plough pan on the site chosen, in order to provide unequivocal information on the effects of subsoil enrichment.

All crops other than potatoes responded to hand digging of the subsoils, supporting previous results from hand-dug experiments. The generally small effects obtained with rigid tine machinery elsewhere, even when plough pans are present, suggests that very intimate disturbance of the subsoil achieved by hand methods has substantially more effect on crop growth.

The two nutrients, P and K, were applied together and at one rate only. The analysis of the topsoil (81 mg P and 160 mg K/kg) was such that responses to fresh P and K applied conventionally would not be expected from cereals on soils with as little organic matter as these contained (Johnston, Mattingly & Poulton, 1976). Of the four crops included only potatoes responded to additional shallow PK (in the presence of a conventional fertilizer application).

Deep PK substantially increased the yields of potatoes and further increased yields, in addition to the effects of subsoiling, of barley and to a smaller extent sugar beet but not of wheat.

Because the plots were small it was not possible to sample for root distribution and moisture characteristics down the soil profile, as this would have caused unacceptable damage. Consequently we can only speculate that loosening of the subsoil and provision of additional nutrients increased ease of root penetration and proliferation of roots in that zone and consequently improved uptake of water and perhaps N that would otherwise have been leached from root range. If more efficient use of subsoil water is a cause, effects should be greatest in dry summers, if lessening the loss of leached N effects should be greatest in wet springs. For cereals the rainfall records (Table 7) may be considered to form three seasonal categories: (i) dry spring (March–May), average summer (June–July) (1974), (ii) a wet spring, dry summer (1975); (iii) dry spring, dry summer (1976 and 1977).

For barley the response to both subsoiling and deep PK was greatest in 1975 when a wet spring was followed by a dry summer (Table 1). Responses in the two other seasonal categories were less, and similar in all 3 years. This suggests that limitation of N leaching losses contributed to the very large 1975 responses. This is supported by the greater effects on N uptake by grain which, in 1975, was increased from 31 to 62 kg/ha by deep PK; a 100% increase compared with the 4-year mean of 37%. Responses in the dry summers of 1976 and 1977 were similar to those in the average summer of 1974 suggesting that if better use of subsoil water caused effects the amount available was no more than would improve yield by the same amount in an average summer.

Wheat yields showed a similar pattern to barley with responses greatest in 1975 but for this crop

Table 7. *Rainfall (mm) at Woburn during the growing season in the years* 1974–7 *and departures from the long-term means (in parentheses)*

Months	Year 1974	1975	1976	1977
March	39 (−2)	106 (+65)	19 (−24)	52 (+10)
April	16 (−30)	71 (+26)	16 (−30)	33 (−12)
May	33 (−22)	62 (+8)	28 (−27)	35 (−19)
June	68 (+18)	34 (−17)	14 (−36)	80 (+30)
July	41 (−14)	30 (−26)	24 (−31)	6 (−48)
August	110 (+49)	10 (−52)	7 (−54)	155 (+95)
September	109 (+58)	94 (+42)	93 (+40)	17 (−36)

the percentage effects on uptake of N in grain were similar and greatest in 1974 and 1975.

For the root crops, with a longer growing season, it is more difficult to categorize seasons. Potatoes gave largest responses to deep PK in 1974 with progressively smaller responses from 1975 to 1977. Responses of sugar yield to deep PK were greatest in 1977 followed by 1976, 1974 and 1975. We can offer no explanation for the contrasted ranking of season given by the two root crops.

There was no appreciable difference in % N, % P or % K due to treatment in those parts of any crop which were analysed. The only exception was that % K was a little larger in sugar beet tops grown on enriched subsoils or topsoils. Where large yields were obtained there was therefore no dilution effect, i.e. % nutrients did not decrease as dry-matter yield increased. This suggests that the crops were able to find sufficient nutrients from either the surface or subsoils. The concentration of all nutrients, especially P, were well above average (cf. values for barley, potatoes and sugar beet given by Johnston *et al.* 1976) which suggests that much of the observed effects on yield could well have been due to improved water availability, or nutrient supply at some earlier part of the growth period.

Although it is not possible adequately to explain the results obtained, because of the simplicity of the treatments and the limited measurements made, the experiment successfully showed that intimate disturbance of subsoil and enrichment with P and K can both cause substantial increases in yield which last at least 4 years after the treatments have been applied (the experiment will continue as long as effects of the treatments can be detected). More research on the subject is clearly justified. Fortunately recently developed machinery such as the winged subsoiler (Spoor, 1975) and the Wye double-digger (Warboys *et al.* 1976) which can disturb subsoils more effectively than conventional tine-subsoilers and can be adapted to incorporate fertilizer into the subsoil will enable future experiments to be fully mechanized and allow sufficient areas to be treated to permit destructive sampling for monitoring the causes of effects.

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