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Effect of Phosphate Residues on Soil P Values and Crop Yields

I. Experiments on Barley, Potatoes and Sugar Beet on Sandy Loam Soils at Woburn

A. E. JOHNSTON, G. E. G. MATTINGLY and P. R. POULTON

Introduction

Johnston *et al.* (1970) described a series of experiments made during 1957–62 which valued the residues of P and K accumulated in soils at Rothamsted and Woburn. Yields on soils with residues were compared with those on soils unmanured for long periods and the effects of adding new P and K to impoverished and enriched soils were also tested. The experiment at Woburn was made during 1960–62 on part of the Continuous Wheat and Barley experiments which had a known history of cropping and manuring (Johnston, 1975a). P and K fertilisers had been tested from 1877 to 1926 but little or none were applied after 1926 and in 1960 the soils contained amounts of bicarbonate-soluble P which ranged from 10 to 60 mg P kg^{-1}.

Fig. 1 shows that in 1960–62 the yields of barley (cv. Plumage Archer) and potatoes (cv. Majestic) were well related to the amount of bicarbonate-soluble P in the soil when N and K but no fresh P were given. For both crops the yield on plot 8 of the Barley experiment was not closely related to soil P. Results given by Johnston and Chater (1975) suggest that on this soil, which became very acid during 1876–1926, the bicarbonate-soluble P is anomalously large.

Subsequently, we decided to investigate in greater detail the relationship between yield and bicarbonate-soluble P in soil and a series of experiments were started at Rothamsted, Woburn and Saxmundham. Our intention was to establish soils in each experiment which contained amounts of bicarbonate-soluble P ranging from less than 10 to 60–80 mg P kg^{-1}, i.e. to have soils ranging from ADAS P Index 0 to the lower end of Index 5 (MAFF, 1973). This range of P values could be got only by adding large amounts of fresh P to some soils. To ensure adequate mixing of soil and fertiliser, and equilibration of the fresh P, applied on Stackyard in 1967, with the native soil P, the testing phase of the experiments did not start until the early 1970s. The results for the experiments made at Woburn are given in this paper, those for the Rothamsted and Saxmundham experiments will be published later.

The Long-term Phosphate experiment, started in 1968 on Stackyard III, used plots 1, 2 and 3 of the Continuous Wheat and Barley experiments. In both old experiments these three plots had received no P or K fertiliser since 1876. By 1969 the dressings of superphosphate applied in autumn 1967 had not increased bicarbonate-soluble P on these impoverished soils as much as was intended. We therefore decided to use the site of the Market Garden experiment on Lansome field (Johnston & Wedderburn, 1975) to include soils with larger amounts of soluble P. The Market Garden and Wheat and Barley experiments were on similar soils though not in the same field. The Market Garden experiment tested two amounts of four bulky organic manures from 1942 to 1967 and yields were compared with those given by fertilisers only. Market garden crops were not grown after 1967; field beans (tic) were grown in 1968 and 1969. In this paper the experiment on the Long-term Phosphate site is referred to as the Stackyard experiment and that on the Market Garden site as the Lansome experiment.

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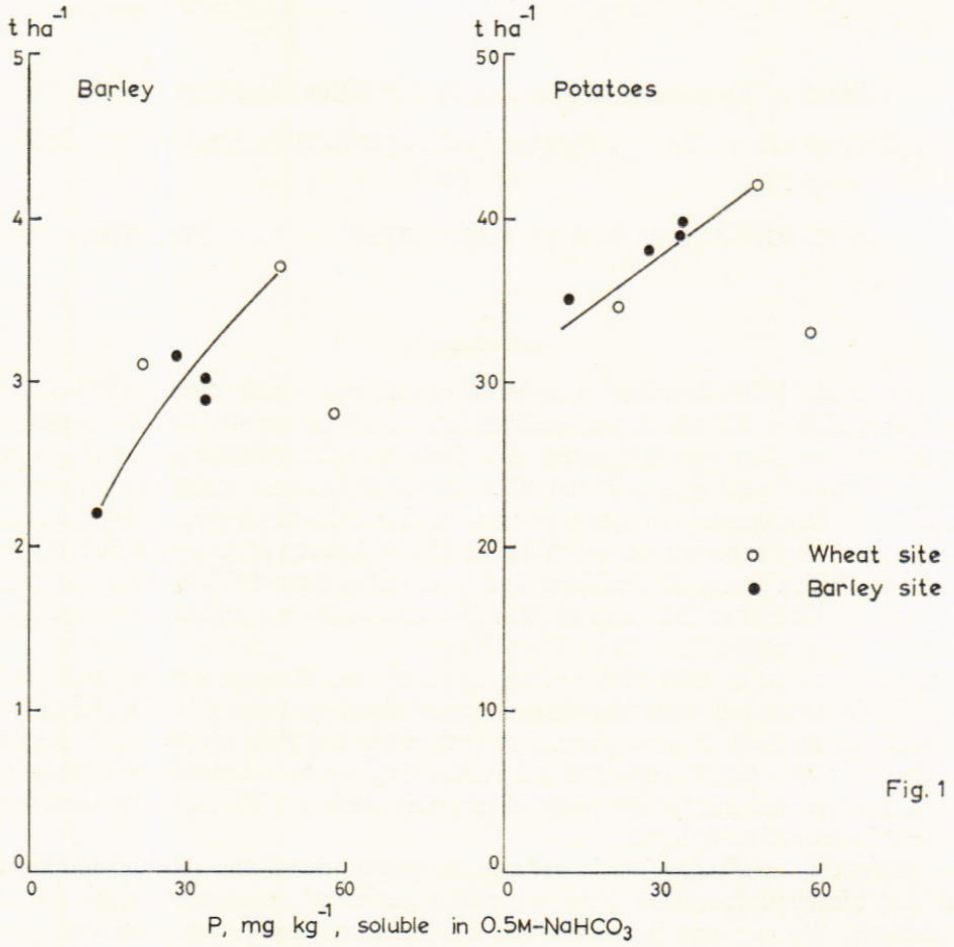

Fig. 1

FIG. 1. Relationship between the yields of barley, (cv. Plumage Archer), and potatoes (cv. Majestic), and bicarbonate-soluble P in soil, Stackyard, Woburn, 1960–62.

The soils and histories of the sites

The soils. The two fields, Stackyard and Lansome, are about 1·6 km apart but both have soils developed on drift over Lower Greensand. The Stackyard experiment was on soil classified as Stackyard Series, the top soil (0–23 cm) is a sandy loam. This soil has a coarser texture than the soil on Lansome Field which is classified as Cottenham Series, the top soil is a loamy sand.

The histories of the sites

The Stackyard experiment. The site of this experiment on Stackyard III formed part of the Continuous Wheat and Barley experiments which have been described in detail by Johnston (1975a), Johnston and Chater (1975) and Mattingly, Chater and Johnston (1975). From 1877 to 1926 plots 1, 2 and 3 of both experiments were manured as follows: plot 1, unmanured; plot 2, ammonium sulphate only; plot 3, sodium nitrate only. After 1927 the plots were not fertilised except for occasional dressings of N. Table 1 gives the pH, %C, %N and soluble P and K contents of the soils in June 1967 just before the start of the Stackyard experiment.

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TABLE 1

Analyses of soils[a] before the start of the Stackyard experiment

Block number 1970–72	Continuous Wheat and Barley experiments: Plot	Treatment	pH in water	%C[b]	%N	P soluble in 0·5M $NaHCO_3$ (mg P kg^{-1})	K soluble in 1N ammonium acetate (mg K kg^{-1})
I	Wheat 1	none	6·4	0·78	0·10	12·0	60
II	Wheat 2	ammonium sulphate	6·7	0·64	0·08	15·8	47
III	Wheat 3	sodium nitrate	6·6	0·74	0·09	10·8	40
IV	Barley 3	sodium nitrate	6·8	0·72	0·09	12·2	45
V	Barley 2	ammonium sulphate	6·7	0·58	0·07	17·8	49
VI	Barley 1	none	6·5	0·59	0·07	15·3	54
	Mean		6·6	0·68	0·08	14·0	49

(a) Soils sampled June 1967 before superphosphate was applied in autumn 1967
(b) %C = 1·3 × Walkley (1947) value

The Lansome experiment. This experiment was made on the site of the Market Garden experiment which was described in detail by Johnston and Wedderburn (1975). The effects of the treatments on the soils were discussed by Johnston (1975b). The four bulky organic manures, each applied at two amounts, 37·5 and 75 t ha^{-1}, were farmyard manure (FYM) and sewage sludge and two composts, vegetable compost made from plant material and FYM and a sludge–straw compost made from cereal straw and sewage sludge. By 1967 the soils contained much bicarbonate-soluble P which ranged from 140 to 200 mg P kg^{-1}. Soil carbon ranged from 1·06 to 2·20% C and exchangeable K from 170 to 350 mg K kg^{-1} because the soils had received different amounts of organic manures. Soil pH in water varied little, 6·8–7.0, because dressings of ground chalk were given, usually in alternate years from 1942 to 1969. Table 2 gives the pH, %C, %N and soluble P and K contents of the soils in autumn 1967 at the end of the Market Garden experiment. No fertilisers were applied for the two crops of field beans taken in 1968–69 so the values would have changed little by the start of the Lansome experiment in 1970.

TABLE 2

Analyses of soils[a] before the start of the Lansome experiment

Market Garden experiment: Treatment and dressing		pH in water	%C	%N	P soluble in 0·5M $NaHCO_3$ (mg P kg^{-1})	K soluble in 1N ammonium acetate (mg K kg^{-1})
Fertilisers	Single	7·0	1·06	0·11	141	166
	Double	7·0	1·06	0·11	155	258
Farmyard manure and vegetable compost	Single	7·0	1·70	0·16	148	173
	Double	7·0	2·20	0·20	178	272
Sewage sludge and sludge compost	Single	6·8	1·69	0·17	158	172
	Double	6·8	2·18	0·21	168	170
FYM and vegetable compost plus extra PK fertiliser	Single	7·0	1·70	0·16	178	270
	Double	7·0	2·20	0·20	200	356

(a) Soils sampled autumn 1967 at the end of the Market Garden experiment
(b) %C = 1·3 × Walkley (1947) value

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Details of cropping, manuring and soil sampling

Build-up of soil P

The Stackyard experiment. Plot 2 on both the old Wheat and Barley experiments became very acid due to the application of ammonium sulphate and the amounts of bicarbonate-soluble P were larger than on plot 3 which had received only sodium nitrate (Johnston & Chater, 1975). Although the pH of the surface soils was increased gradually during 1954–67 it was decided to design the new experiment so that each block occupied one of the six old plots. The three blocks on the Barley site comprised one phase and those on the Wheat site the second phase of the new experiment. Each block was divided into six main plots in 1967; during 1970–72 each plot was halved to test the effects of applying fresh P each year.

Although no phosphate had been applied to these soils since the 1870s they contained on average 14 mg P kg^{-1} (range 11–18) of bicarbonate-soluble P in 1967 (Table 1). The small crops grown between 1876 and 1967 removed little P from these soils so they contained much more soluble P than soils at Rothamsted and Saxmundham (3–7 mg P kg^{-1}) also unmanured and cropped similarly for comparable lengths of time. The reason for this is unclear. The soils of Stackyard contained about 1·5% C in 1876, a value much larger than might have been expected from the present amount, about 0·7% C, in the soils of Stackyard III (Johnston, 1975). It is probable that the field had a long period in grass in the late 18th and early 19th centuries before being ploughed and cropped on a Norfolk four-course rotation. Much P could have been added to the soil in these periods, particularly if animals grazing the grass were given cake or corn as supplementary feed, and generous dressings of FYM were given to the arable crops. The soils of Lansome also contain very large amounts of bicarbonate-soluble P which could only be explained by postulating that the manuring of Lansome had been very generous in the unrecorded past before the 1870s (Johnston & Wedderburn, 1975).

Four amounts of P, one to each of four plots, were applied in August 1967 to increase the range of bicarbonate-soluble P. The amounts were 82 (P1), 164 (P2), 328 (P4) and 492 (P6) kg P ha^{-1} as superphosphate which was well mixed with the soil. No P was applied to the other two plots in each block. While the freshly added P was equilibrating with the soil, both barley and potatoes were grown in both 1968 and 1969. Results given in Table 1 show that in the spring of 1967 the soils contained little soluble K so that in autumn a large basal dressing of K (520 kg K ha^{-1} as potassium sulphate) and magnesium (150 kg Mg ha^{-1} as Epsom salt, $MgSO_4.7H_2O$) was given to all plots in the experiment; these dressings had increased the exchangeable K to 130 mg K kg^{-1} by autumn 1968.

The Lansome experiment. There were 80 plots in the Market Garden experiment divided equally between two series, one for each phase of the experiment. The 40 plots of each series were divided into four blocks each of ten plots. The four organic manures, each at two amounts, and the two fertiliser plots were therefore replicated four times in each series. Large amounts of organic manures (range 713–1828 t ha^{-1}) were applied during 1942–67 and fertiliser applications were generous after 1961 so in autumn 1967 no soil contained less than 100 mg kg^{-1} of bicarbonate-soluble P. It was decided not to increase the range of soluble P by adding fresh P before the experiment started.

Experimental design. Because these experiments were made on the sites of previous experiments there were considerable restrictions on plot size and lay-out. We wished to relate the yields of three arable crops, barley, potatoes and sugar beet to amounts of bicarbonate-soluble P in soil. However, the design of the previous experiments restricted

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the new experiment to no more than two crops each year. These were arranged as follows:

	1970	1971	1972
Phase 1	Barley	Potatoes	Sugar beet
Phase 2	Sugar beet	Barley	Potatoes

We also wished to test the response of the three crops to dressings of fresh P at each level of soil P. On the Stackyard experiment the test was made by halving individual plots to test O *v* P. On the Lansome experiment fresh P was applied to half the number of plots getting any one of the ten treatments in each series. The test P was applied cumulatively during the three years, 1970–72, to the same half or whole plots.

The amount of fresh P varied according to the crop:

	P tested, kg ha^{-1}	
Barley	0	27·5
Sugar beet	0	55
Potatoes	0	82

Cropping and manuring

The Stackyard experiment, 1968–69. Only barley and potatoes were grown in these two years before the start of the main experiment. Details of cropping and nutrients applied per hectare were:

(i) Test P applied once only in August 1967
0, 82, 164, 328, 492 kg P

(ii) N, K and Mg
(a) applied once only in August 1967
520 kg K as potassium sulphate
150 kg Mg as $MgSO_4.7H_2O$ (Epsom salt)
(b) for each crop
nitrogen as 'Nitro-Chalk 21':
barley 150 kg N potatoes 250 kg N
potassium as potassium sulphate for potatoes and potassium chloride for barley:
barley 50 kg K potatoes 155 kg K

(iii) Varieties and cultivation

		Variety	Drilled	Harvested
Barley	1968	Maris Badger	6 March	20 August
	1969	Maris Badger	29 March	25 August
Potatoes	1968	Majestic	27 March	25 September
	1969	Majestic	18 April	20 October

(iv) Liming Ground chalk, 2·5 t ha^{-1}, was applied in the previous autumn to the three blocks growing barley each year.

The Stackyard and Lansome experiments, 1970–72. As far as possible annual manuring was the same in both experiments but much less N was given to barley in the Lansome experiment because these soils contained more organic matter than those in the Stackyard experiment. The arrangement of the three-course rotation between the two phases has already been given; further details of cropping and nutrients applied per hectare were:

(i) Test P O *v* P where P as superphosphate was 27·5 kg P for barley, 55 kg P for sugar beet, 82 kg P for potatoes.

(ii) N, K, Mg and B kg element all applied to seedbed except where otherwise stated. N as 'Nitro-Chalk 21'; K as potassium chloride, 60%

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K_2O; Mg as Epsom salts, $MgSO_4.7H_2O$, 16% MgO; B as 'Solubor' in 400 litre ha^{-1}.

Crop	Experiment	N	K	Mg	B
Barley	Stackyard	150	50	0	0
	Lansome	60	50	0	0
Potatoes	Stackyard	250	425[a]	60	0
	Lansome	250	210	60	0
Sugar beet	Stackyard	190	410[b]	60[c]	2·1[d]
	Lansome	190	410	60	2·1

(a) Split dressing, half in autumn before ploughing, half in spring
(b) Split dressing, three-quarters in autumn before ploughing, one-quarter in spring except in 1970 when only 265 kg K were given, all in spring
(c) 35 kg Mg in 1970
(d) None in 1970

(iii) Varieties and cultivations.

			Drilled		Harvested	
			Stackyard	Lansome	Stackyard	Lansome
Barley	1970	Julia	26 Mar.	26 Mar.	25 Aug.	13 Aug.
	1971	Julia	13 Apr.	17 Mar.	25 Aug.	16 Aug.
Potatoes	1971	Pentland Crown	2 Apr.	31 Mar.	14 Sept.	28 Sep.
	1972	Pentland Crown	19 Apr.	18 Apr.	28 Sep.	2 Oct.
Sugar beet	1970	Klein E	20 Apr.	20 Apr.	23 Oct.	22 Oct.
	1972	Klein E	24 Mar.	23 Mar.	6 Nov.	6 Nov.

(iv) Liming Ground chalk, 2·5 t ha^{-1}, was applied each autumn 1969–71 before ploughing except that none was given in autumn 1969 to the Stackyard experiment.

(v) Cultivations, weedkillers etc. Details for each year are given in the *Yields of the Field Experiments* published annually by Rothamsted Experimental Station.

Soil sampling. Surface soils (0–23 cm) from the Stackyard experiment were sampled in autumn 1968 after the first potato crop on Blocks I, II and III and after the first barley crop on Blocks IV, V and VI. Subsequently, surface soils from all plots of both experiments were sampled in spring each year using a 20 mm diameter semi-cylinder sampling tool. The samples were taken before fertilisers were applied for that year. The soils were air-dried, ground to pass a 2 mm diameter sieve and bicarbonate-soluble P determined using the method of Olsen *et al.* (1954). Appendix Table 1 gives the results for the Stackyard experiment and Appendix Table 2 those for the Lansome experiment. In the discussion below, the yields and responses of the crops are discussed mainly in relation to the $NaHCO_3$-soluble P in the soils. The effects of the manuring and cropping on the amounts of bicarbonate-soluble P in the soil are discussed later.

Yields and uptakes of phosphorus

We give below the results from the two experimental sites separately and in a later section discuss the extent to which they may be combined. We believe that the sites were as free as possible from diseases likely to have any serious effect on yield. Cereals had not been grown since 1942 on Lansome and sugar beet only once previously, in 1967, and on one series only. Early potatoes were grown between 1956 and 1961 but not subsequently because of an infestation of potato cyst nematode (*Heterodera rostochiensis*). When we took the next crop of potatoes in 1971 there was no indication of any effects due to eelworm.

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Potatoes and beet had not been grown since 1876 on Stackyard. Although cereals were grown frequently, there had been a number of years of fallow during 1959–69 and the barley grown in 1968–71 was not badly affected by take-all or eyespot.

Barley (grain plus straw), potato tubers and sugar beet (tops and roots) were all removed from the plots in these experiments.

The Stackyard experiment, 1968–72

Barley. Yields of barley (grain and straw), %P in grain and total P uptakes by the crops are given in Appendix Table 3 for Maris Badger barley (1968–69) and in Appendix Table 4 for Julia barley (1970–71). In all years barley yielded only moderately well, grain yields ranging from 2·86 t ha^{-1} in 1970 on the unmanured soils (containing 18 mg P kg^{-1} of bicarbonate-soluble P) to 4·35 t ha^{-1} in 1968 on soils previously enriched with superphosphate (containing 34 mg soluble P kg^{-1} soil). Yields increased consistently in all years with the amounts of P applied in 1967, although the increases were negligible where more than 328 kg P ha^{-1} had been given and the soils contained more than 30–35 mg P kg^{-1} $NaHCO_3$-soluble P.

Yields of the two cultivars, Maris Badger and Julia, differed little in these experiments and the relationships between yield and $NaHCO_3$-soluble P in the soils are discussed using mean values derived from yields of both varieties. The yield responses of barley to fresh P applied as a dressing of superphosphate broadcast before sowing refer only to Julia barley in 1970–71.

Mean yields of barley grain (1968–71), mean $NaHCO_3$-soluble P in the soils and increases in grain yield for each mg P kg^{-1} increase in $NaHCO_3$-soluble P in the soils are given below:

$NaHCO_3$-soluble P (mg P kg^{-1})	16·0	20·4	23·8	32·5	38·5
Barley, grain (t ha^{-1})	3·40	3·69	3·74	3·98	3·96
Increase in yield for each 1 mg P kg^{-1} $NaHCO_3$-soluble P		0·066	0·015	0·028	−0·003

Increases in yield, for every mg P kg^{-1} increase in $NaHCO_3$-soluble P, were 0·066 t ha^{-1} on soils containing 16–20 mg P kg^{-1} $NaHCO_3$-soluble P and 0·024 t ha^{-1} on soils containing 20–32 mg P mg^{-1}. Yields slightly decreased on soils containing more soluble P.

The increases in barley yields (*cv.* Julia) and P uptakes in 1970–71 due to a fresh dressing of 27·5 kg P ha^{-1}, in relation to $NaHCO_3$-soluble P in the soils at sowing, are given below:

$NaHCO_3$-soluble P (mg P kg^{-1})	17·0	21·0	24·6	35·8	44·3
Increase from applying 27·5 kg P ha^{-1} before drilling					
Grain yield (t ha^{-1})	+0·27	+0·32	−0·02	−0·16	−0·16
P uptake (kg ha^{-1})	+0·8	+0·5	−0·6	−0·3	+0·2

Grain yields increased by 0·27 and 0·32 t ha^{-1} on soils containing 17 and 21 mg P kg^{-1} $NaHCO_3$-soluble P but there was no benefit from fresh superphosphate broadcast on soils containing more than 21 mg P kg^{-1} of soluble phosphorus. The extra P taken up from the fresh dressing of superphosphate was small (0·5–0·8 kg P ha^{-1}) on soils containing 21 mg P kg^{-1} $NaHCO_3$-soluble P and less. The *mean* apparent recovery of phosphorus from 27·5 kg P ha^{-1} (50 units P_2O_5 acre^{-1}) was only 0·4 kg P ha^{-1}, about 1·5% of the phosphate broadcast as superphosphate.

The total amounts of phosphorus removed in the grain and straw (means of all treatments) ranged from 8·4 to 16·3 kg P ha^{-1} (Appendix Tables 3 and 4). Barley grown on soils previously enriched with superphosphate in 1967 took up between 1–4 kg P ha^{-1}

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more phosphate than barley grown on the unmanured soils, i.e. between 2–10 times more phosphate than was apparently removed by barley from superphosphate broadcast before sowing.

These results show that, in this experiment on light land at Woburn, yields of barley (1) increase significantly as the amount of $NaHCO_3$-soluble P in the soils increases up to about 30 mg P kg^{-1}, and (2) increase with freshly applied superphosphate only on soils containing less than 21–22 mg P kg^{-1}. Grain yields were consistently slightly depressed by fresh superphosphate applied to soils containing more than 21 mg P kg^{-1}. The increases in yield that result from increases in soluble P in the soils (0·024–0·066 t ha^{-1} for an increase in $NaHCO_3$-soluble P of 1 mg P kg^{-1}) are similar to those measured previously (0·027 t ha^{-1} for an increase of 1 mg P kg^{-1}) on an old arable soil at Rothamsted containing 13–14 mg P kg^{-1} $NaHCO_3$-soluble P (Mattingly, 1968).

Potatoes. Yields of potatoes (total tubers), %P in tubers and P uptake by tubers are in Appendix Table 5 for Majestic potatoes (1968–69) and are in Appendix Table 6 for Pentland Crown (1971–72). Yields ranged from 26 t ha^{-1} in 1968 on soils containing 16 mg P kg^{-1} of bicarbonate-soluble P to 41–42 t ha^{-1} in 1971 and 1972 on soils previously enriched with superphosphate and containing 29–34 mg soluble P kg^{-1} soil. Yields increased consistently in each year with the amount of P applied in 1967 up to 328 kg P ha^{-1} but decreased in all years on plots given 492 kg P ha^{-1}, which maintained larger mean levels of $NaHCO_3$-soluble P in the soils (≈37 mg P kg^{-1}). There are no obvious explanations for this effect. The blocks in this experiment correspond to the plots of the Continuous Wheat and Barley experiments and had received no fertilisers, except nitrogen, since 1876. The amounts of exchangeable K (Table 1) and Mg were very small in spring 1967 but were increased by large applications of K_2SO_4 and $MgSO_4$ in autumn 1967 (see p. 8); yields may still, however, have been limited by too little potassium in this soil.

As with barley, the two varieties differed little and relationships between yields and $NaHCO_3$-soluble P in the soils are discussed using mean values for both varieties. Responses in yield to superphosphate broadcast before planting refer only to Pentland Crown grown in 1971 and 1972.

The mean $NaHCO_3$-soluble P in the soils, mean yields of tubers and increases in tuber yields for each 1 mg P kg^{-1} increase in $NaHCO_3$-soluble P are given below:

$NaHCO_3$-soluble P (mg P kg^{-1})	15·6	19·6	22·7	31·4	37·2
Yield, total tubers (t ha^{-1})	31·6	34·4	36·4	40·0	37·5
Increase in yield for each 1 mg P kg^{-1} $NaHCO_3$-soluble P		0·70	0·65	0·41	−0·22

The yield of tubers increased by 0·7 t ha^{-1} for each mg P kg^{-1} increase in $NaHCO_3$-soluble P on soils containing 16–20 mg P kg^{-1} soluble P and by about 0·5 t ha^{-1} on soils containing 20–31 mg P kg^{-1} $NaHCO_3$-soluble P. As already mentioned yields decreased on soils containing more soluble P.

The increases in tuber yields and P uptakes in 1971–72 on plots given 82 kg P ha^{-1} (150 units P_2O_5 $acre^{-1}$) as superphosphate before planting are given below in relation to the $NaHCO_3$-soluble P in the soils:

$NaHCO_3$-soluble P (mg P kg^{-1})	17·8	21·0	26·2	34·4	42·8
Increase from applying 82 kg P ha^{-1} before planting					
Tuber yield (t ha^{-1})	5·8	6·2	4·1	−0·7	−0·7
P uptake (kg ha^{-1})	2·3	2·8	2·0	−0·6	−0·1

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Freshly applied superphosphate increased yields by 5·8–6·2 t ha^{-1} on soils containing 18–21 mg P ha^{-1} $NaHCO_3$-soluble P, by 4·1 t ha^{-1} on soils containing 26 mg P kg^{-1} but slightly decreased yields on soils containing more than 34 mg P kg^{-1} $NaHCO_3$-soluble P. The apparent recovery of phosphate from a fresh dressing of 82 kg P ha^{-1} was 2·0–2·8 kg P ha^{-1} on soils containing less than 26 mg P kg^{-1} $NaHCO_3$-soluble P. On soils containing more soluble P, no extra phosphate was taken up by the crop so that on enriched soils potatoes utilise soil rather than fertiliser phosphate. Experiments using ^{32}P-labelled superphosphate, placed near the tubers, established that uptake of the labelled fertiliser was less on soils enriched with broadcast non-radioactive superphosphate than on the original soil (Mattingly & Widdowson, 1958), and, in experiments in the United States, uptakes of fertiliser P decreased significantly on soils of high phosphate status (Jacob *et al*, 1949).

Total removals of P in tubers (means of all treatments) ranged from 11·4 to 17·4 kg P ha^{-1} (Appendix Tables 5 and 6). Potatoes grown on soils previously enriched with superphosphate in 1967 took up very variable amounts of extra phosphate during subsequent years. The larger amounts of $NaHCO_3$-soluble P in soils (30–40 mg P kg^{-1}) increased P uptakes by only 2 kg P ha^{-1} in 1969 but doubled uptakes from 7·9 to 16·2 kg P ha^{-1} in 1968.

In this experiment both varieties of potatoes behaved similarly, tuber yields increased consistently with the amounts of $NaHCO_3$-soluble P in the soils up to about 30 mg P kg^{-1}; yields were depressed at higher soil P levels. Potatoes benefited from superphosphate broadcast before planting (82 kg P ha^{-1}) only on soils containing less than 34 mg P kg^{-1} $NaHCO_3$-soluble P.

Increases in yield from an increase of 1 mg P kg^{-1} $NaHCO_3$-soluble P were about 0·7 t ha^{-1} on soils containing 16–20 mg P kg^{-1} soluble P and about 0·5 t ha^{-1} on soils containing 20–30 mg P kg^{-1}. These increases are closely similar to those measured in experiments on an old arable soil at Rothamsted where yields of potatoes increased 0·6 $\pm$ 0·09 t ha^{-1} for each 1 mg P kg^{-1} increase in $NaHCO_3$-soluble P in soils containing 13–14 mg P kg^{-1} $NaHCO_3$-soluble P (Mattingly, 1968).

Sugar beet. Appendix Table 7 gives the yield of roots and tops, total sugar, %P in tops and brei and the total P removed by the whole crop in 1970 and 1972. Sugar yields were similar in both years and ranged from 5·14 t ha^{-1} in 1970 on soils containing 18 mg P kg^{-1} of bicarbonate-soluble P to 6·76 t ha^{-1} in 1972 on soils previously enriched with superphosphate and containing 29 mg soluble P kg^{-1} soil. Mean yields increased with the amount of P applied in 1967 (up to 328 kg P ha^{-1}) but decreased in both years on plots given 492 kg P ha^{-1}, which increased $NaHCO_3$-soluble P in the soils to about 42 mg P kg^{-1}. Growth of sugar beet, in relation to soil phosphate, was, therefore, similar to potatoes in this experiment.

The mean $NaHCO_3$-soluble P, the yields of sugar and the increases in sugar yields for each 1 mg P kg^{-1} increase in $NaHCO_3$-soluble P in the soils are given below:

$NaHCO_3$-soluble P (mg P kg^{-1} soil)	13·8	18·8	21·6	31·6	42·5
Sugar yield (t ha^{-1})	5·78	5·76	6·33	6·46	6·00
Increase in sugar yield for each 1 mg P kg^{-1} $NaHCO_3$-soluble P		0·071		0·013	−0·042

The increases in yield of sugar for each increase of 1 mg P kg^{-1} $NaHCO_3$-soluble P in the soil were more erratic than for barley and potatoes. The mean increase in sugar yields was about 0·07 t ha^{-1} for each mg P kg^{-1} $NaHCO_3$-soluble P on soils containing 14–22 mg P kg^{-1} soluble P. The rate of increase then decreased rapidly as the amounts of soluble P in the soils increased.

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Increases in sugar yields and P uptakes as a result of broadcasting 55 kg P ha^{-1} (100 units P_2O_5 $acre^{-1}$) are given below for each level of $NaHCO_3$-soluble P:

$NaHCO_3$-soluble P (mg P kg^{-1})	17·4	20·7	25·6	36·2	48·8
Increase from applying 55 kg P ha^{-1} before drilling					
Sugar yield (t ha^{-1})	0·24	0·33	−0·39	0·00	−0·10
P uptake (kg ha^{-1})	4·4	5·4	3·4	3·6	2·8

The increases in yield on soils within the range 17–21 mg P kg^{-1} $NaHCO_3$-soluble P, are very close to the value (+0·2 t ha^{-1}) quoted by Draycott, Durrand and Boyd (1971) from many experiments on mineral soils. The extra phosphorus taken up from superphosphate broadcast before sowing decreased much less with the amount of $NaHCO_3$-soluble P in the soils than uptakes by barley and potatoes. The mean increase (4·0 kg P ha^{-1}) represents an apparent recovery of 7·2% of the applied P.

The Lansome experiment. When this experiment was started in 1942, no attempt was made to balance the amounts of nutrients, particularly P and K, applied in each manure. Also, during the early years of the experiment, amounts of fertiliser P and K applied were small. Although fertiliser P dressings were increased considerably after 1960 those soils which contained most bicarbonate-soluble P in 1967 tended to contain most organic matter. It is not possible to be certain, therefore, whether increases in yield with increasing bicarbonate-soluble P were due to the extra soluble P or to the extra organic matter in

TABLE 3

%C in the soils of the Lansome experiment in 1972

Plot treatment and dressing[a]	%C[b]		
	Series A	Series B	Mean
Without organic manure, PK fertilisers only	1·00	1·15	1·08
Farmyard manure			
Single	1·21	1·70	1·46
Double	1·72	1·99	1·86
Vegetable compost			
Single	1·42	1·62	1·52
Double	1·85	1·85	1·85
Mean farmyard manure and vegetable compost			
Single	1·32	1·66	1·49
Double	1·78	1·92	1·85
Sewage sludge			
Single	1·25	1·48	1·36
Double	1·80	1·86	1·83
Sludge compost			
Single	1·37	1·50	1·44
Double	1·55	1·95	1·75
Mean sewage sludge and sludge compost			
Single	1·31	1·49	1·40
Double	1·68	1·90	1·79
Mean all organic manure treatments			
Single	1·31	1·58	1·44
Double	1·73	1·91	1·82

(a) Dressings of organic manures, when applied, were: single, 37·5 t ha^{-1}; double, 75 t ha^{-1}
(b) %C = 1·3 × Walkley (1947) value

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the soil or to a combination of both. In the Stackyard experiment all the soils contained similar amounts of organic matter which were all very small (Table 1).

Table 3 shows that in 1972 the amounts of organic carbon in soils given different amounts and types of organic manures during 1942–67 depended only on the amounts applied. Effects due to different manures were small. This was not so in 1960 when %C differed according to both type and amount of manure applied (Johnston, 1975b). However, no sewage sludge and sludge compost was applied after 1961 and no farmyard manure and vegetable compost after 1967; by 1972 the amounts of organic carbon in all soils had decreased and depended only on the quantities of manure applied previously. We decided, therefore, to give results for the two rates of fertilisers and organic manures but to average results for soils given

1. farmyard manure and vegetable compost (farmyard manure was applied instead of vegetable compost during 1962–67)
2. sewage sludge and sludge compost.

This not only groups soils with very similar organic carbon contents but with very similar bicarbonate-soluble P contents also (Appendix Table 2).

Barley. Yields of barley (*cv.* Julia) (grain and straw) %P in grain and total P uptakes in grain plus straw are given in Appendix Table 8. For the light land at Woburn yields were excellent, the best yield 6·08 t grain ha^{-1} was much larger than that (4·35 t ha^{-1}) in the Stackyard experiment. Not only were yields of barley larger in this experiment than on Stackyard but they apparently contradict the Stackyard results which suggested that yield increases were negligible where soils contained more than 30–35 mg P kg^{-1} bicarbonate-soluble P. Soluble P in the Lansome soils ranged from 126 to 176 mg P kg^{-1}. It is impossible to establish unequivocally whether the good yields were due to the larger amounts of soluble P, the larger organic matter contents of the soil or because these were the first cereal crops after a break of more than 25 years. Table 4 shows that when the results are grouped according to the organic matter contents of the soils, yields and bicarbonate-soluble P both increased and there were increases in both yield and P uptake from applying a fresh dressing of P (27·5 kg P ha^{-1}).

TABLE 4

Bicarbonate-soluble P and barley grain yields on soils grouped according to their organic carbon contents, Lansome experiment, mean 1970 and 1971

Soil group	%C in air dry soil	Soluble P mg P kg^{-1}	Barley grain t ha^{-1}	Increase from applying 27·5 kg P ha^{-1} to seedbed before drilling	
				Grain, t ha^{-1}	P uptake, kg P ha^{-1}
1	1·08	128	4·93	0·30	1·7
2	1·44	147	5·15	0·18	1·4
3	1·82	165	5·23	0·19	0·5

The effect of the fresh dressing of P both in increasing yield and P uptake was as large as in the Stackyard experiment when the average of all treatments is compared. On this soil, believed to be free from cereal diseases, Appendix Table 8 shows that the average response to a fresh dressing of 27·5 kg P ha^{-1} was small (0·2 t ha^{-1} of barley grain). However, there were positive responses in all but one of the eight comparisons. Percentage P in grain dry matter ranged from 0·395 to 0·472% and total P uptake by grain plus straw ranged from 18·0 to 29·4 kg P ha^{-1} when no fresh P was given. These values were all much larger than in the Stackyard experiment. The *mean* apparent recovery of phos-

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phorus from the fresh dressing (27·5 kg P ha^{-1}) was 1·2 kg P ha^{-1}, about 4·4% of the amount applied. This value was larger than the comparable one (1·5%) for the Stackyard experiment. Possible reasons for the differences between the Stackyard and Lansome experiments will be discussed later.

Potatoes. Appendix Table 9 gives the yields of total tubers, %P in tubers and P uptake by the tubers. Yields ranged from 30 to 63 t ha^{-1} and, although the poorest yields were only little better than those on Stackyard, the best yields were about 20 t ha^{-1} more. Bicarbonate-soluble P ranged from 122 to 223 mg P kg^{-1}. So, as with barley, yields of potatoes in this experiment continued to increase at soil P levels much larger than those in the Stackyard experiment in which yields did not increase on soils containing more than about 35 mg soluble P kg^{-1}.

Soil organic matter and soluble P both increased together, as with barley. Table 5 shows potato yields and bicarbonate-soluble P both increased as the %C in the soil increased and that both yield and P uptake were increased by applying a fresh dressing of 82 kg P ha^{-1}.

TABLE 5

Bicarbonate-soluble P and potato tuber yields on soils grouped according to their organic carbon contents, Lansome experiment, mean 1971 and 1972

Soil group	%C in air dry soil	Soluble P mg P kg^{-1}	Potato tubers t ha^{-1}	Increase from applying 82 kg P ha^{-1} to seedbed before plating: Tubers t ha^{-1}	Increase from applying 82 kg P ha^{-1} to seedbed before plating: P uptake kg P ha^{-1}
1	1·08	137	45·0	5·8	4·0
2	1·44	150	51·4	5·6	4·6
3	1·82	170	58·2	1·1	3·4

If the extra organic matter in the Lansome experiment soils had no effect on yield then the increases in yield for each extra 1 mg P kg^{-1} of $NaHCO_3$-soluble P were the same in both experiments, but at very different levels of soil P:

Experiment	Range of $NaHCO_3$-soluble P mg P kg^{-1}	Extra tubers, t ha^{-1} for each 1 mg P kg^{-1} increase in soluble P
Stackyard	22·7–31·4	0·41
Lansome	137–170	0·40

Yield response to fresh P decreased as soil P increased (as in the Stackyard experiment) and Appendix Table 9 shows that response was positive in seven of the eight comparisons. The seedbed dressing of 82 kg P ha^{-1} gave, on average, an extra 4·0 t ha^{-1} total tubers (range −0·5 to +12·1 t ha^{-1}). Thus the effect of the seedbed dressing of P was, on average, slightly larger in this experiment than in the Stackyard experiment.

Percentage P in tuber dry matter ranged from 0·191 to 0·298% when no fresh P was given and these values were appreciably larger than those in the Stackyard experiment. From soils without fresh P, P uptake by tubers ranged from 12·0 to 38·0 kg P ha^{-1}; the largest value was nearly 10 kg P ha^{-1} more than the total P uptake by the barley grain plus straw. The *mean* apparent recovery of phosphorus from the fresh dressing (82 kg P ha^{-1}) was 4·0 kg P ha^{-1}, about 4·8% of the amount applied.

Sugar beet. Appendix Table 10 gives the yield of tops and roots, total sugar, %P in tops and brei and the total P in tops plus roots at harvest. Bicarbonate-soluble P ranged from 128 to 176 mg P kg^{-1} and sugar yields from 6·01 to 9·12 t ha^{-1}. Yields of sugar,

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like those of barley and potatoes, were much larger than in the Stackyard experiment. Table 6 shows soluble P and sugar yields, total P uptake by tops plus roots, together

TABLE 6

Bicarbonate-soluble P and sugar yields on soils grouped according to their organic carbon contents, Lansome experiment, mean 1970 and 1972

Soil group	%C in air dry soil	Soluble P, mg P kg^{-1}	Sugar, t ha^{-1}	Increase from applying 55 kg P ha^{-1} to seedbed before drilling: Sugar, t ha^{-1}	Increase from applying 55 kg P ha^{-1} to seedbed before drilling: P uptake, kg P ha^{-1}
1	1·08	129	6·72	0·91	5·2
2	1·44	147	8·24	−0·17	1·4
3	1·82	161	8·15	0·35	2·1

with increases in sugar yield and P uptake due to a fresh dressing of 55 kg P ha^{-1} for three groups of soils with increasing organic matter contents. The first increment of extra P and organic matter greatly increased sugar yields, relative to soils with least organic matter and soluble P and a further increase in soluble P and organic matter gave no more sugar. This result is in marked contrast to the potato yields (Table 5) which were increased considerably by the combined effects of a similar increase in soluble P and soil organic matter.

Increases in sugar yields, like those on the Stackyard experiment and most small plot experiments with sugar beet, were more erratic than for barley and potatoes. Appendix Table 10 shows that increases ranged from −0·61 to 1·94 t sugar ha^{-1} due to a fresh dressing of 55 kg P ha^{-1}. The fresh P increased sugar yields consistently on soils with most P and most organic matter; the average increase was 0·35 t ha^{-1}. Total P in tops plus roots ranged from 26·7 to 42·4 kg P ha^{-1}; on average 50% of this P was in the roots. The apparent recovery of the extra phosphorus from the fresh dressing of superphosphate was, on average, only 2·6 kg P ha^{-1}, about 4·7% of the P applied in the fertiliser.

Results from the two experiments

The results of the Lansome experiment highlight one point of interest. When the yields of crops grown on soils receiving farmyard manure and vegetable compost were compared with those on soils receiving similar amounts of sewage sludge and sludge compost there was very little difference in the yield of barley and potatoes. Sugar yields were slightly decreased (by 0·44 t sugar ha^{-1}) on soils which received sewage sludge or sludge compost. The last dressings of sewage sludge and sludge compost were given in 1961 and of farmyard manure and vegetable compost in 1967 so the residual organic matter accumulated in the soil had very similar effects on the yields of crops grown during 1970–72.

This series of experiments was designed to relate crop yield to bicarbonate-soluble P in soil. As already explained, we used an old experimental site in Lansome Field because it was not possible to get a large enough range of soluble P in the Stackyard soils. The soils in Lansome contained not only much larger amounts of soluble P but also more organic matter than those on Stackyard, even where no organic manures had been added since 1942.

Because we knew the detailed histories of the sites over many years we examined the results with the benefit of this knowledge. Often, however, such detailed information is not available to experimenters who have to use many different sites to get a range of soil

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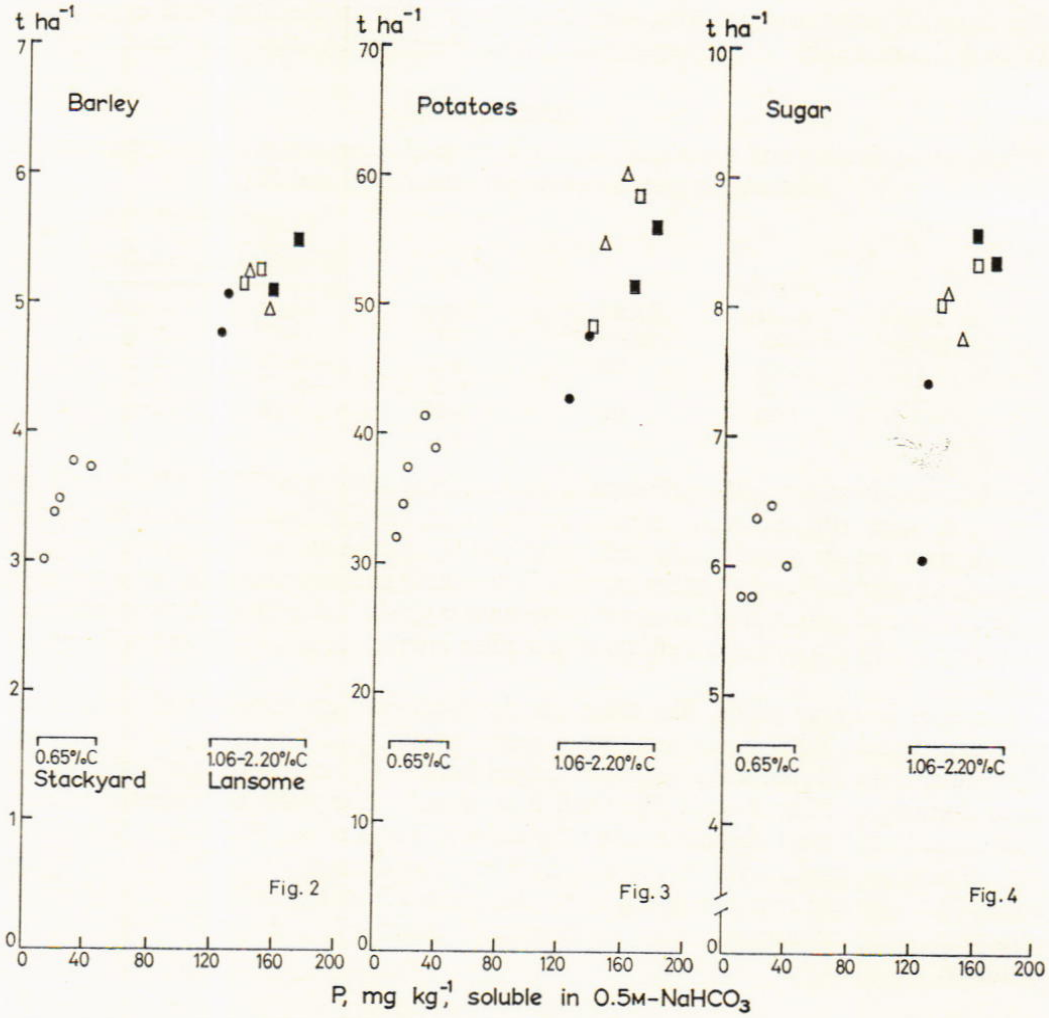

FIGS 2, 3 and 4. Relationships between bicarbonate-soluble P in soil and the yields of barley (cv. Julia) (Fig. 2), potatoes (cv. Pentland Crown) (Fig. 3) and sugar (sugar beet cv. Klein E) (Fig. 4) in the Stackyard and Lansome experiments, Woburn, 1970–72.

Stackyard ○ fertilisers only
Lansome ● fertilisers only
□ farmyard manure and vegetable compost
△ sewage sludge and sludge compost
■ farmyard manure and vegetable compost plus extra PK fertilisers

properties. Problems which can arise are well illustrated by the results of these two experiments. Figs. 2, 3 and 4 show the relationship between bicarbonate-soluble P and barley, potato and sugar yields respectively.

For barley the relationship suggests that yields increased with increasing soluble P above 40 mg P kg^{-1} of soil; grain yield at 40 mg P kg^{-1} was 3·8 t ha^{-1} and at 160 mg P kg^{-1} it was 5·4 t ha^{-1}. It is, however, most unlikely that all this increase in yield was due to extra soil P. Some, probably most, of the increase appears to be due to some effect from the extra organic matter in the soil. The soils on which the experiments were made contain the least (Stackyard) and the most (Lansome) organic matter of any of the lighter textured arable soils on Woburn Farm. Some part of the difference in yield may be because the soils on Lansome had not grown cereal crops since 1940 while those on

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Stackyard had a history of only cereal crops and fallow since 1876. Which factors or combination of factors were most important, and responsible for the large yields on Lansome is not known. However, these yields were only as good as those obtained in many Rothamsted experiments on disease-free sites. Whether much organic matter in these light-textured soils gives them a yield potential nearer to that of Rothamsted soil in the absence of disease cannot be clearly established from these experiments.

For potatoes there was no suggestion of any continuity in the relationship between yield and soil P on the two fields. A line could be fitted to the results if the difference of 80 mg soluble P kg^{-1} between the two fields could be ignored. In both experiments potato yields increased with increasing soil P but on Lansome some of this increase was probably due to extra organic matter in the soil.

Fig. 4 shows that the relationship between sugar yields and soil P was very similar to that for barley. It seems unlikely that the increased yield of sugar, from 6 to 8 t ha^{-1}, was due solely to increasing the soluble P from 40 to 160 mg P kg^{-1}, some must be due to the extra organic matter in the soils of Lansome. The extra organic matter did not affect plant population for neither experiment was precision drilled; both were drilled at a high seed rate and subsequently singled to similar plant populations.

Unfortunately, we were unable to build up the very large amounts of soluble P on Stackyard that existed on Lansome; it would have been difficult to simulate the effects of the 25 years of generous manuring on Lansome in the two years available for building up soil P on Stackyard. However, the results suggest that: (1) There is a need for more work on the effects of soil organic matter on yield testing new varieties of crops which have large yield potentials. (2) If comparisons are made between yields on various sites and the soils contain different amounts of organic matter then these differences may have large effects on yield similar to those reported here. This is especially likely when experiments are made on light soils similar to those at Woburn.

Preliminary observations suggest that much detailed work will be needed to establish unequivocally the value of soil organic matter in light soils. Visual inspection of the soils on Lansome did not suggest that soil particles had been aggregated into more stable crumbs on plots with most organic matter. In fact, the surface of all soils was beaten down to the same extent by rain. However, the extra organic matter may have made it easier for roots to penetrate between soil particles and so explore a greater mass of soil for nutrients. The larger concentrations of P in the dry matter of all crops grown on Lansome suggests that much more P was available to those crops than the ones on Stackyard.

Amounts of water held by the soils do not explain the differences between the sites. The surface soils from all fertiliser and farmyard manure plots (single and double dressings) on Lansome Series B were sampled on 16 August 1966 after carrots had been lifted on 8–10 August. The total gravimetric water content (w/w) of fertiliser-treated soils was 10% while that of farmyard manure-treated soils was 11·6% where the single dressing had been given and 14·0% with the double dressing. The effect of extra organic matter on Lansome could, therefore, be due to the soils holding more water. Salter and Williams (1969) determined the available water capacities in the top 30 cm of soil from selected plots on Stackyard and fertiliser and farmyard manure treated (double dressing) soils on Lansome in May 1967. They found that the Stackyard soils contained 4·5 cm available water but Lansome soils receiving fertilisers contained only 4·0 cm of water; farmyard manure-treated soils contained more, 5·0 cm. Available water contents do not appear to explain the differences in yield on plots given only fertilisers on Stackyard and Lansome.

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Changes in bicarbonate-soluble P due to cropping and manuring

Over the last two years, as fertiliser prices have increased, many farmers have asked if it is necessary to manure with P and K for every crop or whether some crops could get all the P and K they need from soil reserves. The answer to this question depends, in part, on how quickly soluble P and K in soil would be depleted by crop removals if none were given. Results from these two experiments show how soluble P changed in this light-textured soil at Woburn due to cropping and manuring during two-year periods and how the results depended on the P status of the soil. In the calculations which follow we have assumed that the surface soil (0–23 cm depth) weighs 3440 t ha^{-1}.

Stackyard experiment, 1968–69. Table 7 shows the amounts of P applied in 1967, the P removed by the crops in 1968–69, the extra P taken up from the fertiliser dressing and

TABLE 7

P applied and removed in crops and changes in bicarbonate-soluble P during 1967–70, Stackyard experiment

Treatment P applied in 1967, kg P ha^{-1}	P removed in crops 1968–69, kg P ha^{-1}	Extra P taken up from the fertiliser dressing, kg P ha^{-1}	Increase in soil P due to residue of fertiliser dressing, mg P kg^{-1}	$NaHCO_3$-soluble P in 1970, mg P kg^{-1}	Extra soluble P due to residue of fertiliser dressing, mg P kg^{-1}	Increase in $NaHCO_3$-soluble P as a % of the extra P in soil
0	21·4	—	—	15·4	—	—
82	23·4	2·0	23·2	20·6	5·2	22
164	24·4	3·0	46·8	24·6	9·2	20
328	28·9	7·5	93·2	37·2	21·8	23
492	29·6	8·2	140·6	48·1	32·7	23

the P residues remaining, expressed as an increase (mg P kg^{-1}) in soil P. Table 7 also shows the $NaHCO_3$-soluble P in spring 1970, the extra soluble P due to the P residues expressed as mg P kg^{-1} and as a percentage of the extra total P in the soil. On average 22% (range 20–23%) of the P residues were still bicarbonate-soluble in 1970, two and a half years after the P dressing was applied. This result is in good agreement with others summarised by Johnston (1975b).

Stackyard and Lansome experiments, 1970–72. It is unfortunate that soil samples were not taken in spring 1973 to follow changes in soil P after the three years of cropping and manuring. However, we can use the results of the 1972 soil sampling to measure changes over two years, 1970–71. During 1970–71 the two phases of each experiment did not receive exactly the same amounts of P, phase 1 had 109·5 kg P ha^{-1} phase 2, 82·5 kg P ha^{-1}. The average dressing, 96 kg P ha^{-1} is used in these calculations together with the average P removals from both phases. We also give average results for the single and double dressings of each treatment in the Lansome experiment because most of the differences in soluble P are small in relation to the total soluble P in the soil and the results were more variable than those on Stackyard.

Changes in soil P when no fresh P was given. Table 8 shows the amounts of P removed from each experiment during 1970–71 and the change in bicarbonate-soluble P between 1970 and 1972. In the Stackyard experiment the P removed by the crops increased from 21·7 to 30·6 kg P ha^{-1} as bicarbonate-soluble P in soil increased from 16 to 37 mg P kg^{-1}. No more P was taken up from soils which contained the most P (47 mg P kg^{-1}). The largest change was in soil with most soluble P and, as the content of soluble P decreased, so the magnitude of the change declined; this is discussed later. If all the P taken up by the

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TABLE 8

The effect of P removed in crops during 1970–71 on bicarbonate-soluble P when no fresh P was given, Stackyard and Lansome experiments

Treatment[a]	P removed by crops during 1970–71,[b] kg P ha^{-1}	$NaHCO_3$-soluble P, mg P kg^{-1} in 1970	in 1972	1972 minus 1970
Stackyard experiment				
0[c]	21·7	15·5	14·0	−1·5
82	24·4	21·4	17·8	−3·6
164	26·9	24·8	20·0	−4·8
328	30·6	37·0	29·0	−8·0
492	29·5	47·0	37·8	−9·2
Mean all treatments	25·8	26·9	22·1	−4·8
Lansome experiment				
Fertilisers	48·4	126	128	+2
Farmyard manure and vegetable compost	56·4	148	145	−3
Sewage sludge and sludge compost	57·8	146	146	0
Farmyard manure and vegetable compost plus PK fertilisers	61·0	164	161	−3
Mean all treatments	55·9	146	145	−1

(a) Treatments were: Stackyard experiment, amounts of P, kg P ha^{-1}, applied in 1967; Lansome experiment, the average of the single and double dressings are given.
(b) Average uptake by barley and sugar beet in 1970 plus average uptake by barley and potatoes in 1971. P uptakes by individual crops are given in the Appendix Tables.
(c) Duplicate treatments.

crops had come from the bicarbonate-soluble fraction then the average P uptake (25·8 kg P ha^{-1}) would have decreased bicarbonate-soluble P by 7·5 mg P kg^{-1}. Table 8 shows that the measured decrease in soluble P was, on average, only 4·8 mg P kg^{-1}, about two-thirds of the calculated loss so that soluble P had in part been replenished from non-bicarbonate-soluble reserves.

On Lansome much more P was removed, 48·4–61·0 kg P ha^{-1}, because the crops were larger. Averaged over all treatments 55·9 kg P ha^{-1} was removed, equivalent to about 16·2 mg P kg^{-1}. The Lansome soil contained at least three times as much soluble P as the Stackyard soil and soluble P changed very little due to the removal of 16·2 mg P kg^{-1} (Table 8). Bicarbonate-soluble P was obviously well buffered by other P reserves in this soil.

Changes in soil P when fresh P was given. Table 9 shows the amounts of P removed by crops from soils with and without fresh P during 1970–71 and the extra P taken up from the fresh dressings. From these data we have calculated the amount of the P dressing which remained in the soil and the increase in soil P. Table 9 also shows the bicarbonate-soluble P in spring 1972 on soils with and without fresh P in 1970–71 and the increase in soluble P due to the P residues. Finally, the increase in bicarbonate-soluble P is expressed as a percentage of the extra P in the soil.

On Stackyard 23% (range 17–28%) of the P residues were still bicarbonate-soluble in 1972. This result was in excellent agreement with that given above for the proportion of the P residues from the 1967 dressing which were still bicarbonate-soluble in 1970. On Lansome 45% (range 30–58%) of the residues remained bicarbonate-soluble, probably because the soils already contained much bicarbonate-soluble P.

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TABLE 9

The effect of P removed in crops during 1970–71 on bicarbonate-soluble P when fresh dressings of P totalling 96 kg P ha^{-1} were given, Stackyard and Lansome experiments

Treatment[a]	P, kg P ha^{-1}, removed by crops during 1970–71[b] on soils: given no fresh P	given fresh P	Extra P removed by crops given the fresh dressing (kg P ha^{-1})	P remaining in soil from fresh dressing: kg P ha^{-1}	mg P kg^{-1}	Bicarbonate-soluble P, mg P kg^{-1}, in 1972 on soils given: no fresh P	fresh P	Difference, soil with P minus soil without	Increase in $NaHCO_3$-soluble P as a % of the extra P in soil
Stackyard experiment									
0[c]	21·7	25·8	4·1	91·9	26·7	14·0	19·4	5·4	20
82	24·4	30·0	5·6	90·4	26·3	17·8	22·4	4·6	17
164	26·9	29·1	2·2	93·8	27·3	20·0	27·4	7·4	27
328	30·6	32·6	2·0	94·0	27·3	29·0	35·4	6·4	23
492	29·5	32·2	2·7	93·3	27·1	37·8	45·3	7·5	28
Mean all treatments	25·8	29·2	3·4	92·6	26·9	22·1	28·2	6·1	23
Lansome experiment									
Fertilisers	48·4	53·6	5·2	90·8	26·4	128	140	12	45
Farmyard manure and vegetable compost	56·4	63·2	6·8	89·2	25·9	145	160	15	58
Sewage sludge and sludge compost	57·8	61·8	4·0	92·0	26·7	144	152	8	30
Farmyard manure and vegetable compost plus PK fertilisers	61·0	64·4	3·4	92·6	26·9	161	172	11	41
Mean all treatments	55·9	60·8	4·8	91·2	26·5	144	156	12	45

(a) Treatments were: Stackyard experiment, amounts of P, kg P ha^{-1}, applied in 1967; Lansome experiment, the average of the single and double dressings are given.

(b) Average uptake by barley and sugar beet in 1970 plus average uptake by barley and potatoes in 1971. P uptakes by individual crops are given in the Appendix Tables.

(c) Duplicate treatments.

The build up of soil P over a period of years. Recently a number of farmers and advisors have asked why, on some soils, amounts of bicarbonate-soluble P have increased only slowly, or not at all over a period of years, especially where manuring and cropping have been such as to leave P residues. Results from the Stackyard and Lansome experiments may provide an explanation.

In the Stackyard experiment, where no P was applied between 1876 and 1966, we can clearly define P residues of two different ages, those from P dressings applied in 1967 and more recent residues from the 1970–71 dressings. The contribution of the 1967 residues to the bicarbonate-soluble P was measured directly as the difference between bicarbonate-soluble P on the four soils with residues and the soluble P on soil given no fresh P. The percentage of the residues which remained bicarbonate-soluble after two to three years agreed well with other results reported recently.

The contribution of the residues from the 1970–71 dressings could also be measured directly, because the test was made on half plots and we measured the increase in bicarbonate-soluble P at each of the five levels of soil P. The proportion of the residues of the 1970–71 dressings which remained bicarbonate-soluble was in good agreement with the 1968–70 results.

On a commercial farm it would rarely, if ever, be possible to compare the effects of P residues on soils with and without P dressings. At best, all that can be measured is the change in soluble P over a number of years. Table 10 shows the P removed by crops in the

TABLE 10

Bicarbonate-soluble P in soil in 1970 and the changes by 1972 due to the removal of P in crops grown in 1970–71 on soils with and without fresh dressings of P in 1970–71, Stackyard experiment

Treatment in 1967	Soils given no fresh P, 1970–71			Soils given fresh P, 1970–71[b]		
	P removed by crops during	$NaHCO_3$-soluble P, mg P kg^{-1}		P removed by crops during	$NaHCO_3$-soluble P, mg P kg^{-1}	
P applied, kg P ha^{-1}	1970–71,[a] kg P ha^{-1}	in 1970	difference by 1972	1970–71,[a] kg P ha^{-1}	in 1970	difference by 1972
0[c]	21·7	15·5	−1·5	25·8	15·2	+4·2
82	24·4	21·4	−3·6	30·0	19·9	+2·5
164	26·9	24·8	−4·8	29·1	24·4	+3·0
328	30·6	37·0	−8·0	32·6	37·3	−1·9
492	29·5	47·0	−9·2	32·2	49·2	−3·9
Mean all treatments	25·8	26·9	−4·8	29·2	26·9	+1·4

(a) Average uptake by barley and sugar beet in 1970 plus average uptake by barley and potatoes in 1971. P uptake by the individual crops are given in the Appendix Tables.
(b) The average dressing of P applied to the two crops each year was equal to a total dressing of 96 kg P ha^{-1} in the two years.
(c) Duplicate treatments.

Stackyard experiment and the changes in soil P from 1970 to 1972 for soils with and without fresh P during 1970–71. For soils given no fresh P all the changes in soil P were negative and the decrease was largest on soils with most P residues although there was little difference in P uptake on the various soils. This suggests that P applied as superphosphate in 1967 was not in equilibrium with soil P by 1970 and the solubility of these residues, particularly of the larger dressings, continued to decline during 1970–72 as some of the P became non-labile. Johnston (1975b) gave some results which showed that only about 5% of P residues that had been in soil for many years remained bicarbonate-soluble. Table 10 also shows that on soils given fresh P some of the changes

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in soil P from 1970 to 1972 were positive, some negative. When the results on soils with and without fresh P are compared, it is clear that the changes in soluble P on soils given fresh dressings are due primarily to the changes in soluble P on soils given no fresh P rather than to the accumulation of P residues during 1970–71.

The results for the Lansome experiment were different. These soils received much larger dressings of P over many years and contain very much larger amounts of soluble P, which are probably in equilibrium with the soil P. Uptake of P during 1970–71 did not change bicarbonate-soluble P when no fresh P was given (Table 8) and a larger proportion of the residues from fresh dressings given in these two years remained bicarbonate-soluble (Table 9).

These results show clearly that, when the various soil P fractions are not in equilibrium, the changes in soluble P may not be consistent with the net gains or losses of P added to or removed from the soil. The value of the bicarbonate method of soil analysis may be further improved if we can identify those soils where equilibrium is reached quickly and those requiring a longer period of time. We hope to investigate in greater detail the relationship between the labile and non-labile forms of P in soils from Rothamsted, Woburn and Saxmundham.

Summary

1. This paper describes two experiments on the value of the residues of phosphate fertilisers on sandy loam soil at Woburn. One experiment was sited on plots of the Continuous Wheat and Barley experiments (1876–1966) on Stackyard field and the other on plots of the Market Garden experiment (1942–67) on Lansome field. Soils on Stackyard contained 0·65% C in 1967 and small amounts of soluble P; those on Lansome contained much more organic matter, 1·06–2·20% C, and amounts of soluble P increased as soil carbon increased.

2. In 1967 superphosphate was applied at four rates (82, 164, 328 and 492 kg P ha^{-1}) to plots in the Stackyard experiment (previously unmanured) to increase the levels of soil P. The amounts of P in the soils of the Lansome experiment were not increased by adding superphosphate after 1967. To test the effects of applying fresh superphosphate to the crops during 1970–72, main plots were halved in the Stackyard experiment while on Lansome one-half the number of plots received fresh P.

3. During 1968 and 1969 both potatoes (Majestic) and barley (Maris Badger) were grown on Stackyard each year but only field beans (tic) on Lansome. Both experiments were divided into two series between 1970–72 and two crops were grown each year. The rotation was barley (Julia), potatoes (Pentland Crown) and sugar beet (Klein E) on one series and sugar beet, barley and potatoes on the other. The amounts of fresh P tested on each crop were barley (27·5 kg P ha^{-1}), potatoes (82 kg P ha^{-1}) and sugar beet (55 kg P ha^{-1}).

4. All plots were sampled in autumn 1967 (Lansome) and autumn 1968 (Stackyard) and in spring each year from 1970–72 before planting and the soils analysed for $NaHCO_3$-soluble P. In 1967, the $NaHCO_3$-soluble P in the soils was 11–18 mg P kg^{-1} soil on Stackyard and 140–200 mg P kg^{-1} soil on Lansome. The yields and the responses of the crops are discussed mainly in relation to $NaHCO_3$-soluble P in the soils. Changes in the soluble P in the soils are also related to the net gains of P by the soils (amounts of P added *minus* amounts removed).

5. Barley yields on Stackyard increased as the amount of $NaHCO_3$-soluble P in the soils increased up to 30 mg P kg^{-1}; larger crops were grown with freshly applied super-

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phosphate only on soils containing less than 22 mg P kg^{-1}. Yields of grain increased by 0·066 t ha^{-1} for an increase in $NaHCO_3$-soluble P of 1 mg P kg^{-1} in soils containing 16–20 mg P kg^{-1} and by 0·024 t ha^{-1} for each increase of 1 mg P kg^{-1} in soils containing 20–30 mg $NaHCO_3$-soluble P kg^{-1} soil. Yields of barley grain were up to 1·5 t ha^{-1} more on Lansome than on Stackyard and increased further (+0·2 t ha^{-1}) on plots given 27·5 kg P ha^{-1}. Most of the increase in yields appears to be due to some effect of the extra organic matter in Lansome soils.

6. Potato yields on Stackyard increased consistently with the amounts of $NaHCO_3$-soluble P in the soils up to 30 mg P kg^{-1} but were depressed at higher soil P levels. When crops were grown with fresh superphosphate broadcast before planting (82 kg P ha^{-1}) larger yields were obtained only on soils containing less than 34 mg Pkg^{-1}. Increases in yield from an increase of 1 mg P kg^{-1} $NaHCO_3$-soluble P were about 0·7 t ha^{-1} on soils containing 16–20 mg P kg^{-1} $NaHCO_3$-soluble P and 0·5 t ha^{-1} on soils containing 20–30 mg P kg^{-1}. The largest yields on Lansome were about 20 t ha^{-1} more than on Stackyard and yields increased by the same amount (0·4 t ha^{-1}) for each 1 mg P kg^{-1} increase in soluble P on Lansome and on Stackyard. Freshly applied superphosphate (82 kg P ha^{-1}) increased yields on average by 4 t ha^{-1}. Potatoes appeared to benefit greatly from the extra organic matter and soluble P in the soils on Lansome field.

7. Yields of sugar on Stackyard increased as the amount of $NaHCO_3$-soluble P in the soils increased up to 32 mg P kg^{-1} and decreased at higher soil P values. The mean increase in sugar yields was 0·07 t ha^{-1} for each mg P kg^{-1} $NaHCO_3$-soluble P on soils containing 14–22 mg P kg^{-1} soluble P. Sugar yields were increased by 0·2–0·3 t ha^{-1} by fresh superphosphate on soils containing 17–21 mg $NaHCO_3$-soluble P kg^{-1} soil. On Lansome sugar yields were increased by the first, but not the second, increment of extra P and organic matter in the soils. Sugar yields were more erratic than those of barley or potatoes on Lansome and the extra sugar from a fresh dressing of 55 kg P ha^{-1} before drilling ranged from −0·6 to 1·9 t ha^{-1} and averaged 0·35 t ha^{-1}.

8. The combined effects of extra organic matter and of large amounts of $NaHCO_3$-soluble P on crop growth were confounded in the soils from the Lansome experiment and could not be satisfactorily separated. The high yields of all crops on this soil provide evidence for, but do not establish unequivocally, the value of soil organic matter on the light land at Woburn.

9. Changes in $NaHCO_3$-soluble P in soils from both experiments were related to the net gains or losses of P added as fertiliser or removed by crops. Between 1967–70, 22% of the P gained by the soil from large dressings of superphosphate (82–492 kg P ha^{-1}) was recovered as soluble P on Stackyard and about the same proportion (23%) from the residues of two annual dressings applied in 1970–71. Between 1967–70, $NaHCO_3$-soluble P decreased on Stackyard by about two-thirds of the P removed by cropping, suggesting that some soluble P had been replenished from non-$NaHCO_3$-soluble reserves. More phosphate (45%) remained $NaHCO_3$-soluble in the Lansome experiment probably because the soils already contained much soluble P. When soil P fractions are not in equilibrium, changes in soluble P may not be consistent with net gains or losses of P added to or removed from soils.

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APPENDIX TABLE 1

Bicarbonate-soluble P in soils from the Stackyard experiment, 1968–72

P, mg kg^{-1}, soluble in 0·5M $NaHCO_3$

Crop	Year	Blocks	P applied (kg P ha^{-1}) in 1967					Mean
			0	82	164	328	492	
			Soils without additions of fresh P					
Barley	1968	IV, V and VI	15·8	21·7	26·8	34·5	37·6	27·3
	1969	I, II and III	16·6	17·8	20·7	27·9	33·7	23·3
	1970	IV, V and VI	18·2	24·7	29·1	39·9	46·7	31·7
	1971	I, II and III	13·4	17·6	18·5	27·6	35·9	22·6
	Mean		16·0	20·4	23·8	32·5	38·5	26·2
			Soils with additions of fresh P					
	1970	IV, V and VI	17·4	23·5	27·7	42·2	48·7	31·9
	1971	I, II and III	16·6	18·6	21·4	29·5	39·9	25·2
	Mean		17·0	21·0	24·6	35·8	44·3	28·5
			Soils without additions of fresh P					
Potatoes	1968	I, II and III	16·6	17·8	20·7	27·9	33·7	23·3
	1969	IV, V and VI	15·8	21·7	26·8	34·5	37·6	27·3
	1971	IV, V and VI	16·8	22·4	25·9	34·3	39·8	27·8
	1972	I, II and III	13·1	16·3	17·3	28·8	37·8	22·7
	Mean		15·6	19·6	22·7	31·4	37·2	25·3
			Soils with additions of fresh P					
	1971	IV, V and VI	18·7	22·3	27·7	37·7	42·9	29·9
	1972	I, II and III	17·0	19·7	24·8	31·0	42·7	27·0
	Mean		17·8	21·0	26·2	34·4	42·8	28·4
			Soils without additions of fresh P					
Sugar beet	1970	I, II and III	12·8	18·2	20·4	34·0	47·2	26·5
	1972	IV, V and VI	14·9	19·4	22·8	29·3	37·8	24·8
	Mean		13·8	18·8	21·6	31·6	42·5	25·7
			Soils with additions of fresh P					
	1970	I, II and III	13·0	16·3	21·2	32·4	49·6	26·5
	1972[a]	IV, V and VI	21·7	25·1	30·1	39·9	47·9	32·9
	Mean		17·4	20·7	25·6	36·2	48·8	29·7

(a) These soils all received fresh P in spring the previous year. The mean bicarbonate-soluble P values are slightly larger than those for the soils to which no fresh P was added in the same year. The increase was due to the fertiliser residues.

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APPENDIX TABLE 2

Bicarbonate-soluble P in soils from the Lansome experiment, 1970–72

P, mg kg^{-1}, soluble in 0·5M $NaHCO_3$

Crop	Year	Plot treatments and dressing, 1942–67[a]: PK fertilisers single	PK fertilisers double	Farmyard manure single	Farmyard manure double	Vegetable compost[b] single	Vegetable compost[b] double	Sewage sludge[c] single	Sewage sludge[c] double	Sludge compost[c] single	Sludge compost[c] double	Farmyard manure plus P and K[d] single	Farmyard manure plus P and K[d] double	Vegetable compost plus P and K[d] single	Vegetable compost plus P and K[d] double	Mean all treatments single	Mean all treatments double
		Soils without additions of fresh P															
Barley	1970	126	124	137	147	144	143	130	144	135	147	152	168	155	147	140	146
	1971	132	129	131	179	146	173	146	185	158	158	159	185	170	206	149	174
	Mean	129	126	134	163	145	158	138	164	146	152	156	176	162	176	144	160
		Soils with additions of fresh P															
	1970	108	136	137	162	121	144	130	140	126	144	155	169	145	166	132	152
	1971[e]	148	157	155	183	181	172	164	178	158	164	153	200	194	190	165	178
	Mean	128	146	146	172	151	158	147	159	142	154	154	184	170	178	148	165
		Soils without additions of fresh P															
Potatoes	1971	138	138	147	183	165	160	146	163	146	164	179	223	176	160	157	170
	1972	138	114	122	160	128	171	138	167	150	144	163	165	146	181	141	157
	Mean	138	126	134	172	146	166	142	165	148	154	171	194	161	170	149	164
		Soils with additions of fresh P															
	1971[e]	122	154	159	196	132	168	143	164	141	162	192	204	160	181	150	176
	1972[e]	135	150	131	189	157	182	156	164	152	154	159	156	204	179	156	168
	Mean	128	152	145	192	144	175	150	164	146	158	176	180	182	180	153	172
		Soils without additions of fresh P															
Sugar beet	1970	133	122	134	171	142	166	144	174	153	145	158	177	166	192	147	164
	1972[e]	127	133	133	153	144	149	137	144	140	146	158	176	155	140	142	149
	Mean	130	128	134	162	143	158	140	159	146	146	158	176	160	166	144	156
		Soils with additions of fresh P															
	1970	136	152	134	173	170	171	159	162	146	159	163	179	180	182	155	168
	1972	130	146	161	178	129	160	142	156	136	157	162	197	153	165	145	165
	Mean	133	149	148	176	150	166	150	159	141	158	162	188	166	174	150	166

(a) Single and double dressings

1. Fertilisers: two rates tested only from 1961–67: the following amounts of P and K, kg ha^{-1}, were applied during 1942–67: P single, 1175; double 1380; K single, 2330; double, 3735
2. Organic manures: when applied were always tested at two rates: single, 37·5 t ha^{-1}; double, 75 t ha^{-1}

(b) Vegetable compost was replaced by farmyard manure during 1962–67

(c) Sewage sludge and sludge compost not applied after 1961

(d) Extra PK applied as fertilisers only during 1961–67. Amounts were 740 kg P ha^{-1} and 1405 kg K ha^{-1} on FYM plots, slightly less on vegetable compost plots

(e) These soils all received fresh P in spring the previous year. The mean bicarbonate-soluble P values are slightly larger than those for the soils to which no fresh P was added in the same year. The increase was due to the fertiliser residues

APPENDIX TABLE 3

Yields of grain and straw, %P in grain and total P uptakes by barley (cv. Maris Badger) in the Stackyard experiment, 1968–69

	Year	P applied (kg P ha^{-1}) in 1967 0[a]	82	164	328	492	Mean	Standard error[b]
Grain (t ha^{-1} at 85% DM)	1968	4·09	4·25	4·28	4·35	4·29	4·23	0·036
	1969	3·50	3·75	3·79	4·07	4·08	3·78	0·119
	Mean	3·80	4·00	4·04	4·21	4·18	4·00	0·061
Straw (t ha^{-1} at 85% DM)	1968	3·93	4·48	4·49	4·62	4·58	4·33	0·113
	1969	2·90	3·11	3·32	3·90	3·37	3·25	0·195
	Mean	3·42	3·80	3·90	4·26	3·98	3·79	0·113
P in grain (% in DM)	1968	0·357	0·370	0·364	0·382	0·398	0·372	0·0072
	1969	0·248	0·248	0·250	0·259	0·309	0·260	0·0085
Total P uptake, grain + straw (kg P ha^{-1})	1968	15·0	16·4	16·2	17·6	17·6	16·3	0·45
	1969	8·7	9·0	9·3	10·6	12·6	9·8	0·36
	Mean	11·8	12·7	12·8	14·1	15·1	13·0	0·28

(a) Treatment duplicated.
(b) Standard errors for use in comparisons with the duplicated treatments are 0·707 times the errors for single treatments.

APPENDIX TABLE 4 IS ON NEXT PAGE

APPENDIX TABLE 5

Yields of total tubers, %P in tubers and total P uptakes by potatoes (cv. Majestic) in the Stackyard experiment, 1968–69

	Year	P applied (kg P ha^{-1}) in 1967 0[a]	82	164	328	492	Mean	Standard error[b]
Total tubers (t ha^{-1})	1968	26·7	30·7	30·9	37·1	34·7	31·1	0·69
	1969	35·6	38·0	39·4	39·9	38·0	37·7	2·31
	Mean	31·2	34·4	35·2	38·5	36·4	34·5	1·21
P in tubers (% in DM)	1968	0·146	0·159	0·176	0·224	0·227	0·180	0·0094
	1969	0·140	0·138	0·141	0·148	0·151	0·143	0·0041
Total P uptake, tubers only (kg P ha^{-1})	1968	7·9	9·5	10·5	16·2	16·1	11·4	0·76
	1969	11·3	11·9	12·7	13·4	12·9	12·2	0·86
	Mean	9·6	10·7	11·6	14·8	14·5	11·8	0·57

(a) Treatment duplicated.
(b) Standard errors for use in comparisons with the duplicated treatments are 0·707 times the errors for single treatments.

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APPENDIX TABLE 4

Yields of grain and straw, %P in grain and total P uptakes by barley (cv. Julia) grown with and without fresh P in the Stackyard experiment, 1970 and 1971

	Year	P applied in 1970 or 1971 (kg P ha^{-1})	P applied (kg P ha^{-1}) in 1967					Mean	Standard errors for use in horizontal (H) and vertical and interaction (V & I) comparisons[b]	
			0[a]	82	164	328	492			
Grain (t ha^{-1} at 85% DM)	1970	0	2·86	3·10	3·00	3·42	3·24	3·08	0·397 (H)	0·082
		27·5	2·73	3·09	2·91	2·73	2·75	2·82	0·201 (V & I)	(mean)
	1971	0	3·15	3·67	3·91	4·08	4·21	3·69	0·194 (H)	0·081
		27·5	3·81	4·31	3·98	4·45	4·37	4·12	0·198 (V & I)	(mean)
	Mean	0	3·00	3·38	3·46	3·75	3·72	3·38	0·221 (H)	0·058
		27·5	3·27	3·70	3·44	3·59	3·56	3·47	0·141 (V & I)	(mean)
Straw (t ha^{-1} at 85% DM)	1970	0	1·00	1·32	1·06	1·52	1·36	1·21	0·143 (H)	0·047
		27·5	0·93	1·50	1·13	1·43	1·14	1·18	0·114 (V & I)	(mean)
	1971	0	2·11	2·65	2·87	3·04	2·87	2·61	0·143 (H)	0·071
		27·5	2·76	2·98	2·83	3·10	3·15	2·93	0·174 (V & I)	(mean)
	Mean	0	1·56	1·98	1·96	2·28	2·12	1·91	0·101 (H)	0·043
		27·5	1·84	2·24	1·98	2·26	2·14	2·06	0·104 (V & I)	(mean)
P in grain (% in DM)	1970	0	0·302	0·317	0·306	0·305	0·294	0·305	0·0107 (H)	0·0032
		27·5	0·300	0·315	0·313	0·342	0·308	0·313	0·0079 (V & I)	(mean)
	1971	0	0·354	0·339	0·370	0·357	0·344	0·353	0·0118 (H)	0·0026
		27·5	0·334	0·325	0·347	0·341	0·357	0·340	0·0636 (V & I)	(mean)
Total P uptake, grain + straw (kg P ha^{-1})	1970	0	8·1	9·3	8·6	10·0	9·0	8·9	0·97 (H)	0·20
		27·5	7·7	9·2	8·5	8·9	8·1	8·4	0·48 (V & I)	(mean)
	1971	0	10·2	12·2	14·1	14·2	13·7	12·4	0·81 (H)	0·22
		27·5	12·3	13·4	13·2	14·8	15·1	13·5	0·54 (V & I)	(mean)
	Mean	0	9·2	10·8	11·4	12·1	11·4	10·6	0·63 (H)	0·15
		27·5	10·0	11·3	10·8	11·8	11·6	11·0	0·36 (V & I)	(mean)

(a) Treatments duplicated
(b) Standard errors for use in horizontal and vertical comparisons with the duplicated treatments are 0·707 times the errors for single treatments

APPENDIX TABLE 6

Yields of total tubers, %P in tubers and total P uptakes by potatoes (cv. Pentland Crown) grown with and without fresh P in the Stackyard experiment, 1971 and 1972

	Year	P applied in 1971 and 1972 (kg P ha^{-1})	P applied (kg P ha^{-1}) in 1967: 0[a]	82	164	328	492	Mean	Standard errors for use in horizontal (H) and vertical and interaction (V & I) comparisons[b]		
Total tubers (t ha^{-1})	1971	0	32·1	34·4	37·0	41·8	38·4	36·0	2·23	(H)	0·91
		82	38·5	42·0	43·2	41·7	40·1	40·7	2·24	(V & I)	(mean)
	1972	0	32·1	34·4	38·4	41·1	39·0	36·2	1·38	(H)	0·55
		82	37·3	39·1	40·5	39·7	35·9	38·3	1·36	(V & I)	(mean)
	Mean	0	32·1	34·4	37·7	41·4	38·7	36·1	1·31	(H)	0·53
		82	37·9	40·6	41·8	40·7	38·0	39·5	1·31	(V & I)	(mean)
P in tubers (% in DM)	1971	0	0·203	0·215	0·203	0·211	0·211	0·207	0·0095	(H)	0·0032
		82	0·213	0·215	0·203	0·211	0·232	0·214	0·0077	(V & I)	(mean)
	1972	0	0·177	0·187	0·186	0·189	0·188	0·184	0·0081	(H)	0·0023
		82	0·182	0·193	0·199	0·195	0·187	0·190	0·0057	(V & I)	(mean)
Total P uptake, tubers only (kg P ha^{-1})	1971	0	13·9	14·9	15·7	17·8	16·2	15·4	1·18	(H)	0·37
		82	16·4	18·1	18·1	17·5	17·8	17·4	0·91	(V & I)	(mean)
	1972	0	12·3	13·6	15·1	16·5	15·6	14·2	0·88	(H)	0·30
		82	14·3	15·8	16·7	15·7	13·8	15·1	0·73	(V & I)	(mean)
	Mean	0	13·1	14·2	15·4	17·2	15·9	14·8	0·74	(H)	0·24
		82	15·4	17·0	17·4	16·6	15·8	16·2	0·58	(V & I)	(mean)

(a) Treatments duplicated
(b) Standard errors for use in horizontal and vertical comparisons with the duplicated treatments are 0·707 times the errors for single treatments

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APPENDIX TABLE 7

Yields of clean roots, tops and total sugar, %P in brei and tops and total P uptakes by sugar beet (cv. Klein E) in the Stackyard experiment, 1970 and 1972

	Year	P applied in 1970 and 1972 (kg P ha^{-1})	P applied (kg P ha^{-1}) in 1967 0[a]	82	164	328	492	Mean	Standard errors for use in horizontal (H) and vertical and interaction (V & I) comparisons[b]		
Clean roots (t ha^{-1})	1970	0	30·0	29·6	34·5	34·7	32·5	31·9	1·95	(H)	0·65
		55	33·0	32·1	31·4	37·7	30·6	33·0	1·58	(V & I)	(mean)
	1972	0	35·4	36·1	36·5	37·6	35·4	36·1	2·06	(H)	0·52
		55	35·0	36·5	36·2	35·0	36·8	35·8	1·26	(V & I)	(mean)
	Mean	0	32·7	32·8	35·5	36·2	34·0	34·0	1·42	(H)	0·42
		55	34·0	34·3	33·8	36·4	33·7	34·4	1·01	(V & I)	(mean)
Tops, fresh weight (t ha^{-1})	1970	0	31·1	33·4	34·7	33·6	34·0	33·0	2·86	(H)	1·00
		55	35·0	39·1	37·3	37·2	34·3	36·3	2·44	(V & I)	(mean)
	1972	0	25·2	26·3	25·8	27·2	26·3	26·0	2·64	(H)	0·83
		55	26·9	27·2	27·9	28·6	26·5	27·3	2·04	(V & I)	(mean)
	Mean	0	28·2	29·8	30·2	30·4	30·2	29·5	1·95	(H)	0·65
		55	31·0	33·2	32·6	32·9	30·4	31·8	1·59	(V & I)	(mean)
Total sugar (t ha^{-1})	1970	0	5·25	5·14	6·17	6·17	5·73	5·62	0·382	(H)	0·128
		55	5·81	5·64	5·49	6·69	5·32	5·79	0·313	(V & I)	(mean)
	1972	0	6·30	6·39	6·49	6·76	6·27	6·42	0·360	(H)	0·094
		55	6·23	6·54	6·39	6·22	6·47	6·35	0·231	(V & I)	(mean)
	Mean	0	5·78	5·76	6·33	6·46	6·00	6·02	0·262	(H)	0·79
		55	6·02	6·09	5·94	6·46	5·90	6·07	0·194	(V & I)	(mean)
P in brei (%P in DM)	1970	0	0·058	0·063	0·068	0·091	0·097	0·073	0·0055	(H)	0·0010
		55	0·074	0·079	0·083	0·100	0·106	0·086	0·0026	(V & I)	(mean)
	1972	0	0·079	0·087	0·100	0·101	0·107	0·092	0·0045	(H)	0·0018
		55	0·105	0·105	0·101	0·113	0·119	0·108	0·0045	(V & I)	(mean)
P in tops (%P in DM)	1970	0	0·126	0·141	0·160	0·184	0·212	0·158	0·0165	(H)	0·0033
		55	0·149	0·202	0·186	0·215	0·241	0·190	0·0082	(V & I)	(mean)
	1972	0	0·162	0·170	0·178	0·206	0·220	0·183	0·0097	(H)	0·0047
		55	0·205	0·205	0·222	0·233	0·229	0·216	0·0115	(V & I)	(mean)
Total P uptake tops + roots (kg P ha^{-1})	1970	0	11·3	12·2	15·5	19·3	20·0	14·9	1·19	(H)	0·38
		55	15·1	19·1	18·5	23·9	23·5	19·2	0·93	(V & I)	(mean)
	1972	0	14·6	16·4	17·7	20·0	20·4	17·3	1·36	(H)	0·53
		55	19·8	20·3	21·5	22·4	22·6	21·1	1·29	(V & I)	(mean)
	Mean	0	13·0	14·3	16·6	19·6	20·2	16·1	0·90	(H)	0·33
		55	17·4	19·7	20·0	23·2	23·0	20·1	0·80	(V & I)	(mean)

(a) Treatments duplicated
(b) Standard errors for use in horizontal and vertical comparisons with the duplicated treatments are 0·707 times the errors for single treatments

APPENDIX TABLE 8

Yields of grain and straw, %P in grain and total P uptakes by barley (cv. Julia) grown with and without fresh P in the Lansome experiment, 1970 and 1971

	Year	P applied 1970 and 1971 (kg P ha^{-1})	Plot treatments and dressing, 1942–67[a]: PK fertilisers single	PK fertilisers double	Farmyard manure or vegetable compost[b] single	Farmyard manure or vegetable compost[b] double	Sewage sludge or sludge compost[c] single	Sewage sludge or sludge compost[c] double	Farmyard manure or vegetable compost plus PK fertilisers[d] single	Farmyard manure or vegetable compost plus PK fertilisers[d] double	Mean single	Mean double
Grain (t ha^{-1} at 85% DM)	1970	0	4·80	4·87	4·96	4·58	4·92	4·28	5·05	4·98	4·93	4·68
		27·5	4·50	4·88	5·02	4·43	4·83	4·74	4·61	5·53	4·74	4·90
	1971	0	5·36	4·68	5·31	5·94	5·56	5·56	5·12	6·02	5·34	5·55
		27·5	5·84	5·70	5·70	6·08	6·04	5·70	5·84	5·99	5·86	5·87
	Mean	0	5·08	4·78	5·14	5·26	5·24	4·92	5·08	5·50	5·14	5·12
		27·5	5·17	5·29	5·36	5·26	5·43	5·22	5·22	5·76	5·30	5·38
Straw (t ha^{-1} at 85% DM)	1970	0	1·30	1·26	2·59	1·82	2·72	2·09	2·41	2·58	2·26	1·94
		27·5	0·98	1·18	2·52	1·88	2·23	2·41	2·30	2·82	2·01	2·07
	1971	0	3·42	3·18	3·94	4·48	3·74	4·08	3·58	4·08	3·67	3·96
		27·5	3·98	4·06	4·23	4·56	4·46	3·91	3·74	4·25	4·10	4·20
	Mean	0	2·36	2·22	3·26	3·15	3·23	3·08	3·00	3·33	2·96	2·95
		27·5	2·48	2·62	3·37	3·22	3·34	3·16	3·02	3·54	3·05	3·14
P in grain (% in DM)	1970	0	0·440	0·421	0·444	0·466	0·424	0·419	0·442	0·421	0·438	0·432
		27·5	0·411	0·441	0·450	0·458	0·421	0·418	0·464	0·450	0·436	0·442
	1971	0	0·419	0·395	0·418	0·445	0·440	0·442	0·472	0·444	0·437	0·432
		27·5	0·410	0·441	0·432	0·448	0·440	0·440	0·446	0·441	0·432	0·442
Total P uptake by grain plus straw (kg P ha^{-1})	1970	0	19·3	19·1	21·7	20·4	20·6	17·6	22·0	24·2	20·9	20·3
		27·5	16·5	19·6	22·0	19·3	19·6	19·5	20·4	25·4	19·6	21·0
	1971	0	22·8	18·6	23·7	29·1	25·4	27·6	22·4	29·4	23·6	26·2
		27·5	24·6	25·6	26·8	30·5	28·3	26·7	27·1	29·8	26·7	28·2
	Mean	0	21·0	18·8	22·7	24·8	23·0	22·6	22·2	26·8	22·2	23·2
		27·5	20·6	22·6	24·4	24·9	24·0	23·1	23·8	27·6	23·2	24·6

(a) Single and double dressings
1. Fertilisers: two rates tested only from 1961–67: the following amounts of P and K, kg ha^{-1}, were applied during 1942–67: P single 1175, double 1380; K single 2330, double 3735
2. Organic manures: when applied were always tested at two rates: single 37·5 t ha^{-1}; double 75 t ha^{-1}

(b) Vegetable compost was replaced by farmyard manure during 1962–67
(c) Sewage sludge and sludge compost not applied after 1961
(d) Extra PK applied as fertilisers only during 1961–67. Amounts were 740 kg P ha^{-1} and 1405 kg K ha^{-1} on FYM plots, slightly less on vegetable compost plots

APPENDIX TABLE 9

Yield of total tubers, %P in tubers and total P uptakes by potatoes (cv. Pentland Crown) grown with and without fresh P in the Lansome experiment, 1971 and 1972

	Year	P applied 1971 and 1972 (kg P ha^{-1})	Plot treatments and dressing, 1942–67[a]: PK fertilisers single	PK fertilisers double	Farmyard manure or vegetable compost[b] single	Farmyard manure or vegetable compost[b] double	Sewage sludge or sludge compost[c] single	Sewage sludge or sludge compost[c] double	Farmyard manure or vegetable compost plus PK fertilisers[d] single	Farmyard manure or vegetable compost plus PK fertilisers[d] double	Mean single	Mean double
Total tubers (t ha^{-1})	1971	0	53·0	54·3	50·6	58·6	56·6	59·2	61·3	61·4	55·4	58·4
		82	49·2	60·4	60·2	58·4	58·0	61·6	60·4	62·9	57·0	60·8
	1972	0	42·0	30·5	45·6	58·6	53·0	60·4	41·6	51·1	45·6	50·2
		82	44·7	48·6	53·3	59·6	58·1	57·8	52·2	55·6	52·1	55·4
	Mean	0	47·5	42·4	48·1	58·6	54·8	59·8	51·4	56·2	50·5	54·3
		82	47·0	54·5	56·8	59·0	58·0	59·7	56·3	59·2	54·6	58·1
P in tubers (% in DM)	1971	0	0·269	0·233	0·238	0·294	0·255	0·260	0·298	0·284	0·265	0·268
		82	0·250	0·292	0·299	0·316	0·261	0·283	0·311	0·341	0·280	0·308
	1972	0	0·198	0·191	0·203	0·230	0·200	0·203	0·217	0·226	0·204	0·212
		82	0·202	0·212	0·219	0·236	0·200	0·207	0·227	0·236	0·212	0·223
Total P uptake by tubers (kg ha^{-1})	1971	0	31·8	26·9	26·8	35·0	31·2	32·9	38·0	36·7	32·0	32·9
		82	26·6	36·7	37·8	39·8	33·2	38·0	38·2	41·8	34·0	39·1
	1972	0	18·3	12·0	19·2	28·4	23·2	26·3	18·8	23·8	19·9	22·6
		82	19·7	21·6	24·8	29·3	26·0	26·7	24·7	27·5	23·8	26·3
	Mean	0	25·0	19·4	23·0	31·7	27·2	29·6	28·4	30·2	26·0	27·8
		82	23·2	29·2	31·3	34·6	29·6	32·4	31·4	34·6	28·9	32·7

(a) Single and double dressings
1. Fertilisers: two rates tested only from 1961–67: the following amounts of P and K, kg ha^{-1}, were applied during 1942–67: P single 1175, double 1380; K single 2330, double 3735
2. Organic manures: when applied were always tested at two rates: single 37·5 t ha^{-1}; double 75 t ha^{-1}

(b) Vegetable compost was replaced by farmyard manure during 1962–67

(c) Sewage sludge and sludge compost not applied after 1961

(d) Extra PK applied as fertilisers only during 1961–67. Amounts were 740 kg P ha^{-1} and 1405 kg K ha^{-1} on FYM plots, slightly less on vegetable compost plots

APPENDIX TABLE 10 *Yields of clean roots, tops and total sugar, %P in tops and brei and total P uptakes by sugar beet (cv. Klein E) grown with and without fresh P in the Lansome experiment, 1970 and 1972*

			Plot treatments and dressing, 1942–67[a]									
			PK fertilisers		Farmyard manure or vegetable compost[b]		Sewage sludge or sludge compost[c]		Farmyard manure or vegetable compost plus PK fertilisers[d]		Mean	
	Year	P applied 1970 and 1972 (kg P ha^{-1})	single	double	single	double	single	double	single	double	single	double
Clean roots (t ha^{-1})	1970	0	43·6	28·5	42·4	50·4	44·3	44·6	45·2	46·0	43·9	42·4
		55	42·1	44·3	46·8	52·8	45·1	45·0	48·0	50·2	45·5	48·1
	1972	0	42·5	42·6	49·2	47·0	49·2	46·8	51·8	50·0	48·2	46·6
		55	42·2	46·6	50·9	47·6	46·6	46·7	43·6	54·2	45·8	48·8
	Mean	0	43·0	35·6	45·8	48·7	46·8	45·7	48·5	48·0	46·0	44·5
		55	42·2	45·4	48·8	50·2	45·8	45·8	45·8	52·2	45·6	48·4
Tops, fresh weight (t ha^{-1})	1970	0	33·8	24·4	30·0	36·0	37·7	46·2	33·2	32·1	33·7	34·7
		55	31·8	26·2	38·0	35·2	44·2	39·0	35·6	33·5	37·4	33·5
	1972	0	37·6	30·0	36·5	32·8	40·5	39·2	38·6	34·8	38·3	34·2
		55	39·2	36·5	40·2	31·4	42·1	38·4	33·0	37·0	38·6	35·8
	Mean	0	35·7	27·2	33·2	34·4	39·1	42·7	35·9	33·4	36·0	34·4
		55	35·5	31·4	39·1	33·3	43·2	38·7	34·3	35·2	38·0	34·6
Sugar (t ha^{-1})	1970	0	7·42	4·80	7·36	8·72	7·81	7·48	8·05	8·22	7·66	7·30
		55	7·24	7·72	8·12	9·19	7·67	7·83	8·30	8·60	7·83	8·34
	1972	0	7·41	7·22	8·70	7·98	8·49	8·05	9·02	8·46	8·40	7·92
		55	7·36	8·18	8·78	8·02	8·00	8·06	7·56	9·32	7·92	8·40
	Mean	0	7·42	6·01	8·03	8·35	8·15	7·76	8·54	8·34	8·03	7·61
		55	7·30	7·95	8·45	8·60	7·84	7·94	7·93	8·96	7·88	8·36
P in brei (% in DM)	1970	0	0·152	0·140	0·163	0·162	0·168	0·174	0·159	0·175	0·160	0·163
		55	0·159	0·157	0·175	0·179	0·170	0·176	0·169	0·190	0·168	0·176
	1972	0	0·152	0·154	0·168	0·166	0·173	0·179	0·183	0·185	0·169	0·171
		55	0·163	0·172	0·181	0·175	9·173	0·184	0·176	0·198	0·173	0·182
P in tops (% in DM)	1970	0	0·287	0·281	0·303	0·300	0·288	0·333	0·304	0·328	0·296	0·310
		55	0·324	0·323	0·309	0·278	0·350	0·324	0·293	0·285	0·319	0·302
	1972	0	0·309	0·287	0·318	0·287	0·332	0·348	0·322	0·337	0·320	0·315
		55	0·297	0·333	0·299	0·355	0·330	0·350	0·309	0·338	0·309	0·344
Total P uptake, tops plus roots (kg P ha^{-1})	1970	0	33·2	22·1	32·4	36·6	35·0	40·9	34·2	37·5	33·7	34·3
		55	33·6	31·0	39·0	37·7	41·2	40·6	36·1	39·0	37·5	37·1
	1972	0	34·9	31·4	39·5	34·2	42·6	41·6	43·6	40·7	40·2	37·0
		55	37·6	40·2	42·0	38·1	42·0	42·9	35·5	45·9	39·3	41·8
	Mean	0	34·0	26·7	36·0	35·4	38·8	41·2	38·9	39·1	37·0	35·6
		55	35·6	35·6	40·5	37·9	41·6	41·8	35·8	42·4	38·4	39·4

(Footnotes as in Appendix Table 9)