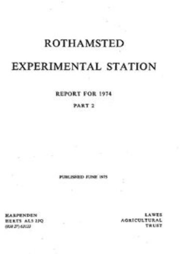
Rothamsted Experimental Station Report for 1974 Part 2


ROTHAMSTED
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PART 2

The Woburn Market Garden Experiment, 1942-69 II. The Effects of the Treatments on Soil pH, Soil Carbon, Nitrogen, Phosporus and Potassium

A. E. Johnston

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The Woburn Market Garden Experiment, 1942–69

II. The Effects of the Treatments on Soil pH, Soil Carbon, Nitrogen, Phosphorus and Potassium

A. E. JOHNSTON

Introduction

The soil on which the experiment was made is a freely draining loamy sand developed in drift over Lower Greensand and is classified as Cottenham Series. The land is now ploughed to about 9 in. deep though in the earlier years of the experiment ploughing was shallower. However, all surface samples have been taken from the 0–9 in. depth of soil so results can be compared. In addition the subsoil was sampled down to 24 in. on several occasions. A single soil sample was taken to represent the whole site in 1942 but it would have been better if each plot had been sampled separately for changes in soil organic matter; P and K could then have been estimated more precisely. Mann and Barnes sampled each plot separately in 1951 and 1960. In 1960 and since samples were taken on many occasions either from all plots (1960 and 1967) or a selection. For example in 1960 adjacent plots with large and small contents of P and K were selected and soil samples taken at 1 and 2 ft intervals across the plots. Amounts of total P and readily soluble P and K showed that after 18 years some soil had moved across plot boundaries; compared to the central area of each plot a strip of soil 3–4 ft wide round the edge of the plot had either gained or lost P and K. The produce from this edge strip was never included in the plot yield. Other samples were taken to determine movement of P and K into the subsoil below plough depth; the results are discussed later.

Weight of soil. Crowther (1936) gave the weight of soil per acre for both surface and subsoils from Stackyard Field, Woburn, which has soil belonging to the same series. The 0–9 in. depth was 1370 tons/acre, the 9–18 in. depth 1420 tons/acre. These data have been used to calculate gains and losses of organic matter and P and K. Williams (1974) gave results for some physical tests, including bulk density and water holding capacity, made on soils from each treatment taken in 1962.

Mechanical analysis

The mechanical composition of the soils was determined to see whether there were any large differences in particle size distribution over the site of the experiment which was on slightly sloping ground. Series A (plots 1–40) was on the upper part of the slope, plots 1–10 being on the highest part; Series B (plots 41–80) was on the lower part. The surface soils (0–9 in.) of all plots were sampled in 1972 and samples from alternate plots, together with a few extra, were analysed. Subsoils from two plots at the top of the slope and two plots at the bottom of the slope which had been sampled in 1960 were also analysed. Appendix Table 1 gives the results for each sample. Diagram 1 shows the arrangement of the plots and the coarse plus fine sand (2000–20 μm) and the silt plus clay (<20 μm) on those plots from which surface soils were analysed. Diagram 1 also shows that plots at the bottom of the slope (plots 61–80) did not contain appreciably more finer

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Diagram 1

Diagrammatic lay-out of the plots showing coarse plus fine sand (>20 μm) and silt plus clay (<20 μm) in the fine soil (<2 mm), Market Garden experiment, Woburn, 1972

SERIES A

Particle size, μm										
Plot	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
>20	82·8	79·7	78·1	77·2	79·3	78·0	79·6	81·8	80·7	79·9
<20	12·4	13·5	13·6	15·1	13·8	14·7	13·9	14·1	13·9	13·8
	11	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
>20	80·7	78·7	—	79·4	—	78·1	—	78·5	—	77·5
<20	13·2	14·3	—	14·7	—	15·0	—	14·7	—	14·1
	21	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*
>20	80·1	—	78·5	—	79·2	—	80·2	—	80·2	—
<20	14·2	—	14·3	—	14·6	—	13·9	—	14·0	—
	31	*32*	*33*	*34*	*35*	*36*	*37*	*38*	*39*	*40*
>20	—	80·2	—	79·5	—	78·7	—	80·3	—	80·2
<20	—	13·9	—	14·5	—	14·6	—	14·6	—	14·2

SERIES B

Particle size, μm										
Plot	*41*	*42*	*43*	*44*	*45*	*46*	*47*	*48*	*49*	*50*
>20	—	78·6	—	78·2	—	78·1	—	80·7	—	80·8
<20	—	14·4	—	14·9	—	15·4	—	14·1	—	13·1
	51	*52*	*53*	*54*	*55*	*56*	*57*	*58*	*59*	*60*
>20	78·7	—	75·9	—	77·8	—	78·3	—	81·0	—
<20	14·8	—	13·9	—	14·4	—	14·2	—	13·2	—
	61	*62*	*63*	*64*	*65*	*66*	*67*	*68*	*69*	*70*
>20	—	77·5	—	75·5	—	75·7	—	77·1	—	79·4
<20	—	15·5	—	16·1	—	16·0	—	14·5	—	14·1
	71	*72*	*73*	*74*	*75*	*76*	*77*	*78*	*79*	*80*
>20	76·5	76·3	—	75·2	—	76·5	—	77·2	—	78·3
<20	14·6	15·0	—	15·8	—	15·7	—	15·2	—	14·6

particles than those at the top of the slope. The mean mechanical analysis of all plots analysed in each Series was:

Mechanical analysis, % oven-dry soil

	Coarse sand 2000–200 μm	Fine sand 200–20 μm	Silt 20–2 μm	Clay <2 μm	Loss on solution	Air-dry moisture
Series A	51·7	27·8	4·7	9·4	4·7	1·2
Series B	50·2	27·6	5·3	9·4	5·2	1·4
Mean	51·0	27·7	5·0	9·4	5·0	1·3

Results in Appendix Table 1 show that the particle size distribution was much the same in subsoils from plots 3 and 4 at the top of the slope and plots 75 and 77 at the bottom. Compared with the surface soil, soil from the 12–18 in. depth had a little more fine sand whilst soil from the 18–24 in. depth had more coarse sand:

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Mechanical analysis, % in oven-dry soil

	Soil depth, in.		
	0–9	12–18	18–24
Coarse sand, 2000–200 μm	51·0	48·6	57·0
Fine sand, 200–20 μm	27·7	33·4	27·0
Silt, 20–2 μm	5·0	4·8	4·7
Clay, <2 μm	9·4	10·0	9·0
Loss on solution	5·0	2·2	1·8
Air-dry moisture	1·3	0·8	0·8

Soil reaction and the effect of chalk dressings

In the 1940s it was known that much of the light soil at Woburn had pH (in water) of about 6. When, therefore, some patches of very poor growth appeared in the first crop of red beet on Series B in 1943 the cause was thought to be acidity and the plots of this Series were sampled. The pH values ranged from 4·3 to 6·5, average 5·6; six of the 40 plots had pH below 5·0. Ground chalk, at 29 cwt/acre was applied to each plot before cabbages were planted in the autumn of 1943. When the soils were sampled again in spring 1945 the average pH value had increased to 6·5. Another dressing of 29 cwt/acre of ground chalk was given before cabbage were planted in autumn 1945.

On Series A there was less patchiness in the red beet in 1944 but the plots were sampled. The pH values ranged from 5·3 to 7·0, average 6·2. Although the soils of Series A were not so acid as those of Series B they were given a dressing of 29 cwt ground chalk/acre before the cabbages were planted in autumn 1944. The immediate effect of this dressing was not measured.

From 1948 dressings of ground chalk were applied for the red beet. The chalk was purchased from a local quarry where the naturally occurring chalk had been ground to a fine powder and, if necessary, 'dried' by the addition of CaO before being sold. The total neutralising value (TNV) was 89–95% equivalent $CaCO_3$ and the $CaCO_3$ content usually 86–92%. During 1948–51 the quantities of chalk applied were based on the

TABLE 1

Amount of ground chalk applied during the Market Garden experiment, Woburn, 1942–69, and in the three subsequent years

Series A		Series B	
Year	Amount of chalk, cwt/acre	Year	Amount of chalk cwt/acre
1944	29	1943	29
1948	11	1945	29
1950	22	1949	22
1952	20	1951	(a few plots only)
1954	20	1953	20
1956	20	1955	40
1958	23	1957	20
1960	23	1959	23
1962	23	1961	23
1964	23	1963	20
1966	23	1967[1]	40
1970	23	1970	23
1971	20	1971	20
1972	20	1972	20

[1] The FYM- and fertiliser-treated plots (16 of the 40 plots in Series B) which were used for the microplot experiment during 1965–67 received 40 cwt/acre of chalk before the sugar beet were drilled in 1967. The remaining 24 plots of this Series did not get this dressing of chalk.

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amounts of ammonium sulphate applied. In 1951 a few plots on Series B, which in 1943 were very acid, received extra dressings of ground chalk to bring the pH nearer to that of the other plots. From 1952–57 each dressing was intended to supply 10 cwt CaO/acre and the quantity of ground chalk varied from 18 to 20 cwt/acre according to the analysis of the material available. In 1955 an extra dressing was given for the cabbages on Series B. During 1958–67 the chalk was applied by one pass of the manure drill which delivered 23 cwt/acre.

Table 1 shows the amounts of chalk applied to both Series; Table 2 gives the pH of those soils sampled in 1943, 1944, 1945 (these results are previously unpublished data of T. W. Barnes), 1960 and 1972. Table 2 shows that none of the manurial treatments had any appreciable effect on soil pH. Any acidifying effects were neutralised by the frequent dressings of ground chalk, which gradually increased soil pH during the experiment.

TABLE 2

Soil reaction, Market Garden experiment, Woburn, 1942–69, and in 1972

pH in water, soil : water ratio 1 : 2·5, each value is the average of four plots except for plots without organic manure and these are the mean of eight

Treatment and dressing[2]	Series A			Series B			
	1944[1]	1960	1972	1943[1]	1945[1]	1960	1972
Without organic manure	5·8	7·0	7·0	5·3	5·9	6·8	7·1
Farmyard manure							
Single	6·1	6·8	7·0	5·3	6·3	6·6	7·0
Double	6·2	6·6	6·8	5·5	6·7	6·5	7·0
Sewage sludge							
Single	6·2	6·6	6·8	5·4	6·4	6·5	6·9
Double	6·0	6·4	6·6	5·8	6·5	6·4	6·8
Vegetable compost							
Single	6·5	6·9	7·0	5·4	6·6	6·6	7·0
Double	6·5	6·8	7·0	5·7	7·0	6·6	7·0
Sludge compost							
Single	6·2	6·7	6·8	5·8	6·7	6·6	6·8
Double	6·3	6·6	6·8	6·2	6·8	6·5	6·8
Mean all treatments	6·2	6·7	6·9	5·6	6·5	6·6	6·9

[1] Previously unpublished results of T. W. Barnes
[2] Single dressing, 30 tons/acre every two years; double dressing, 60 tons/acre every two years

Estimates can be made of the annual loss of chalk from the surface soil in this experiment. Table 3 shows that chalk dressings first increased soil pH, in the early years of the experiment, and then maintained pH at about 6·7–6·9. The amount of chalk needed to increase soil pH was estimated from results given by Johnston and Chater (1975). They found that 35·8 cwt chalk/acre was needed to increase soil pH by 1 unit, when the initial pH was 4·5–5·0, in the Continuous Wheat and Barley experiments at Woburn. These experiments were made on a sandy loam soil, classified as Stackyard Series, which has a slightly coarser texture than the soil on which the Market Garden experiment was made. Also results obtained in the Long-term Liming experiment at Woburn (Bolton, 1971), on soil of the Cottenham Series, showed that one year after applying 2 tons chalk/acre soil pH had increased from 6 to 7; subsequently pH decreased steadily when no more chalk was applied. For the estimates given here for the Market Garden experiment it is assumed that 40 cwt chalk/acre would be needed to increase the pH of soil by one unit. Table 3 shows the amounts of chalk applied and an estimate of the amount needed to change

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soil pH by the observed increase. From this data estimates of the total and annual loss of chalk were calculated.

TABLE 3

Estimated loss of chalk from the Market Garden experiment soil, Woburn, 1942–72

Period	Change in soil pH	Chalk needed for this change,[1] cwt/acre	Chalk applied, cwt/acre	Chalk applied minus chalk needed for pH change, cwt/acre	Chalk lost each year, cwt/acre
1943–60—18 years					
Series A	6·2–6·7	20	168	148	8·2
Series B	5·6–6·6	40	183	143	7·9
1961–72—12 years					
Series A	6·7–6·9	8	132	124	10·3
Series B	6·5–6·9	16	106	90	7·5
Series B microplots	6·6–7·0	16	146	130	10·8
1943–72—30 years					
Series A	6·2–6·9	28	300	272	9·1
Series B	5·6–6·9	53	289	236	7·9
Series B microplots	5·4–7·0	64	329	265	8·8

[1] It was assumed that chalk applied at 40 cwt/acre would increase the pH of the surface soil by 1 unit; for details see text.

The mean annual loss of chalk from the soil was much the same during 1943–60 and 1961–72; it does not seem to be related to manuring. For half of the first period N was applied as ammonium sulphate which had an acidifying effect but subsequently 'Nitro-Chalk' (with 15% N) was used. In the second period soil pH was higher and so leaching losses would be greater (Gasser, 1973). In addition losses may have been increased because: (1) much larger dressings of fertilisers were used and calcium would be the principal cation leached from the surface soil with the increased amounts of anions from the fertiliser dressings. (2) If there was any increase in root residues from the larger crops grown, increased anions, from microbiological activity would remove cations, probably calcium. Over the whole period of the experiment the total amount of chalk applied was equivalent to an average annual dressing of about 10 cwt/acre which raised the soil pH from about 5·9 to 6·9 and then maintained it at 6·9. Of the average annual dressing of 10 cwt/acre it is estimated that about 8·5 cwt/acre was lost from the surface soil.

Soil nitrogen and organic carbon

Mann and Barnes (1957) gave results for the nitrogen and organic carbon in the soils in 1951, nine years after the experiment started. In their Table 2 the amounts of N applied in each manure was the organic nitrogen only; however, there is no reason to assume that the inorganic N added in the manure could not become combined in organic form and remain in the soil. In this paper the total amount of N in each manure is used to allow comparison with other published results.

The text of Mann and Barnes' paper leads to the assumption that the soil carbon figures were values by the Walkley–Black (Walkley, 1947) method multiplied by 1·3 However, checking the results in their Table 5 shows that the soil carbon figures they gave were uncorrected Walkley–Black values if the authors assumed the soil weighed 1400 tons/acre to a depth of 9 in. The results given here for the organic carbon in soil are

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Walkley–Black %C multiplied by 1·3; thus where Mann and Barnes' results for 1942 and 1951 are used the values do not agree with those published previously.

Mann and Patterson (1963) reported %N in the soils in 1960 and concluded that between 1951 and 1960 there had only been small increases in N on FYM and compost-treated plots and none on sludge-treated plots; they did not attempt to explain the results. Their findings seemed unlikely because their data showed that soils with different treatments, and even with the single and double dressing of each treatment, still contained different amounts of N in 1960. Though soils with different treatments might contain different amounts of N when equilibrium between additions and losses was reached it seemed reasonable that soils with the single and double dressing of each treatment should contain the same amount of N at equilibrium. So total N was determined in a second set of soils samples which had been taken in 1960 by members of the Chemistry Department for determination of the carbon content; replicate analyses for N agreed well. The results varied from those reported by Mann and Patterson especially for those soils which contained most N; this suggests that there may have been incomplete digestion of the soil samples (by the Kjeldahl method) in their analyses of the 1960 samples.

In this paper Mann and Barnes' results for N and C (%C corrected here using the factor 1·3) in the soils in 1942 and 1951 are used. All other analyses were done at Rothamsted on samples taken by members of the Chemistry Department.

Throughout the experiment none of the unsaleable portion of the crops grown was returned to the soil, thus tops of red beet and carrots, and leek trimmings were all removed from the plots. Therefore on the plots receiving fertilisers only organic matter additions were no more than the fine root residues remaining in soil.

The organic manures however added large amounts of organic matter. Organic matter in the organic manures was determined as total dry matter *minus* the ash remaining after ignition at 450°C. The amounts added in the various organic manures were:

Total amounts of organic matter added,[1] *tons/acre*

	Farmyard manure	Sewage sludge	Vegetable compost	Sludge compost
Single dressing	55·0	65·9	47·3	47·1
Double dressing	110·0	131·8	94·6	94·2

[1] For full details see Table 2 and Appendix Table 2 in Part 1, pp. 84 and 100

Carbon/Nitrogen ratio. Table 4 shows that the C/N ratio of the soil in 1942 was 10·6; where no organic manures were added this value changed little by 1951 and then decreased slightly between 1951 and 1967. Table 4 also shows that except for the sewage sludge all the organic manures as applied had larger C/N ratios than had soil. At each sampling soils enriched with the organic manure other than sewage sludge had C/N ratios nearer to that in soil without organic matter addition. The C/N ratio of soil to which sewage sludge was added did not increase to the value on soil without organic matter addition during 1942–60. But when dressings ceased after 1961 the C/N ratio increased and by 1967 was about 10 : 1.

Carbon and nitrogen content of the soil. Table 5 shows the %C and %N in the soil at the start of the experiment and the effect of the treatments on the %C and %N in the soils in 1951, 1960 and 1967 and the %C in 1972. Both the carbon and nitrogen content of the soil given fertilisers only increased throughout the experiment and up to 1972. Of the experiments made on the light soil at Woburn, in which changes in organic matter content have been measured over many years, this is the only one in which there has been an increase in the carbon content of soil to which inorganic fertilisers only were applied.

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TABLE 4

C/N ratios in the organic manures used and in the soils which received them, Market Garden experiment, Woburn, 1942–67

The soil in 1942 contained 0·87% C, 0·082% N, C/N ratio 10·6

Results are the averages of Series A and B

Treatment and dressing[1]	C/N ratio of material applied	1951 %C	1951 %N	1951 C/N ratio	1960 %C	1960 %N	1960 C/N ratio	1967 %C	1967 %N	1967 C/N ratio
Without organic manure	—	0·95	0·089	10·7	1·03	0·101	10·2	1·06	0·111	9·5
Farmyard manure	13·0									
Single		1·32	0·110	12·0	1·53	0·145	10·6	1·64	0·158	10·4
Double		1·70	0·140	12·1	2·12	0·189	11·2	2·26	0·204	11·1
Sewage sludge	9·5									
Single		1·69	0·176	9·6	2·00	0·205	9·8	1·70	0·172	9·9
Double		2·25	0·246	9·1	2·87	0·300	9·6	2·29	0·228	10·0
Vegetable compost	13·8									
Single		1·42	0·124	11·4	1·73	0·163	10·6	1·76	0·168	10·5
Double		1·66	0·142	11·7	2·00	0·176	11·4	2·14	0·200	10·7
Sludge compost	11·6									
Single		1·55	0·140	11·1	1·90	0·187	10·2	1·68	0·168	10·0
Double		1·94	0·182	10·6	2·49	0·238	10·5	2·06	0·201	10·2

[1] Single dressing, 30 tons/acre every two years; double dressing, 60 tons/acre every two years

The reason is not known but it may be associated with the fact that with the rotations used the land was only without a crop cover for very short periods. An explanation is being sought in a new experiment. Sludge and sludge compost were not applied after 1961, because they were increasing the amounts of heavy metals in the soils; dressings of FYM ceased on the FYM and vegetable compost plots after 1967 when market garden crops were no longer grown. Table 5 shows that the amount of soil carbon in 1972 had decreased on all plots receiving organic manures, more so on the sewage sludge and sludge compost plots where dressings had been discontinued longest. From the results in Table 5 it can be shown that the average annual rate of loss of carbon between 1961 and 1972 on the sludge and sludge compost plots after additions ceased in 1962 was about 75% of the average annual gain in soil carbon during 1942–61 when these manures were applied.

Rates of build-up of organic matter. All the organic manures increased the organic matter content of the soil. Table 6 shows the increase in %C and %N between 1942 and 1951, and between 1942 and 1960 due to each treatment, and between 1942 and 1967 for the FYM- and vegetable compost-treated plots. When the increase in C and N on plots without organic manure was allowed for, Table 6 shows that, except for FYM, the increase in %C due to the smaller amount of manure was more than half the increase with the larger amount. Table 6 also shows that the increase in soil carbon during the first nine years was from two-thirds to three-quarters of the total build-up in the first 18 years. On the FYM-treated plots the increase in %C during the first nine years was still 62–67% of the increase in 25 years. It appears therefore that the rate of build-up of organic matter has decreased in the second nine-year period and again between the eighteenth and twenty-fifth years. The reason for this is not certain. It does not appear to be related to the amount of organic matter in the soil. In 1960 the carbon content of soil receiving organic manures ranged from 1·53 to 2·87% C and with this wide range of soil

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TABLE 5

%C and %N in the soils of the Market Garden experiment, Woburn, in 1942, 1951, 1960, 1967 and 1972

At the start of the experiment in 1942 the soil contained 0·87% C, 0·082% N

Treatment and dressing[2]	1951[1] Series A	1951[1] Series B	1951[1] Mean	1960 Series A	1960 Series B	1960 Mean	1967[3] Series A	1967[3] Series B	1967[3] Mean	1972[3] Series A	1972[3] Series B	1972[3] Mean
				Percentage of carbon (Walkley–Black %C × 1·3)								
Without organic manure	0·94	0·96	0·95	0·90	1·15	1·02	1·05	1·07	1·06	1·00	1·15	1·08
Farmyard manure												
Single	1·27	1·38	1·32	1·36	1·70	1·53	1·46	1·81	1·64	1·21	1·70	1·46
Double	1·70	1·70	1·70	2·04	2·20	2·12	2·17	2·34	2·26	1·72	1·99	1·86
Sewage sludge												
Single	1·76	1·62	1·69	1·93	2·08	2·00	1·64	1·76	1·70	1·25	1·48	1·36
Double	2·28	2·22	2·25	2·92	2·82	2·87	2·34	2·24	2·29	1·80	1·86	1·83
Vegetable compost												
Single	1·40	1·45	1·42	1·66	1·81	1·74	1·70	1·81	1·76	1·42	1·62	1·52
Double	1·69	1·64	1·66	2·00	2·00	2·00	2·25	2·02	2·14	1·85	1·85	1·85
Sludge compost												
Single	1·50	1·60	1·55	1·77	2·02	1·90	1·68	1·68	1·68	1·37	1·50	1·44
Double	1·90	1·98	1·94	2·38	2·60	2·49	1·91	2·20	2·06	1·55	1·95	1·75
					Percentage of nitrogen							
Without organic manure	0·086	0·092	0·089	0·087	0·115	0·101	0·110	0·112	0·111			
Farmyard manure												
Single	0·106	0·114	0·110	0·130	0·160	0·145	0·136	0·180	0·158			
Double	0·140	0·139	0·140	0·182	0·196	0·189	0·200	0·209	0·204			
Sewage sludge												
Single	0·188	0·165	0·176	0·197	0·214	0·205	0·165	0·180	0·172			
Double	0·258	0·234	0·246	0·307	0·292	0·300	0·232	0·225	0·228			
Vegetable compost												
Single	0·123	0·124	0·124	0·154	0·172	0·163	0·156	0·180	0·168			
Double	0·143	0·140	0·142	0·178	0·173	0·176	0·214	0·187	0·200			
Sludge compost												
Single	0·137	0·144	0·140	0·175	0·199	0·187	0·166	0·171	0·168			
Double	0·176	0·187	0·182	0·228	0·249	0·238	0·180	0·222	0·201			

[1] Results given by Mann and Barnes (1957)
[2] Single dressing, 30 tons/acre avery two years; double dressing, 60 tons/acre every two years
[3] No organic manure to sewage sludge or sludge compost plots in 1962 or since, no organic manure to FYM or vegetable compost plots in 1968 or since

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TABLE 6

The effect of single and double dressings of organic manures on the %C and %N in the soil and the increase in %C and %N during the first nine years as a percentage of the increase in 18 years and in 25 years, Market Garden experiment, Woburn

At the start of the experiment in 1942 the soil contained 0·87% C and 0·082% N

	1951				1960					1967				
Treatment and dressing[1]	% in 1951	1951 minus 1942	Effect of organic manure	Increase due to single dressing as a % of increase due to double dressing	% in 1960	1960 minus 1942	Effect of organic manure	Increase due to single dressing as a % of increase due to double dressing	Increase in first 9 years as a % of the increase in 18 years	% in 1967	1967 minus 1942	Effect of organic manure	Increase due to single dressing as a % of increase due to double dressing	Increase in first 9 years as a % of the increase in 25 years
					Percentage of carbon (Walkley–Black %C × 1·3)									
Without organic manure	0·95	0·08	—	—	1·03	0·16	—	—	—	1·06	0·19	—	—	—
Farmyard manure														
Single	1·32	0·45	0·37	49	1·53	0·66	0·50	46	74 } 72	1·64	0·77	0·58	48	64 } 63
Double	1·70	0·83	0·75		2·12	1·25	1·09		69	2·26	1·39	1·20		62
Sewage sludge														
Single	1·69	0·82	0·74	57	2·00	1·13	0·97	53	76 } 74	No dressings given				
Double	2·25	1·38	1·30		2·87	2·00	1·84		71					
Vegetable compost														
Single	1·42	0·55	0·47	66	1·74	0·87	0·71	73	66 } 70	1·76	0·89	0·70	65	67 } 66
Double	1·66	0·79	0·71		2·00	1·13	0·97		73	2·14	1·27	1·08		66
Sludge compost														
Single	1·55	0·68	0·60	61	1·90	1·03	0·87	60	69 } 68	No dressings given				
Double	1·94	1·07	0·99		2·49	1·62	1·46		68					
							Percentage of nitrogen							
Without organic manure	0·089	0·007	—	—	0·101	0·019	—	—	—	0·111	0·029	—	—	—
Farmyard manure														
Single	0·110	0·028	0·021	41	0·145	0·063	0·044	50	48 } 53	0·158	0·076	0·047	50	45 } 50
Double	0·140	0·058	0·051		0·189	0·107	0·088		58	0·204	0·122	0·093		55
Sewage sludge														
Single	0·176	0·094	0·087	55	0·205	0·123	0·104	52	84 } 82	No dressings given				
Double	0·246	0·164	0·157		0·300	0·218	0·199		79					
Vegetable compost														
Single	0·124	0·042	0·035	66	0·163	0·081	0·062	83	56 } 64	0·168	0·086	0·057	64	61 } 60
Double	0·142	0·060	0·053		0·176	0·094	0·075		71	0·200	0·118	0·089		60
Sludge compost														
Single	0·140	0·058	0·051	55	0·187	0·105	0·086	62	59 } 64	No dressings given				
Double	0·182	0·100	0·093		0·238	0·156	0·137		68					

[1] Single dressing, 30 tons/acre every two years; double dressing, 60 tons/acre every two years

carbon content it might have been expected that soils with least carbon in 1951 would have accumulated most in the second nine-year period. This did not happen. What effect the gradual deepening of the plough layer from 5 to 9 in. would have on the accumulation of organic matter is uncertain.

The increase in soil N during the first nine years ranged from 48 to 84% of the increase in the 18 years. For the FYM-treated plots the increase in %N during the first nine years was 45–61% of the increase in 25 years.

The different amounts of C and N which accumulated on Series A and B between 1951 and 1960 can be calculated from the results given in Table 6. The calculation cannot be made for the earlier period because individual plots were not sampled in 1942. Table 7

TABLE 7

Differences in amounts of carbon and nitrogen accumulated in the soils according to their position in the field, Market Garden experiment, Woburn

Treatment and dressing[1]	Change in %C between 1951 and 1960			Change in %N between 1951 and 1960		
	on Series A	on Series B	B minus A	on Series A	on Series B	B minus A
Without organic manure	−0·04	0·19	0·23	0·001	0·023	0·022
Farmyard manure						
Single	0·09	0·32	0·20	0·024	0·024	0·022
Double	0·34	0·50	0·16	0·042	0·057	0·015
Sewage sludge						
Single	0·17	0·46	0·19	0·009	0·047	0·038
Double	0·64	0·60	−0·04	0·049	0·058	0·009
Vegetable compost						
Single	0·26	0·36	0·10	0·031	0·048	0·017
Double	0·31	0·36	0·05	0·035	0·033	−0·002
Sludge compost						
Single	0·27	0·42	0·15	0·038	0·055	0·017
Double	0·48	0·62	0·14	0·052	0·062	0·010

[1] Single dressing, 30 tons/acre every two years; double dressing, 60 tons/acre every two years

shows that between 1951 and 1960 more of both C and N accumulated on Series B than on Series A in eight of the nine comparisons. It is not possible to offer an explanation for this other than the fact that Series A is on the upper half of the sloping site and the surface soil is usually seen to dry out more rapidly than that on Series B. The whole of the plough layer on Series B may tend to remain wetter than the plough layer on Series A. It was thought that the soils of Series B might have contained more clay and that they would therefore have retained more organic matter. However, results in Diagram 1 show the differences in clay content between the two Series are probably too small to explain the differences in organic matter build-up.

The proportion of added N and C retained in the soil. The increases in %C and %N in the surface soil for each ton of organic matter and nitrogen added in the organic manure has also been calculated. Table 8 gives the results for carbon, Table 9 those for nitrogen. In Table 8 soil organic matter is derived from the percentage of carbon by multiplying the %C figure by 1·72. This is a conventional factor derived from the carbon analysis of many samples of peat.

Table 8 shows that during any period the percentage of added organic matter retained was least with FYM. With FYM, however, the amount retained was independent of the amount added, about 44% from additions made in the first nine years, 30% from addi-

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TABLE 8

Amount of added organic matter retained in the soil and the increase in soil carbon for each ton organic matter added, Market Garden experiment, Woburn

Treatment and dressing[1]	Period	Organic matter added,[4] tons/acre	Increase in %C due to organic manure	Increase in % organic matter[5]	Extra organic matter in soil,[2] tons/acre	% organic matter added retained by the soil		Increase in %C per ton of organic matter added	
Farmyard manure									
Single	1942–50	19·98	0·37	0·636	8·71	43·6	43·9		
Double		39·96	0·75	1·290	17·67	44·2			
Single	1942–60	40·69	0·50	0·860	11·78	29·0	30·3	0·0123	0·0128
Double		81·38	1·09	1·875	25·69	31·6		0·0134	
Single	1942–67	55·00	0·58	0·998	13·67	24·8	25·2	0·0105	0·0107
Double		110·00	1·20	2·064	28·27	25·7		0·0109	
Sewage sludge									
Single	1942–50	28·12	0·74	1·273	17·44	62·0	58·2		
Double		56·24	1·30	2·236	30·63	54·5			
Single	1942–60	62·36	0·97	1·668	22·85	36·6	35·7	0·0155	0·0152
Double		124·72	1·84	3·165	43·36	34·8		0·0148	
Vegetable compost									
Single	1942–50	15·72	0·47	0·808	11·07	70·4	61·8		
Double		31·44	0·71	1·221	16·73	53·2			
Single	1942–60	35·72	0·71	1·221	16·73	46·8	39·4	0·0199	0·0167
Double		71·44	0·97	1·668	22·85	32·0		0·0135	
Single	1942–67[3]	47·33	0·70	1·204	16·49	34·8	30·8	0·0148	0·0131
Double		94·66	1·08	1·858	25·45	26·9		0·0114	
Sludge compost									
Single	1942–50	91·71	0·60	1·032	14·14	71·7	65·4		
Double		39·42	0·99	1·703	23·33	59·2			
Single	1942–60	44·50	0·87	1·496	20·50	46·1	42·4	0·0196	0·0180
Double		89·00	1·46	2·511	34·40	38·6		0·0164	

[1] Single dressing, 30 tons/acre every two years; double dressing, 60 tons/acre every two years
[2] Weight soil, 1370 tons/acre, 0–9 in. depth
[3] FYM, 1962–67
[4] Estimated as total dry matter in fresh manure *minus* the ash (inorganic residue after ignition at 450°)
[5] Organic matter equals %C × 1·72

TABLE 9

Amount of N retained in the soil and the increase in soil N for each ton of N added in the organic manure, Market Garden experiment, Woburn

Treatment and dressing[1]	Period	Total N added tons/acre	Increase in %N due to organic manure	Extra N in soil[2] tons/acre	% of added N retained by the soil		Increase in %N per ton of N added in organic manure	
Farmyard manure								
Single	1942–50	0·803	0·021	0·288	35·9	39·7		
Double		1·606	0·051	0·699	43·5			
Single	1942–60	1·826	0·044	0·603	33·0	33·0	0·0241	0·0241
Double		3·652	0·088	1·206	33·0		0·0241	
Single	1942–67	2·444	0·047	0·644	26·4	26·2	0·0192	0·0191
Double		4·888	0·093	1·274	26·1		0·0190	
Sewage sludge								
Single	1942–50	1·799	0·087	1·192	66·3	63·0		
Double		3·598	0·157	2·151	59·8			
Single	1942–60	3·812	0·104	1·425	37·4	36·6	0·0273	0·0267
Double		7·624	0·199	2·726	35·8		0·0261	
Vegetable compost								
Single	1942–50	0·670	0·035	0·480	71·6	62·9		
Double		1·340	0·053	0·726	54·2			
Single	1942–60	1·537	0·062	0·849	55·2	44·3	0·0403	0·0324
Double		3·074	0·075	1·028	33·4		0·0244	
Single	1942–67[3]	2·039	0·057	0·781	38·3	34·1	0·0280	0·0251
Double		4·078	0·089	1·219	29·9		0·0222	
Sewage compost								
Single	1942–50	0·886	0·051	0·699	78·9	75·4		
Double		1·772	0·093	1·274	71·9			
Single	1942–60	2·220	0·086	1·178	53·1	47·7	0·0387	0·0348
Double		4·440	0·137	1·877	42·3		0·0308	

[1] Single dressing, 30 tons/acre every two years; double dressing, 60 tons/acre every two years
[2] Weight of soil 1370 tons/acre, 0–9 in. depth
[3] FYM, 1962–67

tions in 18 years and 25% of the total added in 25 years. These results can be compared with those from the Green Manuring experiment on Stackyard Field, Woburn, reported by Chater and Gasser (1970). In the Green Manuring experiment 90 tons FYM/acre were added during 1936–53 as 10 ton/acre dressings in alternate years. Their calculation for the amount of organic matter added must be corrected for the ash content of the manure. After making this correction their results show that about 39% of the organic matter added in FYM was still in the soil in 1954 when additions ceased.

Of the organic matter added as sewage sludge about 58% remained in the soil after nine years and 36% after 18 years. Most organic matter remained in the soil when it was added as compost; both vegetable and sludge composts behaved similarly. Averaged over the two amounts added more than 60% was retained in the first nine years and about 40% after annual additions for 18 years. After FYM replaced vegetable compost in 1962 the rate of accumulation of organic matter decreased and after 25 years only 31% of the added organic matter had been retained by the soil.

Table 8 also shows the increases in %C in soil per ton of organic matter added in the organic manures which were applied each year. The increases were least with FYM, 0·0128% C after 18 years and 0·0107% after 25 years, most with the composts, 0·0167 with vegetable compost, 0·0180 with sludge compost after 18 years. The gain from sewage sludge was similar to that with vegetable compost. These differences probably relate to the amount of decomposition that had occurred before the manures were added to the soil. Presumably there had already been much breakdown of easily decomposable

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organic matter and loss of carbon during the making of the vegetable- and sludge-composts so that the organic matter added was relatively more resistant to further breakdown. It is not unreasonable therefore that the carbon content of the soil increased most for each ton of organic matter added as compost.

Table 9 shows that the amounts of N retained from the different manures varied in the same way as the amounts of carbon. From the FYM about 40% of the added N was retained in the first nine years and this decreased to 33% for the 18-year period and 26% for the total period of 25 years. These values can be compared with the estimated gain in soil N due to applying FYM on Broadbalk at Rothamsted. After the first 20 years of the experiment about 37% of the added N had been retained in the surface 9 in. depth of soil (Johnston, 1969).

For each ton of N added in FYM, in the Market Garden experiment, soil N was

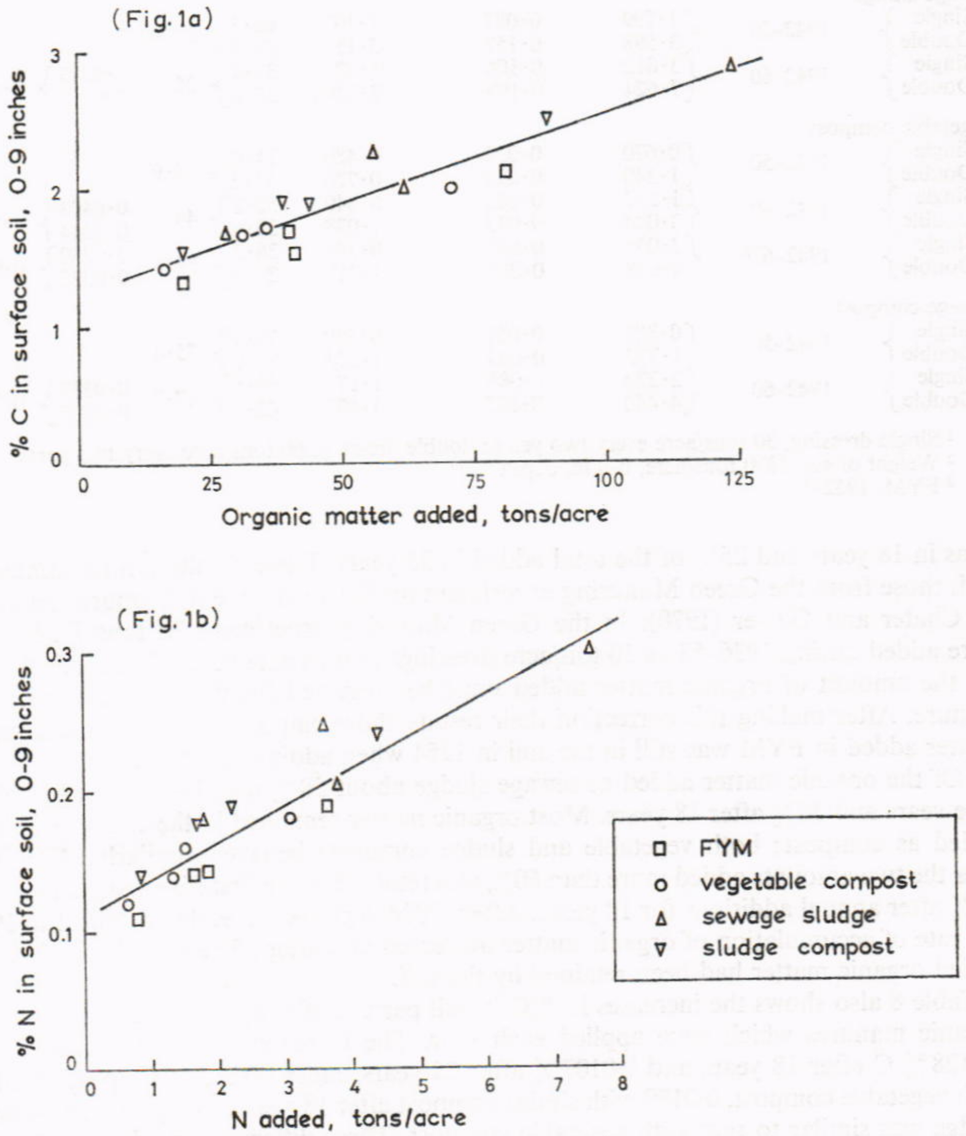

FIG. 1. Relationship between organic matter added and %C in soil (Fig. 1a) and nitrogen added and %N in soil (Fig. 1b); the organic manures were added during 1942–60, the %C and %N in soil were measured in 1951 and 1960, Market Garden experiment, Woburn.

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increased by 0·024% after 18 years and 0·019% N after 25 years. More N was retained from the other organic manures, about 45% of that added in the two composts was retained after annual additions for 18 years. One ton of N applied in these materials increased soil N by approximately 0·033% N. After replacing vegetable compost by FYM 1 ton of N in the two materials increased soil N by 0·025% N after 25 years.

Fig. 1a shows the relationship between the amount of organic matter (tons/acre) added and the %C in the soil. Results for the first nine- and 18-year periods are combined. A straight line relationship accounts for 87% of the variance. Fig. 1b shows the relationship for N added and soil N, a straight line relationship accounts for 86% of the variance.

Phosphorus and potassium

The surface soils, 0–9 in. deep, were sampled in 1960, Series B in July after early potatoes, Series A in September after red beet. All plots on both Series were sampled in autumn 1967 after the last of the Market Garden crops had been taken.

During the 1960s there was much discussion on suitable methods for measuring readily soluble P and K in soil and a selection of reagents were tested on these soils. For P the methods included Olsen's, a modification of Morgan's method and extraction of the soil with 0·3N-HCl. K was also determined in the soil extracts obtained using the Morgan and 0·3N-HCl methods. K exchangeable to neutral N-ammonium acetate and total P were also determined. For full details of the methods used see the Appendix.

Olsen's method was included because results of work done at Rothamsted in 1954 had shown that this method, recently introduced to determine soil P soluble in 0·5M-$NaHCO_3$ at pH 8·5, differentiated Rothamsted soils with and without P residues. The method has now been used in ADAS regional laboratories since 1971 but their analyses are expressed on a volume of soil : volume of extractant basis whereas our results are expressed on a weight of soil : volume of extractant basis. To convert one to the other allowance must be made for the density of the soil. A modified Morgan's reagent, 0·5N-ammonium acetate–0·5N-acetic acid, was used because both P and K could be determined in the same extract. This method was used in some NAAS regional laboratories in the 1960s. Using 0·3N-HCl as an extractant was tested because both P and K could be determined in the extract and Warren and Johnston (1962) had shown that this method was quick and simple and differentiated between soils with and without P residues provided the soils were neutral or slightly acid as were those on which the Market Garden experiment was made.

Total P was determined on the 1960 and 1967 samples. For the 1960 samples the soils were digested with boiling perchloric acid; Mattingly (1970) showed that this method of digestion gave slightly but consistently smaller values than did fusion with Na_2CO_3 probably because boiling perchloric acid did not dissolve all the P in the coarse and fine sand fractions of the soil. Total P in the 1967 samples was determined by fusion with Na_2CO_3.

Amounts of P and K applied. The discussion on phosphorus and potassium in this section must be related to major changes in manuring. The first was that P and K were not applied as basal dressings to plots receiving organic manures after 1960. The second change was that P and K fertiliser dressings were increased in 1961, P to 1·5 cwt P_2O_5/acre and two amounts of K were tested, 1·5 and 3·0 cwt K_2O/acre; extra P was tested (1·5 and 3·0 cwt P_2O_5/acre) only in the last three years of the experiment. After 1961 no further sewage sludge or sludge compost was given. Instead each crop grown on these plots received 1·5 cwt P_2O_5 and 1·5 cwt K_2O/acre during 1962–65, and 3·0 cwt P_2O_5 and 3·0 K_2O/acre during 1966–67; thus when the sludge and sludge-compost plots on Series B were fallowed in 1965–67 no P or K was given. In 1962 the single and double

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dressings of vegetable compost were replaced by equal weights of FYM. In 1961 half the number of plots getting FYM and vegetable compost also got an extra dressing of P and K (1·5 cwt P_2O_5 and 1·5 cwt K_2O/acre). All these dressings were applied to each crop in rotation. Full details of the amounts of P and K applied are in Part 1, Appendix Table 2, pp. 100–101.

Effect of treatment and change with time. Table 10 shows total P and bicarbonate soluble P and exchangeable K in the soil in 1960 and again in 1967. For the 1960 results, when basal P was still given to all plots, the increase in both total and bicarbonate soluble P due to the single and double dressings of organic manures can be calculated. The result is interesting in that whilst the double dressing of both FYM and sludge had increased both total and bicarbonate soluble P twice as much as the single dressing, for both composts the increase was less than double. This is best seen if the increases due to the single and double dressings are expressed as ratios. If the increase due to the single dressing is taken as unity then, in 1960, the ratio of the increases in total and bicarbonate soluble P in surface soils due to the single and double dressings of organic manures are:

	Single dressing : Double dressing			
	FYM	vegetable compost	sewage sludge	sludge compost
Total P	1 : 1·91	1 : 1·26	1 : 1·94	1 : 1·57
Bicarbonate soluble P	1 : 1·93	1 : 1·37	1 : 2·06	1 : 1·54

Table 10 shows that between 1960 and 1967 there was a considerable increase in soluble P on plots receiving fertilisers only; it is possible even to detect the effect on the soluble P of the extra P added in the last three years of the experiment. In contrast there was little or no increase in bicarbonate soluble P where either dressing of FYM was applied to plots receiving FYM or vegetable compost before 1961. The reason for this is not known. It is most unlikely that all the P applied was removed in the crops because yields were not so much larger than on plots receiving only fertilisers where smaller amounts of applied P did increase soluble P in the soil and, in any case, total P in the soil increased between 1960 and 1967. The result is even more perplexing because where extra fertiliser P was given on half the FYM plots, this fertiliser P did increase bicarbonate soluble P; the increase was 26 mg/kg on average. This effect of superphosphate on soluble P was confirmed by results on the sludge- and sludge-compost treated plots. These plots were without organic manures after 1961 but got almost the same amounts of superphosphate as the FYM-treated plots with extra P. On the sludge plots the increase in bicarbonate soluble P due to the superphosphate was 28 mg/kg.

Table 10 shows that in 1960 the sludge- and sludge compost-treated plots had no more exchangeable K than the fertiliser only plots because these two organic manures added so little extra K. There was much more soluble K in soils getting FYM and vegetable compost. For both FYM and vegetable compost the increase in soluble K, compared to soils getting fertilisers only, was only about 80% more at the double than at the single dressing. This was because much K had been leached down the profile, as discussed later. Table 10 also shows that between 1960 and 1967 exchangeable K decreased in soils getting FYM at both rates. This may have been due to increased removal in the crop or to further loss from the surface soil by leaching. However, where fertiliser K was applied in addition to FYM between 1961 and 1967 exchangeable K was maintained at the 1960 amounts or was slightly increased. In 1967 the extra fertiliser K given to FYM-treated plots had increased exchangeable K by about 90 mg/kg. This was more than the increase (74 mg/kg) on the sludge-treated plots which received the same amount of fertiliser K but got no K in organic manures.

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TABLE 10

Total P and readily soluble P and K in the surface soils of the Market Garden experiment, Woburn, 1960 and 1967

Treatment and dressing[5]		P, mg/kg, soluble in 0·5M $NaHCO_3$						K, mg/kg, soluble in 1N ammonium acetate						Total P, mg/kg					
		1960			1967			1960			1967			1960[6] by acid digestion			1967[6] by Na_2CO_3 fusion		
1960	1967	Series A	Series B	Mean	Series A	Series B	Mean	Series A	Series B	Mean	Series A	Series B	Mean	Series A	Series B	Mean	Series A	Series B	Mean
PK fertiliser only		97	91	94				83	106	94				1040	1150	1095			
	P_1K_1				142	141	141				186	147	166				1260	1333	1296
	P_1K_2[1]				154	156	155				306	211	258				1357	1527	1442
Farmyard manure																			
Single dressing	Single dressing	146	135	140	144	154	149	216	280	248	199	152	175	1350	1530	1440	1560	1752	1656
	Single dressing+ P_1K_1[2]				167	190	179				303	266	284				1630	1838	1734
Double dressing	Double dressing	203	163	183	184	179	182	346	420	383	281	313	297	1750	1760	1755	2114	2118	2116
	Double dressing+ P_1K_1[2]				204	208	206				374	388	381				2320	2197	2258
Vegetable compost																			
Single dressing	Single dressing[3]	165	137	151	160	134	146	214	239	226	198	144	171	1520	1600	1560	1738	1600	1669
	Single dressing+ P_1K_1[2]				191	166	178				314	196	255				1838	1944	1891
Double dressing	Double dressing	182	162	172	180	166	173	264	380	322	250	244	247	1700	1660	1680	1978	1920	1949
	Double dressing+ P_1K_1[2]				215	171	193				418	242	330				2405	1924	2164
Sewage sludge																			
Single dressing	P_1K_1[4]	126	124	125	172	142	157	74	100	87	212	123	168	2040	2100	2070	2145	2120	2132
Double dressing	P_1K_1[4]	168	148	158	190	159	175	79	108	94	212	113	163	3190	2790	2990	2944	2660	2802
Sludge compost																			
Single dressing	P_1K_1[4]	121	118	120	174	142	158	84	115	100	228	122	175	1750	1850	1800	2037	1924	1980
Double dressing	P_1K_1[4]	134	134	134	171	151	161	89	124	106	226	131	178	2100	2300	2200	2177	2414	2296

[1] Amounts of fertiliser were increased after 1960. From 1965 on Series B and 1966 on Series A plots receiving K_2 got P_2, i.e. 3·0 cwt P_2O_5/acre (three dressings on Series B, two dressings on Series A).
[2] Half the plots tested an additional dressing of P_1K_1 from 1961–67 except vegetable compost plots on Series B where none was applied 1965–67
[3] FYM replaced vegetable compost 1962–67
[4] No sludge or sludge compost after 1961. P_1K_1 applied 1962–65 (1965 Series A only). 1966–67 P_2K_2 on Series A only.
[5] Single dressing, 30 tons/acre every two years, double dressing 60 tons/acre every two years.
[6] 1960 results by perchloric acid digestion, 1967 results by Na_2CO_3 fusion. Mattingly (1970) showed that perchloric acid digestion gave values slightly, 40 mg/kg, but consistently less than those by Na_2CO_3 fusion. Johnston and Chater (1975) for soils from Stackyard Field, Woburn, found that the perchloric acid digestion gave values about 50 mg/kg less. The 1960 values should, therefore, be increased by about 50 mg/kg to make them comparable with the results for 1967 which were obtained by Na_2CO_3 fusion

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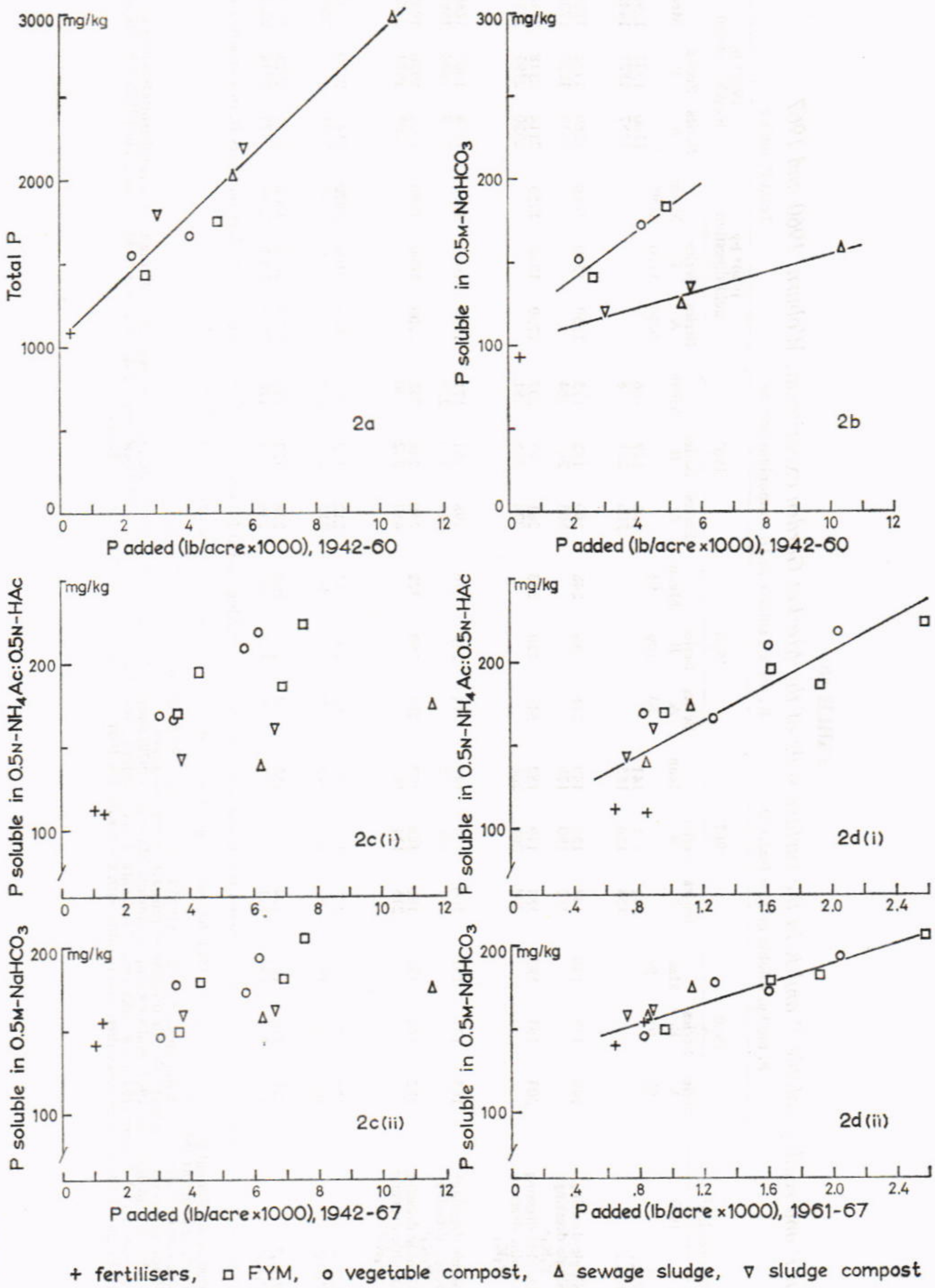

FIG. 2. Relationship between P added in fertilisers and organic manures and the total and soluble P in soil, Market Garden experiment, Woburn. (a) P added during 1942–60 and total P in soil in 1960. (b) P added during 1942–60 and bicarbonate soluble P in 1960. (c) P added during 1942–67 and P soluble in a modified Morgan reagent (Fig. 2c(i)) and in bicarbonate solution (Fig. 2c(ii)) in 1967. (d) P added during 1961–67 and P soluble in a modified Morgan reagent (Fig. 2d(i)) and in bicarbonate solution (Fig. 2d(ii)) in 1967.

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Relationship between P and K applied and amounts in the soil. Very few crops grown in this experiment were analysed so balance sheets for the amounts of P and K remaining in the soil cannot be prepared. Also in this experiment results given later show that with some treatments both P and K moved below plough depth. However, for P, where some of that which was applied remains in the soil as a residue, it is possible in long-term experiments to examine the relationship between P applied and that remaining in soil. Cooke (1972) gave examples of such relationships for bicarbonate soluble P in soil and P applied in long-term experiments at Rothamsted and Saxmundham; Fig. 2 shows such relationships for these soils. Fig. 2a shows the P added during 1942–60 and the total P in the surface soils in 1960; the linear relationship accounts for 94% of the variance. Soils treated with FYM and vegetable compost are on the lower side of the fitted line because it was on these soils that some P had moved down below 9 in.

Fig. 2b shows the relationship between the bicarbonate soluble P in 1960 and the P applied by then. More of the added P has remained bicarbonate-soluble on soils with

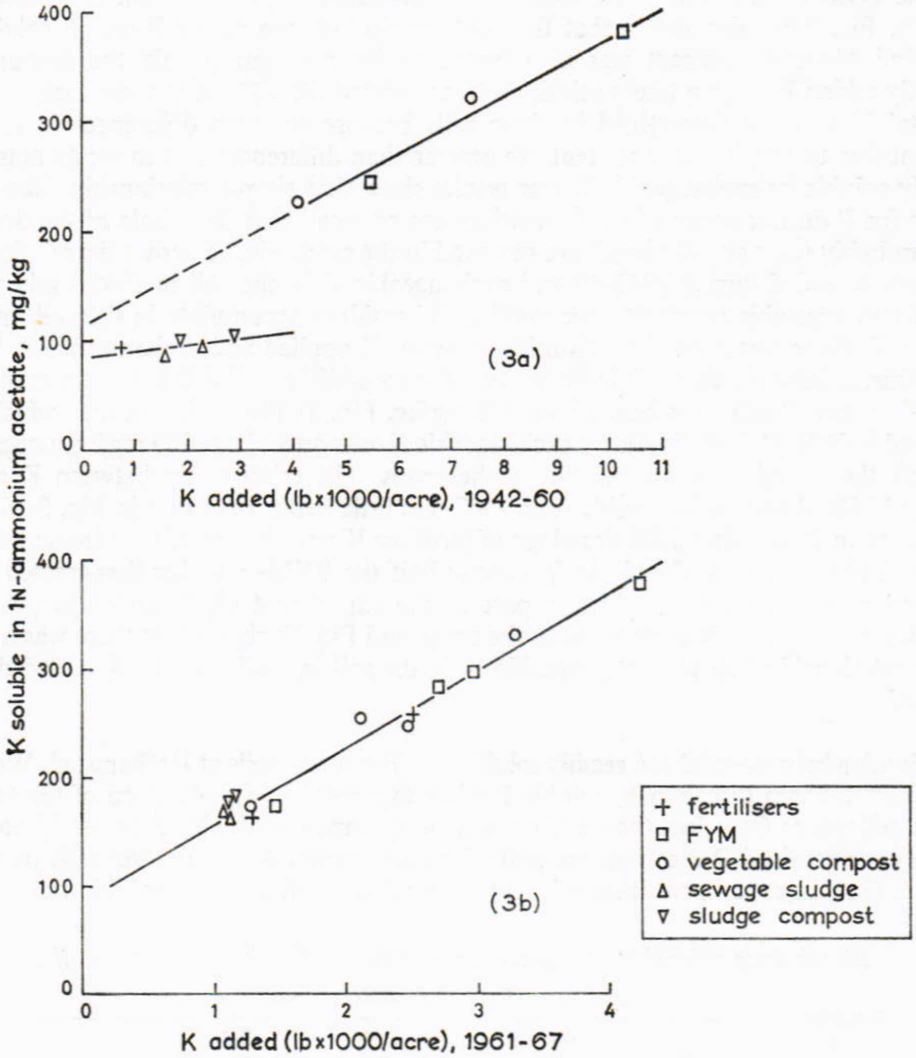

FIG. 3. Relationship between K added in fertilisers and organic manures and K soluble in 1N-ammonium acetate, Market Garden experiment, Woburn. (a) K added during 1942–60 and exchangeable K in 1960. (b) K added during 1961–67 and exchangeable K in 1967.

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FYM and vegetable compost than on soils with sewage sludge and sludge compost. For both groups of soils linear relationships account for 80% of the variance for soils receiving FYM and 93% of the variance for soils receiving sewage sludge. These linear relationships ignore fertiliser only plots to which only small amounts of P were added before 1960.

Fig. 2c shows for soils sampled in 1967 the relationship between P applied during 1942–67 and P soluble in 0·5M-$NaHCO_3$ (Fig. 2c(ii)) and in Morgan's reagent (Fig. 2c(i)). For bicarbonate soluble P there was no longer an obvious difference between FYM-treated soils and those which had received sludge until 1961. For all treatments a linear relationship accounted for only 28% of the variance. For the relationship between P applied and that soluble in Morgan's reagent a linear relationship accounted for 25% of the variance. Fig. 2d shows the relationship between the P applied during 1961–67 and the soluble P in the soil in 1967. For all soils the relationship between P applied in 1961–67 and bicarbonate soluble P (Fig. 2d(ii)) was linear (accounting for 86% of the variance) and was much closer than the relationship with the total P applied since 1942. This suggests that recently applied P contributes proportionately more to the bicarbonate soluble P than older residues, a suggestion considered in greater detail in a following section. Fig. 2d(i) also shows that the relationship between added P and P soluble in modified Morgan's reagent was also improved by considering only the amounts of recently added P when a linear relationship accounted for 72% of the variance.

Total K was not determined in these soils because so often differences in total K content due to varying clay content are greater than differences due to treatments. For readily soluble or exchangeable K our results show that simple relationships like those above for P do not occur when K dressings are so small that the whole of the dressing and probably some soil K as well are removed in the crop. Fig. 3a shows the relationship between K added during 1942–60 and exchangeable K in the soil in 1960. Only where FYM and vegetable compost were applied did residues accumulate in the soil and for these soils there was a good relationship between K applied and exchangeable K in the soil. Extrapolating backwards indicates that for an addition of 2000 lb K/acre exchangeable K values should have been about 150 mg/kg. Fig. 3a shows that in soils which had received only 1000–3000 lb K/acre exchangeable K was only about 100 mg/kg, suggesting that all the added K was removed by the crops. The relationship between K added during 1942–67 and exchangeable K in 1967 was little better than that in Fig. 3a for the period up to 1960. After 1960 dressings of fertiliser K were increased; sludge and sludge compost plots received K only in fertilisers; half the FYM- and fertiliser-treated plots received extra K. During the latter part of the experiment all K dressings probably supplied more K than was removed in the crops and Fig. 3b shows that there was a good linear relationship between exchangeable K in the soil in 1967 and the K added during 1961–67.

Relationship between total and readily soluble P. For many soils at Rothamsted, Woburn and Saxmundham bicarbonate soluble P when expressed as a percentage of the total P in the soil varies from less than 1% on soils long unmanured with P to 5–6% on soils which have received P dressings annually for many years. Atypically the soils from the Market Garden experiment have a larger proportion of bicarbonate soluble P:

Bicarbonate soluble P as a percentage of the total P in the surface soils

Dressing of manure	Organic manure applied: FYM	sewage sludge	vegetable compost	sludge compost	none
Single	9·7	6·0	9·7	6·6	8·5
Double	10·4	5·3	10·2	6·1	

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The reason for this is not known but may relate to the fact that these soils contain much more total P than most of those at Rothamsted or Woburn.

Bicarbonate soluble P is probably only a small proportion of the total P because much (probably 30–50%) of the total P contributes little to the bicarbonate-soluble fraction. To attempt to discriminate between the effects of new and old residues two methods have been examined:

1. The amounts of P remaining in soil were calculated from known additions and removals and the increases in bicarbonate soluble P were measured. This method was used by Mattingly, Chater and Poulton (1974); they calculated, from crop removals, the P remaining in soil as residues from manuring during eight years cropping in the Organic Manuring experiment at Woburn. They showed that, of this P remaining in the soil, 20–36% was bicarbonate-soluble. However, these values may have been enhanced because about a third of the P applied was given only four to five months before the final soil sampling.

2. Increases in both total and bicarbonate soluble P in soil are measured. (a) Mattingly, Johnston and Chater (1970) took samples from the Rotation II experiment at Saxmundham before and after a four-year period in which much P (200–425 lb P/acre) was added. Increases in total P in soil by analysis (equivalent to 300–350 lb P/acre from the larger dressing) agreed well with the calculated increases (additions minus removals). After the four years about 25% of the P from the recent additions was bicarbonate-soluble. (b) Johnston (unpublished data) measured the increases over unmanured soils of both total and bicarbonate soluble P on soils given P both as superphosphate and FYM. At Rothamsted 10–12% of the extra P was bicarbonate soluble when about 30 lb P/acre was applied each year for 100 years. Where no P had been given for the last 70 years after annual dressings of 30 lb P/acre for 50 years the proportion of bicarbonate soluble P had decreased to 5–6% of the extra total P.

For the Market Garden soils total and bicarbonate soluble P in 1960 were measured and the increases in both on soils receiving organic manures were calculated. After manuring which had lasted for 18 years results were:

Increase in bicarbonate soluble P as a percentage of the measured increase in total P in the soil in 1960

Dressing of manure	Organic manure added			
	FYM	vegetable compost	sewage sludge	sludge compost
Single	13·5	12·4	3·2	3·7
Double	13·5	13·4	3·2	3·6

Again the results emphasise the difference between FYM and sewage sludge. Little of the P added in sludge is bicarbonate-soluble. Much, if not all, the water soluble P will have been leached out at the sewage works and the remainder must be in a chemical form which has little solubility in 0·5M-$NaHCO_3$. Of the P added in FYM 12–14% of that remaining in soil during 18 years is bicarbonate-soluble, a result in agreement with that for Rothamsted soils.

Relationships between methods of analysis for P and for K

Because P and K were added both as fertilisers and in a number of organic manures there is a unique opportunity to examine whether the results from different methods of analysis are affected by the form in which the nutrient was added.

Phosphorus. Soluble P in the soils in 1960 can be related to the total P in the soil.

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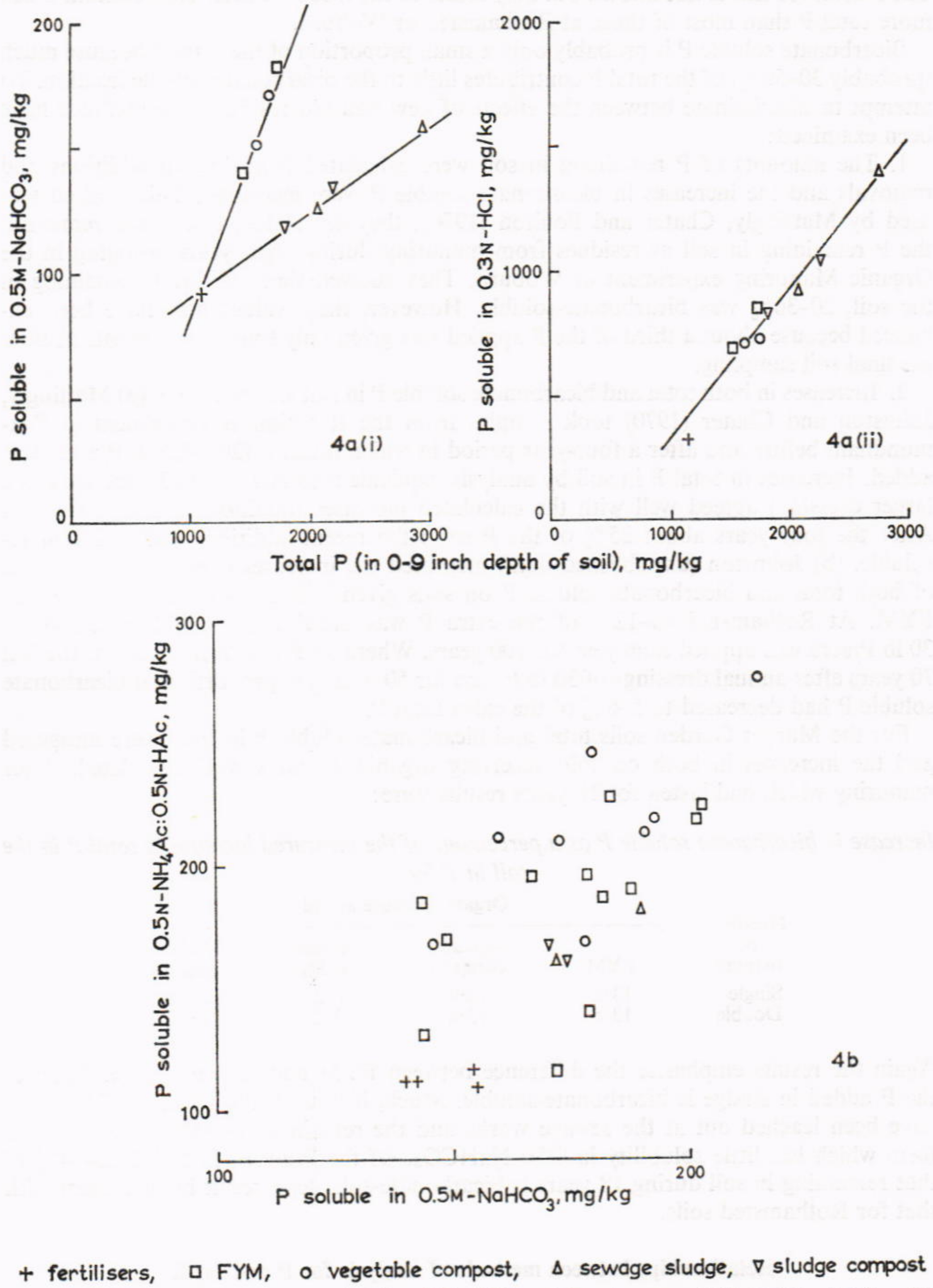

FIG. 4a. Relationship between total P in soil in 1960 and bicarbonate soluble P (Fig. 4a(i)) and P soluble in 0·3N-HCl (Fig. 4a(ii)).

FIG. 4b. Relationship between bicarbonate soluble P and P soluble in a modified Morgan reagent, Market Garden experiment, Woburn, 1960.

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Only samples from Series B were extracted with 0·3N-HCl; Fig. 4a(ii) shows that for all treatments there was a linear relationship between the acid soluble P and the total P in the soil. Fig. 4a(i), however, shows that for a given amount of total P in the soil a greater proportion was soluble in 0·5M-$NaHCO_3$ when the P had been added in FYM or vegetable compost than when added in sewage sludge or sludge compost. This confirmed results in previous sections. P soluble in 0·5M-$NaHCO_3$ and in Morgan's reagent was determined in samples taken in 1967. Fig. 4b shows that when P was added in different organic manures the amounts extracted by the two reagents were poorly related. Also the results

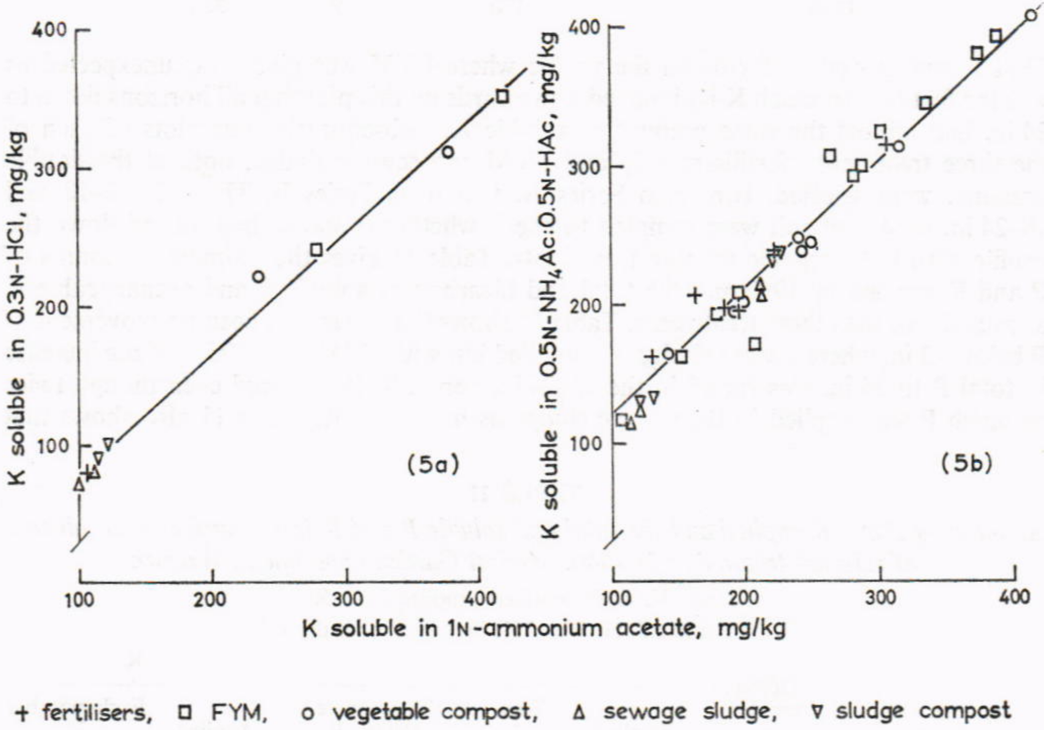

FIG. 5. Relationship between K soluble in 0·3N-HCl in soil in 1960 (Fig. 5a) and K soluble in a modified Morgan reagent in soil in 1967 (Fig. 5b) and K soluble in 1N-ammonium acetate in the same soil, Market Garden experiment, Woburn.

in Fig. 4b do not suggest that the relationship would be better if the P added in each material was considered separately.

Potassium. Fig. 5a shows for soils sampled in 1960 the relationship between K soluble in 0·3N-HCl and in 1N-ammonium acetate. There was a good linear relationship which supports a similar observation for Rothamsted soils (Warren & Johnston, 1962). Fig. 5b shows the relationship between K soluble in 1N-ammonium acetate and in the modified Morgan's reagent for soils taken in 1967. There was an excellent linear relationship over the range 100–450 mg/kg exchangeable K. The results in Figs. 5a and b suggest that the solubility of K once it was in the soil was independent of the manure in which it was applied. Figs. 5a and b also show that the amounts of K extracted by the three reagents are well correlated which supports a similar observation on Rothamsted soils by Johnston and Addiscott (1971).

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Movement of P and K into the subsoils

Early in 1960 samples taken from below plough depth on soil treated with fertiliser only (plot 76) and with the double dressing of FYM (plot 75) showed that both P and K had moved down below 9 in. on the FYM treated soil:

P and K soluble in 0·3N-HCl

Depth, in.	P, mg/kg Plot 76	P, mg/kg Plot 75	K, mg/kg Plot 76	K, mg/kg Plot 75
0–9	310	850	80	350
12–18	120	210	60	330
18–24	90	170	50	320

That P had moved so far down the profile where FYM was given was unexpected as was the fact that so much K had moved downwards on this plot that all horizons down to 24 in. had almost the same amount of soluble K. Subsequently four plots of each of the three treatments, fertilisers only and FYM and sewage sludge, both at the double dressing, were selected, two from Series A, two from Series B. The 0–9, 12–18 and 18–24 in. depths of soil were sampled to check whether P and K had moved down the profile with both organic manure treatments. Table 11 gives the estimated amounts of P and K applied by 1960 and the total and bicarbonate soluble P and exchangeable K at each depth with these treatments. Table 11 shows that there had been no movement of P below 12 in. where sewage sludge was applied but with FYM about 25% of the increase in total P to 24 in. was found in the 12–24 in. depth. This occurred even though twice as much P was applied in the sewage sludge as in the FYM. Table 11 also shows that

TABLE 11

Amounts of P and K applied and the total and soluble P and K in the surface and sub-soils of selected treatments in 1960, Market Garden experiment, Woburn

P and K, lb element/acre, applied 1942–60

Total P and soluble P and K, in mg/kg in air dry soil

Treatment	Depth sampled in.	P Applied	P Total P	P Bicarbonate soluble P	K Applied	K Exchangeable K
Fertilisers only		388			822	
	0–9		1120	94		109
	12–18		850	73		120
	18–24		790	77		100
FYM		4 974			10 364	
Double dressing	0–9		1780	176		383
	12–18		960	114		385
	18–24		860	109		320
Sewage sludge		10 434			2315	
Double dressing	0–9		3000	151		90
	12–18		850	69		85
	18–24		770	65		86

much more K was applied in FYM than in sewage sludge and where FYM was given the results confirm those above. So much K had leached down the profile that there was much the same amount of exchangeable K at each depth. With sewage sludge there was less K than with fertilisers only.

Table 12 is taken from Warren and Johnston (1961) except that the total P results given here were those determined by the perchloric acid digestion method used for the 1960 samples. Most of the gain in total P was as inorganic P soluble in acetic acid and in

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TABLE 12

Extra P in soils of the Woburn Market Garden experiment receiving farmyard manure and sewage sludge, as compared with soils having fertilisers only

	Farmyard manure plots				Sewage sludge plots			
		P soluble in				P soluble in		
			NaOH				NaOH	
Depth, in.	Total	Acetic acid	Inorganic	Organic	Total	Acetic acid	Inorganic	Organic
	mg/kg P in air dry soil							
0–9	390	34	9	7	1420	79	36	18
12–18	250	8	19	3	80	3	5	1
18–24	230	4	10	2	180	3	2	0
	Gain in soluble P at each depth as a percentage of the total gain							
0–9	—	74	24	58	—	93	84	95
12–18	—	17	50	25	—	4	12	5
18–24	—	9	26	17	—	4	4	0

NaOH. Increases in organic P were small, this is best seen when the extra P at each depth is expressed as a percentage of the total gain for each profile. This difference between FYM and sewage sludge must be related to the observation made previously about the solubilities of the P in bicarbonate solution. The P in sewage sludge must be in a very insoluble form.

To check these results all plots on Series B were sampled in 1961 at four depths, 0–9, 9–12, 12–18, 18–24 in.; the 9–12 in. depth was kept separate because it was not certain whether ploughing had been to 9 or 10 in. Table 13 shows the results for bicarbonate soluble P and Table 14 those for exchangeable K. Table 13 shows that under all treat-

TABLE 13

Extra P bicarbonate soluble P in soils of the Woburn Market Garden experiment, as compared with soils receiving fertilisers only

P, mg/kg, in air dry soil

		Organic manures applied at							
		single dressing				double dressing			
Depth, in.	Fertiliser only plots	FYM	vegetable compost	sewage sludge	sludge compost	FYM	vegetable compost	sewage sludge	sludge compost
		Gain in soluble P over fertiliser only plots							
0–9	103	48	49	40	31	75	72	63	55
9–12	93	49	44	27	25	56	68	57	47
12–18	79	33	18	8	0	48	43	18	15
18–24	78	15	−5	−3	−10	30	26	0	5
		Gain at 12–24 in. depth as a percentage of the gain for the whole profile							
		33	12	7	−21	37	33	13	16

ments the 9–12 in. depth of soil was enriched with P probably because ploughing was occasionally below 9 in. deep. Movement of P below 12 in. was much the same with both FYM and vegetable compost. It was much less with sewage sludge and sludge compost but with these manures the amount of movement was about the same. Composting green material with FYM had not decreased the risk of movement of P and conversely composting straw with sewage sludge had not increased the solubility of the P in the sludge. When the gain for the 12–24 in. depth was expressed as a percentage of

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TABLE 14

Extra exchangeable K in soils of the Woburn Market Garden experiment as compared with soils receiving fertilisers only

K, mg/kg, in air dry soil

Depth, in.	Fertiliser only plots	Organic manures applied at: single dressing FYM	single dressing vegetable compost	single dressing sewage sludge	single dressing sludge compost	double dressing FYM	double dressing vegetable compost	double dressing sewage sludge	double dressing sludge compost
		Gain in soluble K over fertiliser only plots							
0–9	111	163	144	−18	0	266	205	−9	6
9–12	101	169	137	−18	0	265	213	−13	5
12–18	93	174	134	−13	1	268	206	−9	10
18–24	83	143	91	−15	−4	226	186	−16	9
	Gain at 12–24 in. depth as a percentage of the gain for the whole profile								
		49	45	−44	—	48	48	−53	63

the gain for the whole profile then for FYM there was little difference in the proportion of the P which had moved according to the amounts applied. For the other three treatments more P moved down the profile where more was applied.

Table 14 shows that in 1961 where sludge and sludge compost were used there was in many cases a depletion of soil K at all depths compared to soil of plots receiving only fertilisers; only where sludge compost was applied at the double dressing did a small amount of K move down into the subsoil. This contrasts with the FYM and vegetable compost plots where residual K in the surface soil leached down to enrich all depths of soil to 24 in., the maximum depth sampled. It should be noted that there was much movement of K out of the plough layer where the single dressing of FYM and both dressings of vegetable compost were applied even though the soil at each depth sampled under these treatments contained less K than where FYM was applied at the double

TABLE 15

Total and soluble P and exchangeable K in the surface and sub-soils of selected treatments in 1960 and 1974, Market Garden experiment, Woburn

P and K, mg/kg, in air dry soil

Treatment	Depth sampled in.	P: Total[1] 1960	P: Total[1] 1974	P: Bicarbonate soluble 1960	P: Bicarbonate soluble 1974	Exchangeable K 1960	Exchangeable K 1974
Fertilisers only[2]	0–9	1170	1610	94	162	109	196
	9–12	n.s.	1062	n.s.	112	n.s.	138
	12–18	900	906	73	101	120	137
	18–24	840	804	77	89	100	100
	24–27	n.s.	738	n.s.	78	n.s.	78
FYM,[2] double dressing	0–9	1830	1844	176	179	383	296
	9–12	n.s.	1260	n.s.	157	n.s.	216
	12–18	1010	1302	114	149	385	206
	18–24	910	1020	109	114	320	199
	24–27	n.s.	802	n.s.	82	n.s.	227

n.s.—not sampled

[1] Total P, 1960 results given in Table 10 are here increased by 50 mg/kg to make them comparable with the 1974 results. See footnote to Table 10 for explanation

[2] FYM not applied after 1967. Fertiliser dressings of P and K were the same to FYM and fertiliser plots 1968–73

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dressing. This suggests that leaching occurs readily on this soil and that there is considerable risk of residual K leaching down to depths from which the roots of shallow rooting crops cannot recover it.

To see whether the increased use of fertiliser P and K since 1961 and ceasing FYM dressings in 1967 had affected the distribution of P and K down the profile a small number of plots were sampled to 27 in. in the spring of 1974. Table 15 shows the amounts of total and bicarbonate soluble P and exchangeable K in comparable soils in 1960 and 1974. Increased dressings of P to the fertiliser plots increased total P in the surface soils and there was no indication of downward movement of P. On the FYM plots total P had not increased in the surface soils but there was some indication of further movement of P down into the 12–18 in. depth. Changes in bicarbonate soluble P were much the same as for total P except that there was an increase in soluble P in the 12–18 in. depth on the fertiliser-treated plots. Increased dressings of K on the fertiliser plots increased exchangeable K in the surface 9 in. of these soils and there appears to have been no downward movement of K probably because much of the K applied in this latter period was removed in the crops. In 1974 the FYM plots had less K than in 1960 but more than in 1967. Presumably the small crops grown in the early years of the experiment removed little K, then as yields increased more K was removed decreasing exchangeable K by 1967. Since then increased K dressings have increased exchangeable K in the surface soil but the sub-surface horizons still contain less K than in 1960.

Summary

1. An experiment was made on a loamy sand soil at Woburn from 1942–67 in which four bulky organic manures were tested. They were: farmyard manure (FYM); sewage sludge; a vegetable compost, made by composting green material collected on the farm with FYM; and a compost of sewage sludge and straw. The amounts of fresh manure tested were, on average, 15 and 30 tons/acre each year and it is estimated that at the double dressing the total amounts of organic matter added per acre in the manures during the experiment were: FYM, 110 tons; sewage sludge, 132 tons; vegetable compost, 95 tons; sludge compost, 94 tons. In addition some soils received fertilisers only. This paper gives the effects of these treatments on soil pH, and the carbon, nitrogen, phosphorus and potassium contents of the soil. Some results are also given for soils sampled in 1972, five years after the last organic manures were applied.

2. Although the experiment was on a sloping site there was little variation in the mechanical composition of the soil which contained about 9% clay and 50% coarse sand.

3. Dressings of ground chalk were given in alternate years and soil pH increased slowly during the experiment. None of the treatments had any appreciable effect on pH probably because chalk was applied frequently. The total amount of chalk applied during the experiment was equal to an annual dressing of 10 cwt/acre and it was estimated that of this amount about 8·5 cwt/acre was lost from the surface soil each year.

4. Both the carbon and nitrogen content of soil given fertilisers only increased slightly during the experiment. This was an unexpected result and an explanation is being sought.

5. All the organic manures increased soil carbon and nitrogen whilst dressings were given annually. With FYM the double dressing increased soil carbon twice as much as the single dressing; with the other manures the increase due to the double dressing was less than twice that due to the single dressing. With all manures the increase in soil

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carbon during the first nine years was from two-thirds to three-quarters of the total increase during the first 18 years. Sewage sludge and sludge compost were not applied after 1961, because they were adding large amounts of heavy metals to the soil, and the carbon and nitrogen content of these soils had decreased by 1972. The average annual loss of carbon during 1962–72 was about 75% of the average annual gain during 1942–61.

6. About 30% of the total C added in FYM during the first 18 years of the experiment was retained in the soil. However, most carbon was retained in the soil when added either as vegetable- or sludge-compost, about 40% after annual additions for 18 years. FYM-treated plots continued to get dressings for 25 years; after this period only 25% of the added carbon was retained in the soil. The amounts of N retained from the different manures varied in the same way as the amounts of carbon; 26% of the total N added in FYM during 25 years was retained.

7. Before 1961 annual dressings of inorganic fertiliser P and K were small and whilst there was a small increase in the soluble P content of the soil soluble K decreased on soils given fertilisers only or where sewage sludge and sludge compost were applied. After 1960 fertiliser dressings were increased and both total and soluble P and exchangeable K in the soil increased. There was a good relationship between total P in the soil and total P added either as fertiliser or in organic manure. However, more of the added P had remained bicarbonate-soluble in soils treated with FYM or vegetable compost than in soils given sewage sludge or sludge compost. Of the extra total P in the FYM- and vegetable compost-treated soils 12–14% was bicarbonate-soluble whilst on the sewage sludge- and sludge compost-treated soils only 3–4% was bicarbonate-soluble.

8. The relationship between P soluble in 0·5M-$NaHCO_3$ and in 0·5N-NH_4Ac : 0·5N-HAc is discussed as are those between exchangeable K and K soluble both in 0·3N-HCl and 0·5N-NH_4Ac : 0·5N-HAc.

9. Where much K had been given in FYM and vegetable compost much had been leached from the surface 9 in. of soil and all the soil to 24 in. had about the same amount of exchangeable K. P also had been leached into the subsoils where FYM had been given but this was due not only to the amount of P added but to the fact that it was added in FYM. Much larger amounts of P were added to soils treated with sewage sludge but none of this P had leached below plough depth.

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References

BOLTON, J. (1971) Long-term liming experiments at Rothamsted and Woburn. *Rothamsted Experimental Station. Report for 1970*, Part 2, 98–112.

COOKE, G. W. (1972) *Fertilising for maximum yield.* London: Crosby Lockwood & Son Ltd., 296 pp.

CHATER, M. & GASSER, J. K. R. (1970) Effects of green manuring, farmyard manure and straw on the organic matter of soil, and of green manuring on available nitrogen. *Journal of Soil Science* **21**, 127–137.

CROWTHER, E. M. (1936) The soils of the Woburn Plots. In: *Fifty years of field experiments at the Woburn Experimental Station.* Ed. E. J. Russell and J. A. Voelcker. London: Longmans, Green and Co., Chap. XXII, pp. 315–345.

GASSER, J. K. R. (1973) An assessment of the importance of some factors causing losses of lime from agricultural soils. *Experimental Husbandry* **25**, 86–95.

HANSON, W. C. (1950) The photometric determination of phosphorus in fertilisers using the phospho-vanado–molybdate complex. *Journal of the Science of Food and Agriculture* 1, 172–173.

JOHNSTON, A. E. (1969) The plant nutrients in crops grown on Broadbalk. *Rothamsted Experimental Station. Report for 1968*, Part 2, 50–62.

JOHNSTON, A. E. & ADDISCOTT, T. M. (1971) Potassium in soils under different cropping systems. I. Behaviour of K remaining in soils from classical and rotation experiments at Rothamsted and Woburn and evaluation of methods of measuring soil potassium. *Journal of Agricultural Science, Cambridge* **76**, 539–552.

JOHNSTON, A. E. & CHATER, M. (1975) Experiments made on Stackyard Field, Woburn, 1876–1974. II. Effects of treatments on soil pH, P and K in the Continuous Wheat and Barley experiments. *Rothamsted Experimental Station. Report for 1974*, Part 2, 45–60.

MANN, H. H. & BARNES, T. W. (1957) The permanence of organic matter added to soil. *Journal of Agricultural Science, Cambridge* **48**, 160–163.

MANN, H. H. & PATTERSON, H. D. (1963) The Woburn Market Garden experiment: Summary 1944–60. *Rothamsted Experimental Station. Report for 1962*, 186–193.

MATTINGLY, G. E. G. (1970) Total phosphorus contents of soils by perchloric acid digestion and sodium carbonate fusion. *Journal of Agricultural Science, Cambridge* **74**, 79–82.

MATTINGLY, G. E. G., CHATER, M. & POULTON, P. R. (1974) The Woburn Organic Manuring experiment. II. Soil analysis, 1964–72, with special reference to changes in carbon and nitrogen. *Rothamsted Experimental Station. Report for 1973*, Part 2, 134–147.

MATTINGLY, G. E. G., JOHNSTON, A. E. & CHATER, M. (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, 91–112.

MORGAN, M. F. (1937) The Universal Soil Testing System. *Connecticut Agricultural Experiment Station. Bulletin No. 392*, 129–159.

OLSEN, S. R., COLE, C. V., WATANABE, F. S. & DEAN, L. A. (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *United States Department of Agriculture. Circular No. 939*, 19 pp.

SALT, P. D. (1968) The automatic determination of phosphorus in extracts of soils made with 0·5M-sodium hydrogen carbonate and 0·01M-calcium chloride. *Chemistry and Industry*, 584–586.

WALKLEY, A. (1947) A critical examination of a rapid method for determining organic carbon in soils—effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science* **63**, 251–264.

WARREN, R. G. & JOHNSTON, A. E. (1961) Soil organic matter and organic manures: farmyard manure. *Rothamsted Experimental Station. Report for 1960*, 45–48.

WARREN, R. G. & JOHNSTON, A. E. (1962) The accumulation and loss of soil potassium in long-term experiments, Rothamsted and Woburn. *Proceedings of the Fertiliser Society*, No. 72, 5–24.

WILLIAMS, R. J. B. (1974) The influence of soil type and manuring on measurements of physical properties and nutrient status of some British soils. In: *Soil Physical Conditions and Crop Production. Ministry of Agriculture, Fisheries and Food, Technical Bulletin* No. 29, 324–343.

APPENDIX

Soil pH was measured in a soil water suspension (ratio soil : water, 1 : 2·5) using a glass electrode.

Total carbon was measured on soil ground <0·5 mm by the method described by Walkley (1947); no phosphoric acid was added before titrating and *N*-phenylanthranilic acid was used as indicator. The percentage carbon was multiplied by a factor of 1·3 which, for Woburn soils, increases %C to values almost the same as those obtained by dry combustion.

Soil organic matter was calculated from the corrected %C values by multiplying by the factor 1·72.

Total N by Kjeldahl digestion using a Cu–Se caaltyst. Ammonia in the digests was estimated by distillation.

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Total P. Solutions were prepared either by perchloric acid digestion of the soil or sodium carbonate fusion as described by Mattingly (1970). P in the perchloric acid digest was estimated colorimetrically as the vanado–molybdate complex (Hanson, 1950). After sodium carbonate fusion P was estimated on the 'Technicon AutoAnalyzer' using the method described by Salt (1968).

Sodium bicarbonate-soluble P was determined by the method of Olsen *et al.* (1954). Soil (5 g) was shaken with 100 ml of 0·5M-$NaHCO_3$ at pH 8·5 for 30 min at 25°C. P was measured colorimetrically as a molybdenum-blue complex.

P soluble in 0·5N-ammonium acetate : 0·5N-acetic acid. In this modification of Morgan's (1937) method 0·5N-sodium acetate in the original reagent was replaced with 0·5N-ammonium acetate. Ten grammes of soil were shaken with 50 ml reagent for 30 min. P was measured colorimetrically as a molybdenum-blue complex.

P soluble in 0·3N-HCl. Soil (8 g) was shaken with 20 ml of 0·3N-HCl for 1 min. P was measured colorimetrically as a molybdenum-blue complex.

Exchangeable K. Soil (6·25 g) was successively leached with N-ammonium acetate until 250 ml of leachate had been collected. K in the leachate was determined by flame photometry.

K soluble in the Morgan's reagent and 0·3N-HCl was determined by flame photometry.

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APPENDIX TABLE 1

Mechanical analysis[1] *of the fine soil (<2 mm), Market Garden experiment, Woburn*

Plot	Coarse sand 2000–200 μm (% in oven-dry soil)	Fine sand 200–20 μm (% in oven-dry soil)	Silt 20–2 μm (% in oven-dry soil)	Clay <2 μm (% in oven-dry soil)	Loss on solution	Air-dry moisture
In surface soils 0–9 in. deep						
01	62·1	20·7	3·5	8·9	2·5	1·2
02	56·4	23·3	3·6	9·9	4·6	1·1
03	55·0	23·1	4·6	9·0	5·5	1·6
04	41·4	35·8	4·7	10·4	4·9	1·1
05	65·3	14·0	4·7	9·1	3·7	1·3
06	52·7	25·3	4·7	10·0	4·8	1·2
07	44·4	35·2	4·6	9·3	3·2	1·3
08	56·4	25·4	4·1	10·0	2·6	0·9
09	50·4	30·3	5·1	8·8	4·2	1·2
10	48·1	31·8	5·1	8·7	4·5	1·1
11	70·4	10·3	3·8	9·4	4·2	1·0
12	44·5	34·2	4·4	9·9	5·3	1·5
14	55·2	24·2	4·8	9·9	4·3	1·4
16	50·4	27·7	5·4	9·6	5·5	1·5
18	44·4	34·1	5·3	9·4	5·5	1·4
20	60·9	16·6	5·4	8·7	6·2	1·5
21	47·4	32·7	4·4	9·8	5·0	1·2
23	41·0	37·5	4·7	9·6	6·2	1·2
25	52·0	27·2	4·4	10·2	5·2	1·2
27	49·0	31·2	4·5	9·4	3·6	1·0
29	49·5	30·7	5·1	8·9	6·0	1·2
32	65·0	15·2	4·5	9·4	5·1	1·2
34	40·1	39·4	5·1	9·4	4·0	1·1
36	52·2	26·5	5·2	9·4	5·7	1·3
38	45·3	35·0	4·9	9·7	4·3	1·2
40	44·8	35·4	5·4	8·8	4·7	1·1
42	50·9	27·7	4·6	9·8	5·4	1·5
44	44·7	33·5	4·9	10·0	5·2	1·5
46	45·5	32·6	5·6	9·8	5·9	1·6
48/2	63·9	16·8	5·1	9·0	3·4	1·1
50/1	49·8	31·0	5·3	7·8	4·0	1·2
51/1	45·4	33·3	5·0	9·8	4·2	1·3
53/2	53·8	22·1	4·9	9·0	5·0	1·4
55	47·1	30·7	4·4	10·0	5·0	1·4
57	46·9	31·4	5·2	9·0	5·0	1·3
59/2	52·9	28·1	5·0	8·2	4·1	1·1
62	42·3	35·2	5·3	10·2	5·0	1·5
64	51·3	24·2	5·9	10·2	5·7	1·6
66	44·3	31·4	5·7	10·3	6·0	1·6
68	44·6	32·5	5·7	8·8	5·5	1·4
70	51·4	28·0	5·2	8·9	5·2	1·2
71	46·4	30·1	4·8	9·8	5·4	1·4
72/1	46·3	30·0	4·9	10·1	5·7	1·5
74	50·8	24·4	5·4	10·4	6·1	1·5
76/1	49·7	26·8	5·6	10·1	6·1	1·5
78	48·8	28·4	5·6	9·6	5·1	1·2
80/1	64·6	13·7	7·4	7·6	5·5	1·4
80/2	62·3	16·0	5·4	8·8	5·8	1·3
In subsoils 12–18 in. deep						
3	46·9	37·0	4·1	9·6	2·1	0·8
4	48·1	34·0	4·2	10·1	1·9	0·8
75	48·5	31·9	5·7	9·9	2·3	0·8
77	51·0	30·7	5·3	10·2	2·5	0·9
In subsoils 18–24 in. deep						
3	54·5	32·2	3·2	7·8	1·5	0·8
4	60·3	24·3	3·6	9·1	1·7	0·7
75	68·3	14·9	5·6	9·2	1·7	0·7
77	45·0	36·6	6·3	10·0	2·2	0·8

[1] Mechanical analyses were done by E. Bird, using the International pipette method. Organic matter was removed with H_2O_2 and the soils dispersed with NaOH

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