Rothamsted Experimental Station Report for 1969 Part 2


ROTHAMSTED
EXPERIMENTAL STATION
REPORT FOR 1969
PART 2

Full Table of Content

The Residual Value of Farmyard Manure and Superphosphate in the Saxmundham Rotation II Experiment, 1899-1968

G. E. G. Mattingly, A. E. Johnston and Margaret Chater

G. E. G. Mattingly, A. E. Johnston and Margaret Chater (1970) *The Residual Value of Farmyard Manure and Superphosphate in the Saxmundham Rotation II Experiment, 1899-1968 ;* Rothamsted Experimental Station Report For 1969 Part 2, pp 91 - 112 **- DOI: https://doi.org/10.23637/ERADOC-1-34865**

The Residual Value of Farmyard Manure and Superphosphate in the Saxmundham Rotation II Experiment, 1899–1968

G. E. G. MATTINGLY, A. E. JOHNSTON and MARGARET CHATER

Introduction

The Rotation II experiment on Harwood's field at Saxmundham started in autumn, 1899, in the same year and tested the same 4-course rotation (wheat, roots, barley and a legume), as Rotation I. It was designed by Sir William Somerville, the first Drapers Professor of Agriculture at Cambridge, to determine how limited amounts of farmyard manure (FYM), nitrogen (as sodium nitrate) and phosphorus (as superphosphate) could best be distributed throughout the rotation. There were four blocks, one for each crop, and ten manurial treatments in each block. The history, including changes in manuring and results from the experiment were described by Oldershaw (1941) and Boyd and Trist (1966).

By 1952, although the cropping and manuring were no longer relevant to East Anglian farming, it was decided to keep seven of the original treatments on two of the four blocks for a further three rotations. The arrangement of these 14 plots, in relation to Rotation I, is shown schematically by Trist and Boyd (1966). They were manured and cropped, continuing the original rotation on the blocks known as Victors and Neals, until 1964.

In 1965 a new experiment was started on these plots to assess the value of soil P analysis on this soil. The adjacent two plots of treatment 8 of the original experiment, to which no P was added between 1952 and 1964, were included in the new experiment.

The sequence of cropping during the 4 years was barley, potatoes, turnips or sugar beet and barley. In 1969, the main plots of the experiment were divided into microplots to test, between 1969 and 1972, the value of the 'old' (1899–1964) and 'new' (1965–68) phosphate residues for three crops, potatoes, sugar beet and barley grown each year.

In this paper we describe:

1. the analysis of the soils, at the end of the original (1899–1964) manuring,
2. the changes in soil analysis between 1964 and 1968 and
3. the crop yields and nutrients removed between 1965 and 1968.

Methods of analysis

Soils were sampled 0–8 in. deep during autumn 1964 and 0–10 in. during autumn 1966 and 1968. These depths represented the plough layer, which was deepened in winter 1964/65 to improve the drainage and water-holding capacity of the surface soil.

https://doi.org/10.23637/ERADOC-1-4

The methods of analysis used were those described for soils from Rotation I (Cooke, Mattingly & Williams, 1958), except that:

1. ***$CaCO_3$*** was measured by the method of Tinsley, Taylor and Moore (1951).
2. ***Total P*** was determined after fusion with Na_2CO_3 (Mattingly, 1970).
3. ***Exchangeable-K*** was measured by successively extracting 6·25 g of soil with *N*-ammonium acetate (250 ml).
4. ***Labile P (Pe)*** was measured by isotopic exchange in 0·02*M* KCl (Arambarri & Talibudeen, 1959) using a soil : solution ratio of 1 : 200 and a period of 150 hours for exchange.

Treatments, 1899–1964

Table 1 lists the treatments and mean yields of all crops, which were given previously by Boyd and Trist (1966). Although different crops in the rotation were dressed with FYM (10 tons/acre), sodium nitrate (26 lb N/acre) and superphosphate (73·5 lb P/acre), treatments 3 to 7 received the same total amounts of FYM, N and P in each 4-course rotation; treatment 8 received twice the amount of superphosphate (until 1952), treatment 2 received only FYM and treatment 1 was always unmanured.

Boyd and Trist stated in 1964:

'Perhaps the most important lesson to be learnt from the results of Rotation II came from the evidence it provided of the value of FYM and P fertiliser in raising yields of all crops in the rotation, not only those to which they were applied. Thus a single dressing of 10 tons FYM applied to wheat (treatment 2) not only increased the wheat yield by about a third compared with the unmanured plots (treatment 1) but also doubled the yield of mangolds, increased barley yield by almost a quarter and the yield of beans and clover, three crops later, by about a third. The application of P in addition to FYM gave further large increases in yield for all crops of the rotation whether or not the P fertiliser was applied directly to them. Indeed it is obvious from a study of the yields of treatments 3 to 7 that profitability of the rotation as a whole was only slightly influenced by the particular crop of the rotation to which the P was applied.'

The small differences between yields of treatments 3 to 7 are important to the subsequent use of the site which, in 1964, consisted of large areas of two blocks (Victors and Neals) that had received the same manuring for 65 years and from which almost the same quantities of crops had been removed.

The exact amounts of P applied to this soil are not known as neither the FYM nor superphosphate were analysed. Table 2 gives the total weights of FYM and superphosphate applied between 1899 and 1964 and estimates of the total P and K applied. These estimates are based on the following assumptions:

https://doi.org/10.23637/ERADOC-1-4

TABLE 1

Treatments 1 to 8 and mean yields[a] *Rotation II, 1899–1952*

Treatment	Manuring per acre 1899–1952 (per 4 years)	Yields/acre: Wheat Treatment[b]	Wheat Grain (cwt)	Mangolds Treatment[b]	Mangolds Roots (tons)	Barley Treatment[b]	Barley Grain (cwt)	Beans Treatment	Beans Grain (cwt)
1	None	—	11·7	—	4·7	—	9·2	—	12·5
2	10 tons FYM	FYM	15·9	—	11·3	—	11·8	—	16·6
3		FYM	17·7	NP	19·3	—	13·4	—	20·6
4		NP	19·5	FYM	18·4	—	14·0	—	22·1
5	10 tons FYM plus 7½ cwt superphosphate (P) (5 cwt before 1921)	N	19·6	FYM	18·8	—	14·2	P	22·6
6		FYM + N	21·0	P	17·6	—	14·2	—	21·6
7		FYM	18·3	P	17·7	N	18·4	—	21·9
8	10 tons FYM plus 15 cwt superphosphate (10 cwt before 1921)	FYM	18·8	NP	21·7	½P	15·4	½P	22·8

[a] From Boyd and Trist (1966). [b] N, sodium nitrate (N), 1½ cwt/acre (1 cwt before 1921).

https://doi.org/10.23637/ERADOC-1-4

1. that superphosphate contained 8·75% P, which very much overestimates the amounts applied in the early years of the experiment;

2. that FYM contained 44 lb P/10 tons, a value used previously for Rotation I (Cooke, Mattingly & Williams, 1958), which agrees well with analyses of the FYM applied in 1965 and 1966 (Table 6).

TABLE 2

Total amounts of FYM and superphosphate, and estimates of total P and K applied to Rotation II, 1899–1964

Treat-ment	Manuring per acre 1899–1964 (per 4 years)	Treatment symbol	Total applied per acre: FYM (tons)	Total applied per acre: Superphosphate (cwt)	Estimated P applied (lb/acre): FYM	Estimated P applied (lb/acre): Superphosphate	Estimated P applied (lb/acre): Total	Estimated K applied (lb/acre): FYM
1	None	None	None	None	None	None	None	None
2	10 tons FYM	FYM	160	None	705	None	705	1600
3	10 tons FYM plus 7½ cwt superphosphate (P) (5 cwt before 1921)	FYM + P	160	107·5	705	1050	1755	1600
4		FYM + P	160	107·5	705	1050	1755	1600
5		FYM + P	160	107·5	705	1050	1755	1600
6		FYM + P	160	107·5	705	1050	1755	1600
7		FYM + P	160	107·5	705	1050	1755	1600
8	Manuring stopped in 1952; until then 10 tons FYM plus 15 cwt superphosphate (2P) (10 cwt before 1921)	FYM + 2P	130	170	575	1665	2240	1300

Soil analysis, 1964

Table 3 gives analyses of the soils taken from the experiment in 1964, as means of the two blocks. Analyses from the two blocks were similar except for values of $NaHCO_3$-soluble P, labile P and $\frac{1}{2}pCa + pH_2PO_4$, some of which are given for the separate blocks (Table 4) and are discussed further below.

All plots contain free $CaCO_3$ (0·3 to 0·6%) and pH values (in 0·01 M $CaCl_2$), greatest on treatment 1, range only from 7·05 to 7·36. Farmyard manure alone (treatment 2) increased %C, %N, total P, all values of soluble P and exchangeable K and decreased $\frac{1}{2}pCa + pH_2PO_4$. Where superphosphate was given once in the rotation, in addition to FYM (treatments 3 to 7), or twice until 1952 (treatment 8), the %C was slightly (0·10%) larger, the mean %N was the same and total soil P about 180 ppm more than with only FYM. The $NaHCO_3$-soluble P and labile P values for treatments 3 to 8 (averaging both blocks) range from 38 to 44 and 108 to 120 ppm P respectively and are approximately three times larger than on the FYM only plot (treatment 2). The monocalcium phosphate potentials ranged from 6·90 to 6·98 and are about 0·8 units less than on treatment 2.

The mean analyses of the two blocks (Table 3) conceal the differences between soluble and labile P analyses because of the year when the last dressings of superphosphate were applied. Table 4 shows values of $NaHCO_3$-soluble P, labile P, P concentrations in 0·01 M $CaCl_2$ and $\frac{1}{2}pCa + pH_2PO_4$ in 1964, for single plots given superphosphate in either autumn 1963 or autumn 1960. There was more soluble and labile P in soils given superphosphate one year before sampling than in soils given

https://doi.org/10.23637/ERADOC-1-4

TABLE 3

Chemical analyses of air-dry soils (0–8 in.) from Rotation II in 1964

Treatment	Manuring,[a] 1899–1964	Total C[b] (%)	Total N (%)	C/N ratio[b]	$CaCO_3$ (%)	pH in 0·01 *M* $CaCl_2$	Total P (ppm)	Labile P (ppm)	$NaHCO_3$-P (ppm)	½pCa + pH_2PO_4	Exchange-able K (ppm)
1	None	0·82	0·127	6·4	0·49	7·36	434	20	6	8·36	149
2	FYM	1·08	0·160	6·8	0·42	7·17	505	44	12	7·79	182
3	FYM + P	1·13	0·160	7·1	0·32	7·04	648	109	40	6·91	167
4	FYM + P	1·15	0·152	7·6	0·40	7·08	683	118	42	6·91	161
5	FYM + P	1·23	0·170	7·2	0·35	7·07	706	108	38	6·98	173
6	FYM + P	1·19	0·166	7·2	0·40	7·05	684	112	40	6·92	159
7	FYM + P	1·18	0·162	7·3	0·56	7·15	712	120	44	6·90	162
8	FYM + 2P	1·20	0·170	7·1	0·51	7·06	720	116	38	6·98	136

[a] For full details, see Tables 1 and 2. [b] Walkley-Black, uncorrected.

https://doi.org/10.23637/ERADOC-1-4

TABLE 4

Soil analysis in relation to the application of FYM and superphosphate

Block	Treatment	FYM last applied	Superphosphate last applied	$NaHCO_3$-P (ppm)	Labile P (ppm)	P concentration (μM P/l.)	$\frac{1}{2}$pCa + pH_2PO_4
Victors	2	1962	None	10	41	0·5	7·81
Neals	2	1963	None	12	48	0·5	7·77
Victors	3	1962	1963	52	132	6·3	6·69
Neals	3	1963	1960	28	86	2·0	7·13
Victors	7	1962	1963	54	136	6·4	6·75
Neals	7	1963	1960	35	105	2·7	7·06

phosphate four years before. Values of $NaHCO_3$-soluble P ranged from about 50 ppm, in the year when P was applied, to about 30 ppm three years later. The yields of cereals and mangolds, however, increased only slightly when P was given (Table 1), probably because small crops were grown with the little N (26 lb/acre in addition to FYM) applied in the old rotation.

Unlike Rotation I, which tested K, potassium fertilisers were not given in Rotation II but some K was applied in the FYM given to treatments 2 to 8. If the FYM applied between 1899 and 1964 contained the same amount of K (100 lb K/10 tons FYM) as that applied in 1965 and 1966, then only 25 lb K was given on average each year. Most of this small amount of K was probably removed by the crops because increases in exchangeable K in the soils shown in Table 2 were small. Cooke and Williams (1966) showed by crop analysis that in Rotation I in 1964 and 1965 nearly all the K (50 lb K/acre) applied annually as potassium chloride was removed in the crops when N and P were also given.

Comparison of soil analyses of Rotation I (1957) and Rotation II (1964)

Total C, N and P. All plots of Rotation I were sampled (0–8 in.) and analysed in March, 1957 (Cooke, Mattingly & Williams, 1958), when the experiment was still ploughed to the same depth as Rotation II. Table 5

TABLE 5

Comparison of soil analyses (0–8 in.) on Rotation I[a] *(in 1957) and Rotation II (in 1964)*

Rotation	Treatment	Treatment/acre/4 years	%C	%N	Total P (ppm)	$NaHCO_3$-P (ppm)	Labile P (ppm)	$\frac{1}{2}$Ca + pH_2PO_4
I	6	None	0·94	0·135	460[b]	2	28	8·60
	1	24 tons FYM	1·55	0·199	750[b]	33	145	6·64
	10	Sodium nitrate, 8 cwt superphosphate, 8 cwt potassium chloride, 4 cwt	1·01	0·144	600[b]	19	92	7·60
	1	None	0·82	0·127	434	6	20	8·36
	2	10 tons FYM	1·08	0·160	505	12	44	7·79
	3–7	10 tons FYM plus 7½ cwt superphosphate, sodium nitrate, 1½ cwt	1·18	0·162	687	41	113	6·92

[a] Some analyses of Rotation I are from Cooke, Mattingly and Williams (1958).

[b] Measured by $HClO_4$ digestion (P_p) and calculated for fusion analysis (P_f) using the following relation $P_f = 38 \cdot 8 + 1 \cdot 0021\ P_p$ (Mattingly, 1970).

https://doi.org/10.23637/ERADOC-1-4

compares some analyses of soils taken from the two experiments in 1957 and 1964 respectively. The %C, %N and total P contents of the unmanured soils from both experiments were very similar. The *increases* in %C, %N and total P contents (Δ%C, Δ%N, ΔP_t) of soils given FYM in both rotations (Rotation I, treatment 1; Rotation II, treatment 2) were:

	Δ%C	Δ%N	ΔP_t (ppm)
Rotation I	+0·61	+0·064	+290
Rotation II	+0·26	+0·033	+71
Ratio I/II	2·3	1·9	4·1

The ratio of the increases in %C and %N are very close to the ratio (2·2) of the total amounts of FYM applied to the two rotations, which suggests that, *for the same rotation*, the accumulation of organic matter is proportional to the amounts applied and is the same at Saxmundham whether FYM is given each year (Rotation I) or every 4 years (Rotation II).

In contrast to the good agreement between the accumulation of C and N and the amounts of FYM added in both rotations, proportionally more P remained in the soil from the larger amounts of FYM given to Rotation I. The amounts of P applied in FYM to Rotations I and II can be estimated assuming that a ton of FYM contained 4·4 lb P. The total amounts of P removed by crops in each experiment were estimated from the difference between the total applied and the increase in total soil P in the plough layer. Using a bulk density of 1·6 g/cm³ (Williams, 1966), the total weight of soil in an 8 in. plough layer is $2{\cdot}8 \times 10^6$ lb.

On the basis of the above assumptions, the amounts of P applied to and recovered from both rotations were:

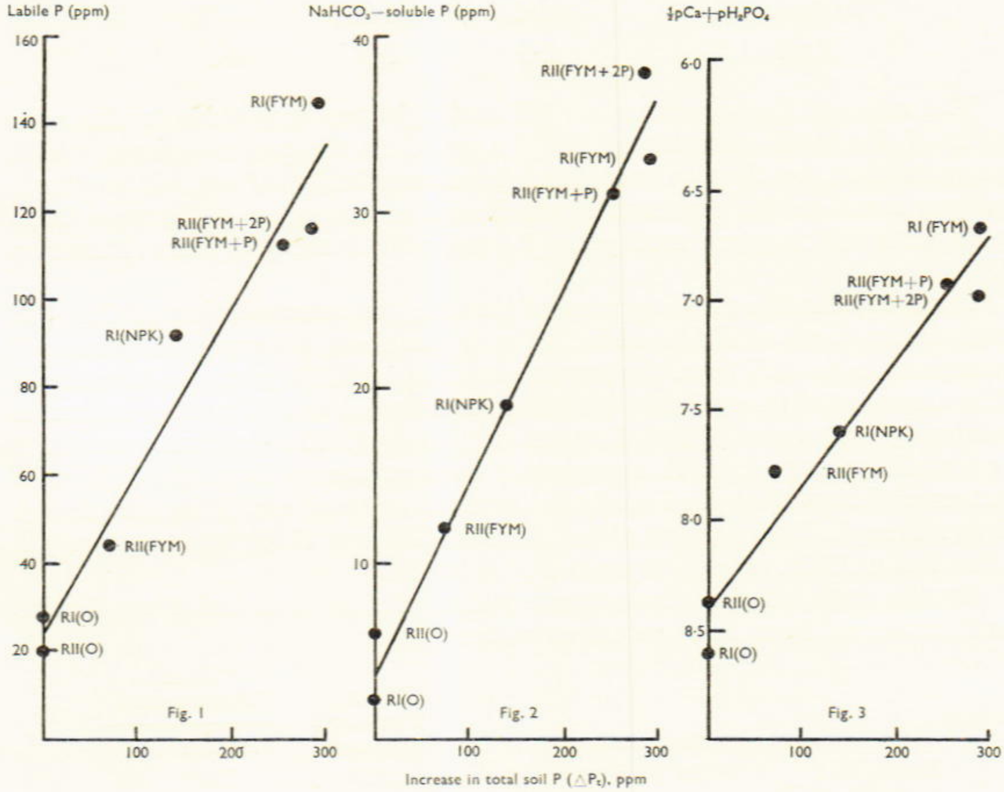
Treatment/acre/rotation		Total P applied (lb/acre)	Total P recovered lb/acre	%
Rotation I (1899–1957)	FYM 24 tons	1530	710	46
Rotation II (1899–1964)	FYM 10 tons	705	505	72
Rotation II (1899–1964)	FYM 10 tons + Superphosphate 7½ cwt	1755	1045	60

Despite the small amounts of N given in both rotations, between 46% and 72% of the total P applied has been recovered by cropping. Much less P would presumably remain in these soils had more N been used and larger crops grown.

Soluble and labile P. Figs. 1, 2 and 3 show the changes in labile P, $NaHCO_3$-soluble P and $\frac{1}{2}pCa + pH_2PO_4$ in the soils of both rotations in relation to the net increase in total soil P (ΔP_t)) between 1899–1957 (Rotation I) or 1899–1964 (Rotation II). Values for the two rotations agree well. Soil P increased most (+290 ppm P) on FYM plots of Rotation I, which also contained the most labile P and maintained the smallest values of $\frac{1}{2}pCa + pH_2PO_4$. The $NaHCO_3$-soluble P (33 ppm) was less on these

https://doi.org/10.23637/ERADOC-1-4

plots than the *mean* value (41 ppm) for Rotation II (treatments 3 to 7), given in Table 3, which was derived from analyses of all 10 plots given 73·5 lb P/acre as superphosphate during the three years before the soils were sampled. The $NaHCO_3$-soluble P in the 4 plots, last given P in 1960 or 1961 (31 ppm), probably more nearly represents an equilibrium value for this treatment and is used in the calculations below and in Fig. 2.



FIGS. 1, 2 and 3. Relationships between labile P (Fig. 1), 0·5*M* $NaHCO_3$-soluble P (Fig. 2) and $\frac{1}{2}pCa + pH_2PO_4$ (Fig. 3) and increases in total soil P (ΔP_t) for soils from Rotation I (1899–1957) and Rotation II (1899–1964).

Rotation	Symbol	Manuring	Treatment
I	RI(FYM)	FYM, 6 tons/acre annually	1
	RI(O)	Unmanured	6
	RI(NPK)	NK plus superphosphate, 2 cwt/acre, annually	10
II	RII(O)	Unmanured	1
	RII(FYM)	FYM, 10 tons/acre, once in 4 years	2
	RII(FYM + P)	FYM, 10 tons/acre, plus superphosphate, 7½ cwt/acre, once in 4 years	3–7
	RII(FYM + 2P)	FYM, 10 tons/acre, plus superphosphate, 15 cwt/acre, once in 4 years until 1952	8

https://doi.org/10.23637/ERADOC-1-4

TABLE 6

FYM and superphosphate applied in Rotation II, 1965–68

(No FYM or superphosphate in 1968)

Treatment	Manuring 1899–1964	1965		1966		1967		Total P applied (lb/acre) 1965–68		
		FYM tons/acre	Superphosphate lb P/acre	FYM tons/acre	Superphosphate lb P/acre	FYM tons/acre	Superphosphate lb P/acre	FYM	Superphosphate	Total
1	None	None	None	None	None	None	None	None	None	None
2	FYM	None	None	None	None	None	None	None	None	None
3	FYM + P	None	None	None	None	None	None	None	None	None
4	FYM + P	None	None	20[a]	None	20[c]	None	206	None	206
5	FYM + P	None	73·5	20[a]	73·5[b]	20[c]	73·5[d]	206	220	426
6	FYM + P	None	73·5	None	73·5[b]	None	73·5[d]	None	220	220
7	FYM + P	None	147	None	147[b]	None	147[d]	None	440	440
8	FYM + 2P	None	None	None	None	None	None	None	None	None

[a] Applied autumn, 1965.
[b] Half in autumn, 1965; half in spring, 1966.
[c] Applied autumn, 1966.
[d] Half in autumn, 1966; half in spring, 1967.

(All autumn dressings before ploughing.)

https://doi.org/10.23637/ERADOC-1-4

TABLE 7

Yields of barley and nutrient uptakes in 1965

Treatment	Manuring, 1899–1964	Manuring[a] in 1965 (lb P/acre)	Yields, cwt/acre: Green crop in July (dry matter)	Yields, cwt/acre: Grain at harvest (85% dry matter)	Total nutrients in grain plus straw, lb/acre: N	P	K
1	None	None	23·5	15·9	29	4·7	12
2	FYM	None	50·7	31·3	58	12·2	23
3	FYM + P	None	54·8	34·6	71	15·2	29
4	FYM + P	None	54·1	34·2	71	15·2	31
5	FYM + P	73·5	56·7	34·3	75	15·7	28
6	FYM + P	73·5	56·6	34·1	74	15·8	28
7	FYM + P	147	62·8	33·2	75	15·9	29
8	FYM + 2P	None	52·8	31·4	72	14·5	26

TABLE 8

Yields of potatoes and nutrient uptakes in 1966

Treatment	Manuring, 1899–1964	Manuring[a] in 1966: P (lb/acre)	Manuring[a] in 1966: FYM (tons/acre)	Yields, tons/acre: Total tubers	Yields, tons/acre: Dry matter	Total nutrients in tubers, lb/acre: N	P	K
1	None	None	None	7·45	2·02	60	5·7	75
2	FYM	None	None	14·56	4·11	98	14·3	152
3	FYM + P	None	None	16·85	4·74	112	20·2	172
4	FYM + P	None	20	20·47	5·42	129	24·3	214
5	FYM + P	73·5[b]	20	20·34	5·55	136	24·8	211
6	FYM + P	73·5[b]	None	18·23	4·98	114	21·7	181
7	FYM + P	147[b]	None	18·60	5·16	118	23·6	189
8	FYM + 2P	None	None	16·28	4·61	108	19·9	148

[a] All plots received N and K manuring (see p. 101). [b] The same dressings were applied for barley in 1965.

https://doi.org/10.23637/ERADOC-1-4

Fitted regression lines give the following changes in $\frac{1}{2}pCa + pH_2PO_4$, $NaHCO_3$-soluble P and labile P for every 1 ppm (about 2·8 lb P/acre) that accumulates in the soil from residues of FYM or superphosphate.

(a) $\Delta(\frac{1}{2}pCa + pH_2PO_4)/\Delta P_t = -57 \pm 5{\cdot}3 \times 10^{-4}$
(b) $\Delta NaHCO_3\text{-soluble } P/\Delta P_t = +0{\cdot}11 \pm 0{\cdot}007$
(c) $\Delta P_e/\Delta P_t = +0{\cdot}37 \pm 0{\cdot}038$

These measurements provide an *approximate* guide to the changes in $\frac{1}{2}pCa + pH_2PO_4$, $NaHCO_3$-soluble P and labile P in Saxmundham soils, and probably also in similar Chalky Boulder-Clay soils, as P residues accumulate in them. The proportion of the total applied P that remains isotopically labile ($\approx$ 40%) is about the same (30–40%) as in Rothamsted soils (Mattingly & Talibudeen, 1961). $NaHCO_3$-soluble P increased in about 60 years by about one-tenth of the total P remaining in the soil.

Yields and nutrient uptakes, 1965–68

After the deeper ploughing in autumn, 1964, new dressings of FYM and/or superphosphate were given from 1965 to 1967 to produce 'new' P residues to compare with the 'old' P residues on treatments 2, 3 and 8. Treatments 4 and 5 were given 40 tons FYM/acre between 1965 and 1966; treatments 5 and 6 were given a total of 220 lb P/acre, and treatment 7 a total of 440 lb P/acre as triple superphosphate (21% P) between 1965 and 1967. P was not given in 1968, to ensure mixing and equilibration of the new P throughout the plough layer. Table 6 gives the amounts of FYM, superphosphate and P added between 1965 and 1968.

The plots of the old experiment (1899–1964) were 132 ft long and 18 ft wide. Each plot was divided at harvest in 1965 into two halves, each 66 ft long and 18 ft wide. Between 1965 and 1968 yields were taken from each half-plot, making four replications for each treatment. Barley was drilled along the plots and rows of potatoes (at 28 in. spacing) and sugar beet and turnips (in split plots at 18 in. spacing) were planted across the plots. The varieties grown and basal manuring were:

Year	Crop	Variety	lb/acre N	lb/acre K
1965	Barley	Proctor	90	93
1966	Potatoes	Pentland Dell	135	186
1967	Sugar beet	Klein E	135	111
1967	Turnips	Green	135	111
1968	Barley	Zephyr	84	45

Tables 7 to 11 give the crop yields and nutrients removed. Barley (grain and straw), potato tubers and sugar beet roots were all removed from the plots. Sugar beet tops and turnips (tops and roots) were all ploughed in on the plots where they grew.

Barley, 1965. Grain yields (Table 7) ranged from 16 to 34 cwt/acre. The residues of FYM given once every 4 years from 1899–1964 doubled yields (treatment 2) and the residues of FYM + P (treatments 3 and 4) gave slightly better yields (34·4 cwt/acre). Fresh superphosphate given in 1965 (treatments 5, 6 and 7) gave no extra yield.

https://doi.org/10.23637/ERADOC-1-4

TABLE 9

Yields of turnips and nutrient uptakes in 1967

Treat-ment	Manuring, 1899–1964	Manuring[a] in 1967: P (lb/acre)	Manuring[a] in 1967: FYM (tons/acre)	Yields, tons/acre: Fresh roots	Yields, tons/acre: Dry matter Roots	Yields, tons/acre: Dry matter Tops	Total nutrients in tops plus roots, lb/acre: N	P	K	Na	Ca	Mg
1	None	None	None	2·22	0·29	1·16	91	5·7	102	7·0	100	10·0
2	FYM	None	None	5·00	0·68	1·30	81	10·6	144	6·7	93	9·6
3	FYM + P	None	None	6·84	0·91	1·51	96	17·6	169	11·3	96	9·4
4	FYM + P	None	20[c]	7·71	0·94	1·73	134	26·9	217	21·1	109	11·1
5	FYM + P	73·5[b]	20[c]	8·13	1·00	1·89	144	30·0	234	25·6	117	11·8
6	FYM + P	73·5[b]	None	7·92	0·97	1·51	107	22·7	181	22·8	98	9·5
7	FYM + P	147[b]	None	7·88	1·02	1·64	112	24·7	187	15·8	112	10·3
8	FYM + 2P	None	None	7·25	0·91	1·35	92	17·5	157	19·2	89	8·4

TABLE 10

Yields of sugar beet and nutrient uptakes in 1967

Treat-ment	Manuring, 1899–1964	Manuring[a] in 1967: P (lb/acre)	Manuring[a] in 1967: FYM (tons/acre)	Yields/acre: Roots Fresh (tons)	Yields/acre: Roots Dry (tons)	Yields/acre: Tops dry (tons)	Sugar (cwt)	% sugar	Total nutrients in tops plus roots, lb/acre: N	P	K	Na	Ca	Mg
1	None	None	None	8·30	1·91	1·15	26·2	15·7	89	5·1	133	30	63	19·8
2	FYM	None	None	13·50	3·22	1·00	47·5	17·6	83	9·0	140	26	44	18·1
3	FYM + P	None	None	16·88	3·96	1·04	59·4	17·6	96	15·3	149	34	42	20·2
4	FYM + P	None	20[c]	19·55	4·44	1·30	67·2	17·2	125	20·9	182	50	43	24·6
5	FYM + P	73·5[b]	20[c]	19·51	4·40	1·24	67·3	17·3	128	22·8	179	55	39	23·5
6	FYM + P	73·5[b]	None	18·35	4·12	1·28	63·4	17·3	117	19·6	166	64	45	22·1
7	FYM + P	147[b]	None	18·61	4·24	1·17	64·4	17·3	111	21·0	153	43	44	20·8
8	FYM + 2P	None	None	17·44	4·03	1·19	60·1	17·3	104	16·2	151	43	44	19·5

[a] All plots received N and K manuring (see p. 101).
[b] The same dressings were applied for barley (1965) and potatoes (1966).
[c] 20 tons FYM to potatoes, 1966.

https://doi.org/10.23637/ERADOC-1-4

Potatoes, 1966. Potatoes, which were planted in an excellent seedbed and grew well throughout the season, gave yields ranging from about 7·5 to more than 20 tons tubers/acre (Table 8). Yields were doubled by residues of farmyard manure (treatment 2) and increased by a further 1·7 to 2·3 tons/acre where FYM + P was given before 1964 (treatments 3 and 8). In contrast to barley, potatoes gave bigger yields with new P in 1966 in the presence of residues. Compared to FYM + P residues (treatment 3), which gave 16·8 tons/acre, 73·5 and 147 lb P/acre as fresh superphosphate (treatments 6 and 7) both produced a further increase of about 2 tons/acre, whereas the largest yields, about 20·4 tons/acre, were on plots given 20 tons FYM/acre the previous autumn, either without (treatment 4) or with (treatment 5) fresh superphosphate.

The following table compares yields and uptakes of N, P and K with and without FYM.

		Total P applied 1966 (lb P/acre)	Yield (tons/acre)	Uptake (lb/acre) N	P	K
With FYM	4	111	20·47	129	24·3	214
	5	184	20·34	136	24·8	211
	Mean	147	20·40	132	24·6	212
Without FYM	6	73·5	18·23	114	21·7	181
	7	147	18·60	118	23·6	189
	Mean	110	18·42	116	22·6	185

Potato tops remained greener throughout the season on plots given FYM and this better growth, which may have increased yield, was associated with larger uptakes of N, P and K.

Turnips and sugar beet, 1967. Early growth of both crops was good, but during the dry weather later the turnips flowered before lifting and were dry and poor quality when harvested in July. Yields of turnip roots (Table 9) increased from 2·2 tons/acre (treatment 1) to 7 tons/acre on plots with old residues (treatments 3 and 8). Adding fresh P, either as FYM or superphosphate (treatments 4, 5, 6 and 7), gave only 1 ton/acre more roots. As the potatoes, turnips removed more N, P and K (Table 9) from plots given fresh FYM than from those given fresh superphosphate but, in contrast to potatoes in 1966, or sugar beet in 1967, yields were not larger.

Sugar-beet yields (Table 10) ranged from 8·3 to 19·6 tons of roots/acre and sugar yields from 26 to 67 cwt/acre. 'Old' residues of FYM (treatment 2) and of FYM + superphosphate (treatment 3) increased sugar yields by 21 and 33 cwt/acre respectively. Compared to treatment 3 (59 cwt/acre), fresh superphosphate (treatments 6 and 7) increased yields by a further 4 to 5 cwt/acre, and fresh FYM, alone or with superphosphate (treatments 4 and 5), gave a further 3 cwt sugar/acre. The larger yields of tops and roots with fresh FYM contained more N and K and slightly more P and Mg.

Barley, 1968. The yield without P (treatment 1) in 1968, 24 cwt/acre (Table 11) was 8 cwt/acre more than in 1965 (Table 7). The crop, especially on treatments 4 to 8, lodged and yields with 'old' and 'new' P residues were

https://doi.org/10.23637/ERADOC-1-4

TABLE 11

Yields of barley and nutrient uptakes in 1968

(No FYM or superphosphate applied in 1968)

Treatment	Manuring, 1899–1964	Manuring[a] in 1965–67 P (lb/acre)	Manuring[a] in 1965–67 FYM (tons/acre)	Yields at 85% dry matter cwt/acre Grain	Yields at 85% dry matter cwt/acre Straw	Total nutrients in grain plus straw, lb/acre N	P	K
1	None	None	None	24·2	12·3	49	7·7	22
2	FYM	None	None	29·7	15·8	56	10·7	26
3	FYM + P	None	None	34·3	24·2	67	13·2	30
4	FYM + P	None	40	32·0	22·2	68	13·3	30
5	FYM + P	220	40	31·1	23·7	68	13·8	31
6	FYM + P	220	None	31·4	21·5	64	13·2	25
7	FYM + P	440	None	32·7	21·2	65	14·0	26
8	FYM + 2P	None	None	32·2	21·9	66	12·7	24

[a] All plots received N and K manuring (see p. 101).

https://doi.org/10.23637/ERADOC-1-4

TABLE 12

Chemical analyses of air-dry soils (0–10 in.) from Rotation II in 1966

Treatment	Manuring[a] per acre 1965–68	Total C[b] (%)	Total N (%)	C/N[b]	$CaCO_3$ (%)	pH in 0·01 *M* $CaCl_2$	Total P (ppm)	Labile P (ppm)	$NaHCO_3$-P (ppm)	$\frac{1}{2}$pCa + pH_2PO_4	Exchangeable K (ppm)
1	None	0·76	0·118	6·4	0·61	7·36	390	22	6	8·24	159
2	None	0·95	0·139	6·8	0·38	7·19	455	40	11	7·90	194
3	None	0·97	0·138	7·0	0·34	7·14	520	76	25	7·34	170
4	FYM, 40 tons	1·05	0·154	6·8	0·31	7·04	585	105	35	7·09	190
5	FYM, 40 tons + 220 lb P as superphosphate	1·06	0·154	6·9	0·41	7·12	601	123	46	6·93	184
6	220 lb P as superphosphate	1·03	0·150	6·9	0·38	7·10	610	106	37	7·03	173
7	440 lb P as superphosphate	1·03	0·156	6·6	0·69	7·20	645	146	58	6·78	174
8	None	1·06	0·156	6·8	0·55	7·22	591	103	36	7·22	160

TABLE 13

Chemical analyses of air-dry soils (0–10 in.) from Rotation II in 1968

Treatment	Manuring[a] per acre 1965–68	Total C[b] (%)	Total N (%)	C/N[b]	$CaCO_3$ (%)	pH in 0·01 *M* $CaCl_2$	Total P (ppm)	Labile P (ppm)	$NaHCO_3$-P (ppm)	$\frac{1}{2}$pCa + pH_2PO_4	Exchangeable K (ppm)
1	None	0·80	0·119	6·7	0·61	7·45	402	28	3	8·58	176
2	None	0·97	0·136	7·1	0·32	7·32	450	44	7	8·35	189
3	None	1·04	0·134	7·8	0·36	7·25	530	81	21	7·69	187
4	FYM, 40 tons	1·21	0·156	7·8	0·50	7·16	644	123	39	7·20	213
5	FYM, 40 tons + 220 lb P as superphosphate	1·24	0·157	7·9	0·42	7·19	696	152	54	6·94	198
6	220 lb P as superphosphate	1·09	0·153	7·1	0·50	7·24	631	123	44	7·13	171
7	440 lb P as superphosphate	1·14	0·148	7·7	0·61	7·28	692	166	67	6·84	185
8	None	1·05	0·149	7·0	0·62	7·33	582	90	28	7·68	161

[a] All plots received N and K manuring (see p. 101). [b] Walkley-Black, uncorrected.

https://doi.org/10.23637/ERADOC-1-4

2 to 3 cwt smaller in 1968 than in 1965. Straw yields in 1968 were doubled by 'old' residues of FYM and superphosphate (treatment 3), but were not increased further by 'new' residues (treatments 4 to 7).

Soil analyses, 1966 and 1968

Changes in total P and exchangeable K. Tables 12 and 13 give analyses of soils from all treatments sampled before ploughing in 1966 and 1968. It is impossible to compare them quantitatively with those from 1964 (Table 2) without allowing for the increase in the depth of ploughing (from about 8 to about 10 in.) between 1964 and 1966. Table 14 shows that deeper ploughing diluted the mean concentration of soil C, N and P on treatments 1, 2, 3 and 8 (to which no P was added between 1965 and 1968) by a factor of 0·85 to 0·89. In contrast, ploughing increased % $CaCO_3$ in the surface soil because the soil below 8 in. is calcareous. There was no further significant change between 1966 and 1968.

TABLE 14

Mean %C, %N, total P (ppm) and %$CaCO_3$ in soils from treatments 1, 2, 3. and 8 in 1964, 1966 and 1968

				Ratio	
	1964	1966	1968	1966/1964	1968/1966
%C	1·06	0·94	0·97	0·89	1·03
%N	0·154	0·138	0·134	0·89	0·97
Total P (ppm)	577	489	491	0·85	1·00
% $CaCO_3$	0·44	0·47	0·48	1·07	1·02

Between 1965 and 1968 the amounts of both P and K applied as fertilisers and in FYM exceeded the amounts removed by cropping. Table 15 gives a balance for the additions and removals of P and K and the changes in total P and exchangeable K in the soils between 1964 and 1968. In these calculations we assume:

1. the effective plough depth was 8·0 in. in 1964 and 9·5 in. in 1968. (This is consistent with the dilution factor of 0·85 for total P measured between 1964 and 1968).
2. The weight of soil per acre per in. = 0.35×10^6 lb, corresponding to a bulk density of 1·6 g/cm^3.
3. No P and K in turnip tops and roots and sugar beet tops was lost before they were ploughed back into the soil.

Except for treatments 1 and 2, the net loss or gain of P by manuring and cropping agreed well with the change in total soil P in the plough layer, and the average of the two values for all 8 treatments differed by only 30 lb P/acre.

Fig. 4 shows the decline in the total P content of all the soils between 1964 and 1966 as a result of deeper ploughing. Where P was not given (treatments 1, 2, 3 and 8), there was little further change between 1966 and 1968, but where it was total soil P increased, especially where the most

https://doi.org/10.23637/ERADOC-1-4

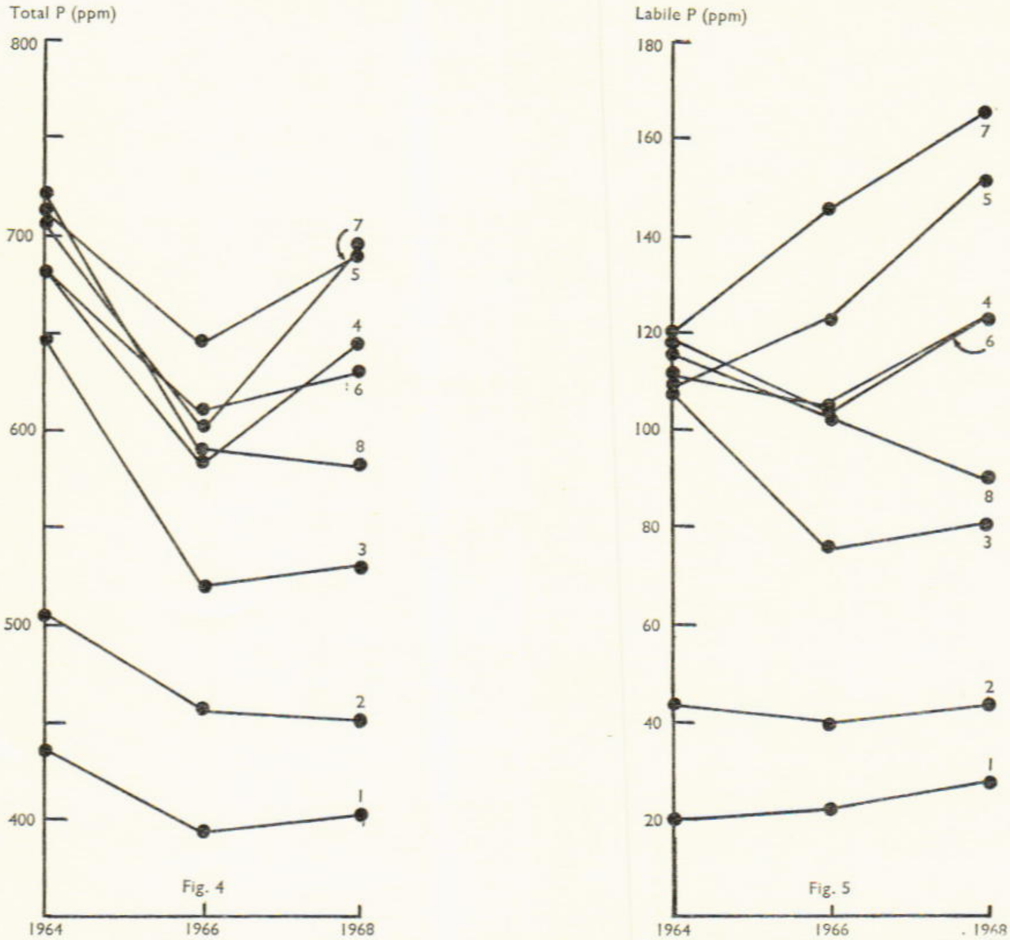
TABLE 15

Changes in total P and exchangeable K in surface soils between 1964 and 1968 and net gains or losses of P and K

Treatment	Manuring[a] per acre 1965–68	Total P, lb/acre 1964 (to 8 in.)	Total P, lb/acre 1968 (to 9·5 in.)	Total P, lb/acre Increase (1968–1964)	P applied *minus* P removed	Exchangeable K, lb/acre 1964 (to 8 in.)	Exchangeable K, lb/acre 1968 (to 9·5 in.)	Exchangeable K, lb/acre Increase (1968–1964)	K applied *minus* K removed
1	None	1215	1340	+125	−19	417	585	+168	+306
2	None	1415	1500	+85	−40	510	629	+119	+204
3	None	1815	1760	−55	−54	468	622	+154	+168
4	FYM, 40 tons	1910	2140	+230	+147	450	710	+260	+526
5	FYM, 40 tons + 220 lb P as superphosphate	1980	2320	+340	+366	484	659	+175	+528
6	220 lb P as superphosphate	1915	2100	+185	+163	445	570	+125	+163
7	440 lb P as superphosphate	1995	2300	+305	+380	454	615	+161	+153
8	None	2020	1935	−85	−52	381	535	+154	+201

[a] All plots received N and K manuring (see p. 101).

https://doi.org/10.23637/ERADOC-1-4



FIGS. 4 and 5. Changes in total soil P (Fig. 4) and labile P (Fig. 5) in Rotation II between 1964 and 1968.

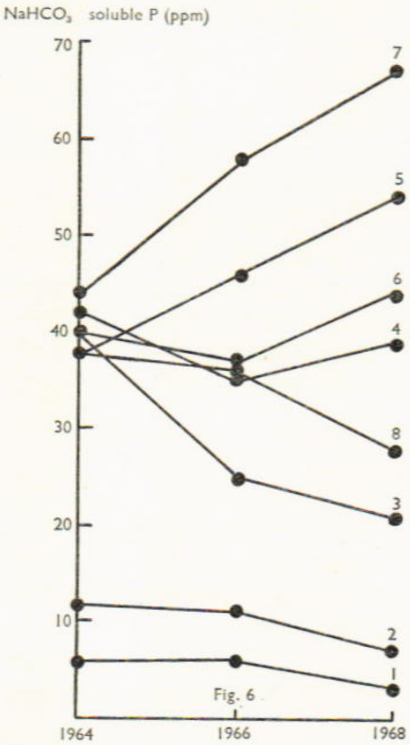
Treatment	Manuring, 1899–1964[a]	P applied (lb/acre), 1965–68[b]
1	None	None
2	FYM	None
3	FYM + P	None
4	FYM + P	206
5	FYM + P	426
6	FYM + P	220
7	FYM + P	440
8	FYM + 2P	None

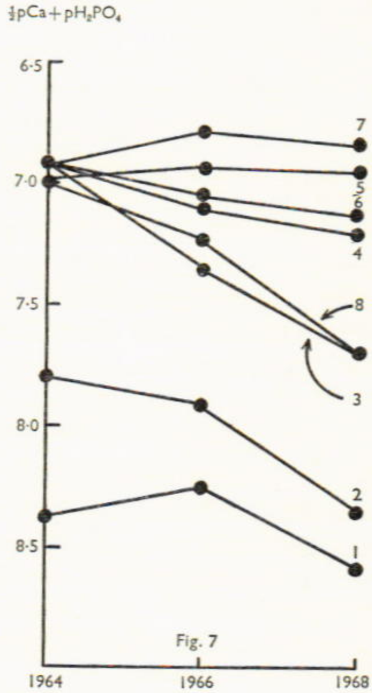
[a] For details, see Table 1. [b] For details, see Table 6.

FYM and superphosphate were given (treatments 5 and 7). However, the largest P contents in 1968 (696 ppm) were still smaller than in 1964, even though 440 lb P/acre was given as superphosphate (treatment 7) and 426 lb P/acre as FYM and superphosphate (treatment 5).

In contrast, the exchangeable K in the plough layer increased less than the net gain in applied K. Where FYM was given the increase in exchangeable K in the top 9·5 in. of soil was only one-half and one-third of the gain in K from manuring on treatments 4 and 5 respectively. Much of the apparent loss probably reflected fixation in non-exchangeable forms

https://doi.org/10.23637/ERADOC-1-4





FIGS. 6 and 7. Changes in 0·5*M* $NaHCO_3$-soluble P (Fig. 6) and ½pCa + pH_2PO_4 (Fig. 7) in Rotation II between 1964 and 1968.
(For key to treatments, see Figs. 4 and 5.)

(which were not measured) in this slightly calcareous soil, but some K may have leached below plough depth.

Changes in $NaHCO_3$-soluble and labile P. Values of labile P (Fig. 5) either declined or remained almost constant, and $NaHCO_3$-soluble P values (Fig. 6) all declined where fresh P was not given (treatments 1, 2, 3 and 8), not only between 1964 and 1966 but also between 1966 and 1968. Soluble and labile P increased where most fresh FYM or superphosphate were given (treatments 5 and 7) and were maintained at the 1964 amounts in treatments 4 and 6. This increase occurred even though the residues of 'fresh' FYM and superphosphate did not increase total soil P content (ppm) because they were distributed through more soil in 1968 than in 1964. The increases in $NaHCO_3$-soluble P and labile P between 1964 and 1968 were:

		Increase 1964–68			
		ppm		lb P/acre	
Treat-ment	Manuring 1965–67	$NaHCO_3$ soluble-P	Labile P	$NaHCO_3$ soluble-P	Labile P
5	FYM, 40 tons plus 220 lb P/acre as superphosphate	+16	+44	+76	+203
7	440 lb P/acre as superphosphate	+23	+46	+100	+207

The net gains in total P in the top 9·5 in. of soils from new residues (treatments 5 and 7) were 340 and 305 lb P/acre respectively (Table 15). The

https://doi.org/10.23637/ERADOC-1-4

increases in $NaHCO_3$-soluble P and labile P (Pe), per unit increase in total soil P, for 'old' and 'new' residues were:

	$\Delta NaHCO_3$-soluble $P/\Delta P_t$	$\Delta P_e/\Delta P_t$
'Old' residues, 1899–1964	0·11	0·37
'New' residues, 1965–68	0·25	0·60

Changes in the solubility of soil P. Values of $\frac{1}{2}pCa + pH_2PO_4$ (Fig. 7) show that the solubility of soil P declined (treatments 1, 2, 3 and 8) between 1964 and 1968 and was maintained, but not appreciably increased, (treatments 4, 5, 6 and 7) where fresh P was given. In contrast to soils from some of the Classical Experiments at Rothamsted (Aslyng, 1954), all the Saxmundham soils from Rotations I or II are undersaturated with octa-calcium phosphate.

Soil analysis and crop response

Table 16 summarises yields of barley, potatoes, turnips and sugar beet between 1965 and 1968 in relation to soil P analysis. Yields of barley, grown on soils with 20–40 ppm $NaHCO_3$-soluble P and adequate N and K, were not increased by fresh superphosphate (73·5 lb P/acre) in 1965 or by fresh residues of cumulative dressings (1965–67) in 1968. Yields of potatoes, turnips and sugar beet, however, were all more with fresh superphosphate than with residues alone.

TABLE 16

Yields and responses of barley, potatoes, turnips and sugar beet in relation to soil analysis, 1965–67

	Soil analysis			Yields/acre				
							Sugar beet	
Treat-ment	$NaHCO_3$-soluble P (ppm)	Labile P (ppm)	$\frac{1}{2}pCa + pH_2PO_4$	Barley[a] grain (cwt)	Potatoes tubers (tons)	Turnips roots (tons)	Roots (tons)	Sugar (cwt)
1	4–6	20–25	8·4–8·2	15·9	7·4	2·2	8·3	26
2	9–12	40–45	8·1–7·8	31·3	14·6	5·0	13·5	48
3	20–40	75–110	7·5–6·9	34·6	16·8	6·8	16·9	59
	Increase from 73·5 lb P/acre (treatment 6 *minus* 3)			−0·3	+1·4	+1·1	+1·7	+4

[a] At 85% dry matter.

At the end of 1968 the soils ranged widely in $NaHCO_3$-soluble P (about 3 to 67 ppm) and in labile P (about 28 to 166 ppm). Residues of 'old' and 'new' FYM and P are now being evaluated, relative to fresh superphosphate applied in the seedbed, in a crop rotation of potatoes, barley (without P), sugar beet and barley (without P) to compare crop response and soil analysis on the Chalky Boulder-Clay soil at Saxmundham with crop response at Rothamsted and Woburn.

Conclusions and Summary

1. Between 1899 and 1964 more P was applied in FYM alone (10 tons/acre/rotation) and in FYM (10 tons/acre/rotation) plus superphosphate

https://doi.org/10.23637/ERADOC-1-4

(about 74 lb P/acre/rotation) than was removed by cropping. $NaHCO_3$-soluble P and isotopically-exchangeable (labile) P were directly proportional, and $\frac{1}{2}pCa + pH_2PO_4$ inversely proportional, to the increase in total $P(\Delta P_t)$ in the soil. $NaHCO_3$-soluble P and labile P increased by the same amounts, per unit increase in total soil P, in Rotation I (when sampled in 1957) as in Rotation II in 1964, and were about 10% and 40% respectively of the increases in total soil P that accumulated from 'old' P residues.

2. $NaHCO_3$-soluble P, labile P and $\frac{1}{2}pCa + pH_2PO_4$ in 1964 were 6 ppm, 20 ppm and 8·36 on plots without P, 12 ppm, 44 ppm and 7·79 where FYM only was given (treatment 2) since 1899 and 41 ppm, 113 ppm and 6·92 where FYM and superphosphate were given (treatments 3 to 7) in the old rotation.

3. The only K applied in the old rotation came from FYM which supplied about 100 lb K/acre/rotation. Negligible amounts remained in the soil as exchangeable K in 1964.

4. Between 1964 and 1968, deeper ploughing (from about 8 to 10 in.) lessened the total P content of the soil by a factor of about 0·85 where further P was not applied (treatments 1, 2, 3 and 8). Where FYM (40 tons/acre containing 206 lb P) or superphosphate (220 lb P/acre) were given between 1965 and 1967 (treatments 4 and 6), total P was less in 1968 than in 1964; where FYM plus superphosphate (total P 426 lb/acre) or 440 lb P/acre were given as superphosphate (treatments 5 and 7), the extra P applied just maintained the original P content (in ppm) of the soil. The 'fresh' P given between 1965 and 1967 was incorporated within the deeper (9·5 in.) plough layer and increased both the concentration of $NaHCO_3$-soluble P and labile P (ppm) and the total amounts (lb P/acre) in the plough layer. The increases in $NaHCO_3$-soluble P and labile P were about 25% and 60% respectively of the increases in total soil P that accumulated from 'new' P residues.

5. Between 1965 and 1968 more K was applied as FYM and/or inorganic K than was removed by cropping. Exchangeable K (in ppm) increased during this period despite dilution by ploughing.

6. Yields of barley in 1965 and 1968, with adequate NK fertiliser, ranged from 16 to 35 cwt/acre and increased in the order: no P $<$ FYM residues $<$ FYM + superphosphate residues. Fresh superphosphate in 1965 did not increase yields further. Yields of potatoes in 1966, given NK fertilisers, ranged from 7·4 to 20·5 tons/acre. Yields with FYM + P residues (treatment 3) were 16·8 tons/acre and 'fresh' superphosphate (74 lb P/acre) increased yields by 1·4 tons/acre and 'fresh' superphosphate (74 lb P/acre) plus FYM (20 tons/acre) by 3·5 tons/acre. Yields of turnips (2 to 8 tons/acre) and sugar beet (8·3 to 19·6 tons/acre), given NK fertilisers were greater by 1·3 and 2·6 tons roots/acre respectively with 'fresh' FYM plus superphosphate than with only residues of 'old' dressings.

7. The treatments given between 1965 and 1968 modified the soils which now contain different amounts of soluble P. The range of soils include 'no P' since 1899 (treatment 1), P residues from FYM alone or

https://doi.org/10.23637/ERADOC-1-4

with superphosphate, applied between 1899 and 1964 (treatments 2, 3 and 8), P residues from 'old' FYM and superphosphate with (i) new FYM alone (treatment 4); (ii) new superphosphate alone (treatments 6 and 7); (iii) new FYM and superphosphate together (treatment 5).

Cultivations have ensured, and soil analyses have confirmed, that both P and K residues are distributed throughout a plough layer of about 0–10 in. These residues will be evaluated, relative to fresh superphosphate, in a crop rotation of potatoes, barley (without P), sugar beet and barley (without P) between 1969 and 1972.

Acknowledgements

We thank G. W. Cooke and R. Hull for help and advice with these experiments, V. C. Woolnough at Saxmundham and many members of the Chemistry Department and Broom's Barn Experimental Station for help with field work, and F. Hamlyn for the N analyses.

References

Arambarri, P. & Talibudeen, O. (1959) Factors influencing the isotopically exchangeable phosphate in soils. I. The effect of low concentrations of organic anions. *Pl. Soil* **11**, 343–354.

Aslyng, H. C. (1954) The lime and phosphate potentials of soils: the solubility and availability of phosphates. *Asskr. K. Vet.—Landbohøjsk.* 1–50.

Boyd, D. A. & Trist, P. J. O. (1966) The Saxmundham rotation experiments: Rotation II, 1899–1952. *J. agric. Sci., Camb.* **66**, 337–339.

Cooke, G. W., Mattingly, G. E. G. & Williams, R. J. B. (1958) Changes in the soil of a long-continued field experiment at Saxmundham, Suffolk. *J. Soil Sci.* **9**, 298–305.

Cooke, G. W. & Williams, R. J. B. (1966) *Rep. Rothamsted exp. Stn for 1965*, 234–236.

Mattingly, G. E. G. (1970) Total phosphorus contents of soils by perchloric acid and sodium carbonate fusion. *J. agric. Sci., Camb.* **74**, 79–82.

Mattingly, G. E. G. & Talibudeen, O. (1961) Isotopic exchange of phosphates in soil. *Rep. Rothamsted exp. Stn for 1960*, 246–265.

Oldershaw, A. W. (1941) Experiments on arable crops at Saxmundham. *Jl R. agric. Soc.* **102**, 136–155.

Tinsley, J., Taylor, T. G. & Moore, J. H. (1951) The determination of carbon dioxide derived from carbonates in agricultural and biological materials. *Analyst, Lond.* **76**, 300–310.

Trist, P. J. O. & Boyd, D. A. (1966) The Saxmundham rotation experiments: Rotation I. *J. agric. Sci., Camb.* **66**, 327–336.

Williams, R. J. B. (1966) *Rep. Rothamsted exp. Stn for 1965*, 44–45.

https://doi.org/10.23637/ERADOC-1-4