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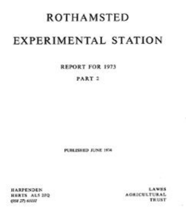

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G. E. G. Mattingly

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The Woburn Organic Manuring Experiment
I. Design, Crop Yields and Nutrient Balance, 1964–72

G. E. G. MATTINGLY

Introduction

Many attempts have been made to improve the fertility of the light soil at Woburn by green manures (Crowther & Mann, 1933; Mann, 1958, 1959; Barnes & Clarke, 1963), by farmyard manure, composts and sewage sludge (Russell, 1936; Mann & Patterson, 1963), by rotations which include leys (Mann & Boyd, 1958; Boyd, 1968) and by the use of peat and soil conditioners (Johnston & Warren, 1965). Cooke (1967) recently reviewed, and discussed critically, all work done in Britain, including the experiments at Woburn, on the value of organic manures and leys in arable farming. He concluded (*loc. cit.*, pp. 459–460) 'It seems more certain than it was ten years ago that most farmers may grow the crops that suit them financially without worrying about humus in their soils, or about running down the fertility of their land. This conclusion depends on farmers using all our modern information on the place of fertilisers in crop production, and on their cultivations being good. In addition, their soil and farming system together must not favour a build-up of soil-borne pests and diseases that may lessen yields to the point where they are not economic. These conclusions are tentative and may not apply to all British soils; more experiments testing leys and organic manures are still needed on soils believed to be "difficult" structurally, and with sensitive crops.'

The experiment described in this paper was started in 1964 to compare, within a single long-term experiment, most of the treatments to increase soil organic matter which have previously been tested in separate experiments at Woburn. Its purpose is to evaluate, from crop yields and soil analyses, the cumulative effects of organic matter on a light, poorly-structured, soil with a long history of arable cropping. Experience in previous experiments at Woburn, particularly during the early years of the Ley–Arable Experiment (Mann & Boyd, 1958) showed the need (i) to minimise the build-up of soil-borne pathogens and nematode infestations by using long rotations and (ii) to avoid differential additions or removals of nutrients, especially potassium.

The Organic Manuring experiment is a logical successor to, and an extension of, the Green Manuring experiment (1936–63), the Ley–Arable experiment, started in 1938 and the Market Garden experiment started in 1941. Major differences from previous experiments were:

(i) The initial sequence of arable crops lasted six to seven years instead of three.
(ii) The leys were established for seven to eight years, instead of three, and were given the same net amounts of P, K and Mg fertilisers as the arable crops.
(iii) Organic manures (peat and straw), applied cumulatively for six years and green manures, grown in four out of seven years, were also compared with control plots (without organic manures) all given the same net amounts of P, K and Mg fertilisers.
(iv) The value of farmyard manure, applied cumulatively for six years to arable crops, was compared with equivalent plots given the same total amounts of P, K and Mg as fertilisers.
(v) The design of the experiment will allow residues of organic matter from previous

treatments to be evaluated by four test crops (instead of two in the Ley–Arable experiment); two test crops will be grown each year.

The experiment is divided into two phases (i) arable cropping (1966–71/2) or continuous leys (1965–71/2) followed by (ii) an arable rotation (potatoes–winter wheat–sugar beet–barley) to evaluate organic matter accumulated during the first phase.

This paper (Part I) describes the design and purpose of the experiment, gives the yields from seven consecutive arable crops and from the leys, and discusses the attempts made to avoid depleting soil nutrients and building up soil-borne diseases. Part II describes changes in the composition of the surface soil (0–23 cm) with particular reference to C and N, and the effects of organic matter on movement and 'fixation' of P, K and Mg, between 1964–72.

Design and site of the experiment

Design. The eight treatments fall into two separate groups, the larger consisting of six treatments each receiving each year the same amounts of P, K and Mg either as fertilisers or as organic manures. The amounts were determined by the P, K and Mg present in barley straw plus supplementary P given as superphosphate. The remaining two treatments compared cumulative annual dressings of farmyard manure with control plots given P, K and Mg as inorganic fertilisers equal to the *total* amounts of these nutrients applied in the farmyard manure. Throughout this paper the two groups of treatments are described as PKMg manuring equivalent to straw plus supplementary P (as superphosphate) and as PKMg manuring equivalent to farmyard manure. The amounts of

TABLE 1

Outline of eight main-plot treatments, 1965–72

Treatment	Symbol	Organic material[a] (tonnes/ha)	Supplementary fertilisers[a] (kg/ha) P	K	Mg	Notes
Fertilisers equivalent to PKMg in straw plus supplementary P						
Grass–clover ley	Lc	(b)	27	104	12	Leys sown 23 April 1965. Leys ploughed up on 28 October 1971 (Blocks I & III) and on 30 November 1972 (Blocks II & IV)
Grass ley with N	Ln	(b)	27	104	12	
Peat	Pt	7·5 (dry matter)	27	104	8	Applied annually in autumn, 1965–70
Straw	St	7·5 (dry matter)	22	none	8	
Green manures	Gm	(c)	27	104	12	Italian ryegrass, 1965. Trefoil undersown in barley, 1966. Red clover undersown in winter wheat, 1968 and winter rye, 1971 and 1972 (Blocks II & IV only)
No organics	Fs	none	27	104	12	
Fertilisers equivalent to PKMg in farmyard manure						
No organics	Fd	none	55	312	30	Applied annually in autumn, 1965–70
Farmyard manure	Dg	50 (fresh weight)	none	none	none	

(a) Actual amounts depended on the analyses of the organic materials (Appendix Table 2)
(b) Amounts ploughed under are in Table 6.
(c) Amounts ploughed under are in Table 3.

PKMg in FYM were between two and three times larger than those in straw plus supplementary P.

Table 1 lists the eight treatments together with the symbols used to distinguish them and the nominal amounts of P, K and Mg and organic matter applied annually from autumn 1965 to autumn 1970. The plots in continuous leys, sown in 1965, were either (i) grass–white clover leys (Lc), receiving no inorganic N or (ii) all-grass leys (Ln) given N as 'Nitro-Chalk' for each cut. The organic manures were sedge peat (Pt); barley straw (St), chaffed, except in 1970; green manures undersown in the cereals (Gm), and farmyard manure (Dg). The plots maintained in continuous arable cultivation at the two levels of PKMg tested (Fs and Fd) received no organic materials except the cereal and bean roots and stubble, the potato haulms and sugar beet tops which were ploughed down in autumn. The amounts of both organic manures and inorganic fertilisers applied each year differed considerably from the nominal amounts shown in Table 1. Appendix Table 1 gives the amounts applied, including the balancing dressings of inorganic fertilisers required to compensate for differential removals of P, K and Mg by the arable crops and leys and the basal PKMg applied each year. Superphosphate (8·7% P), muriate of potash (50% K) and Epsom salts (9·7% Mg) were used throughout the experiment.

The experiment contained four blocks; each of the eight main plots were 30·6 m long by 8·55 m wide and were separated by paths 0·76 m wide. Main plots in the arable rotation were divided into four sub-plots, 15·3 m long by 4·28 m wide. Nitrogen (as 'Nitro-Chalk', 21% N) was applied to the sub-plots at four rates for the first four arable crops in the rotation; no N was given to beans in 1970 and all sub-plots were given the same amounts of N for rye in 1971. The main plots in the ley rotation were not sub-divided, except when the soils were sampled, and in 1971/72, when root weights were measured.

TABLE 2

Cumulative amounts of dry matter, organic matter, N, P, K, Na, Ca and Mg applied in farmyard manure, straw and peat, 1965–70

	tonnes/ha		kg/ha					
Year	Dry matter	Organic matter	N	P	K	Na	Ca	Mg
			Farmyard manure					
1965	9·7	7·6	293	50	446	29	146	32
1966	22·2	14·3	640	300	759	74	499	121
1967	30·1	18·3	826	402	952	98	722	173
1968	41·3	25·3	1128	479	1435	135	927	234
1969	51·9	32·3	1379	542	1903	161	1054	263
1970	61·4	36·2	1582	590	2252	184	1193	293
			Barley straw					
1965	7·1	6·7	41	6	123	5	25	3
1966	14·3	13·4	90	14	213	11	56	8
1967	22·6	21·1	136	20	314	16	87	12
1968	30·3	28·5	187	27	366	29	113	17
1969	37·8	35·7	217	32	453	33	143	20
1970	46·0	43·4	289	37	517	52	173	26
			Sedge peat					
1965	4·8	4·6	48	1	1	2	68	9
1966	8·9	8·5	91	2	2	3	135	20
1967[a]	14·3	13·7	170	3	3	5	224	30
1967[b]	20·9	20·1	232	4	4	8	323	44
1968	27·4	26·3	332	6	5	10	428	62
1969	36·5	34·8	449	7	6	12	562	85
1970	43·9	41·8	534	9	10	14	645	99

(a) Applied in spring; (b) Applied in autumn

Site of experiment. The experiment occupies most of Series B on Stackyard Field, which was cropped from 1930–60 in a six-course rotation of sugar beet, barley, clover, wheat, potatoes and rye (Yates & Patterson, 1958; Rothamsted Experimental Station, 1967). The average amounts of N, P and K applied each year during the 30 years of the experiment were 37·7, 16·5 and 52·1 kg/ha respectively. The manurial treatments in the six-course rotation experiment were not cumulative and every plot received each of the 15 treatment-combinations in 15 years so that the nutrient status of the soils in 1964 was very uniform. Soil analyses, which show variations between blocks, are in Part II of this paper.

Manurial treatments, 1965–71

Organic manures. Moisture contents of the peat and chaffed straw were measured before these manures were used and fresh weights, calculated to be about 7·5 tonnes dry matter/ha were applied before ploughing in autumn. Fresh farmyard manure was applied at 50 tonnes/ha in 1965, 1966, 1968 and 1969 and at 25 tonnes/ha in 1967 and 1970, the total amounts being about 250 tonnes/ha in six years.

Table 2 gives the cumulative amounts of dry matter, organic matter, N, P, K, Na, Ca and Mg applied in farmyard manure, straw and peat between 1965–70. Appendix Table 2 gives the chemical analyses of the farmyard manure, straw and peat.

Green manures

Italian ryegrass. The first green manure crop (Hybrid Italian ryegrass) was sown on 7 May 1964. The remaining plots of the experiment, except the leys, were fallowed. Perennial weeds, grasses and *Equisetum* sp. infested all plots and the site was rotary cultivated in July and fallowed during the summer. Hybrid Italian ryegrass (34 kg/ha) was re-sown on 23 April 1965. In both 1964 and 1965 the green manure plots received 63 kg N/ha, 27 kg P/ha and 52 kg K/ha in the seedbed before sowing. The ryegrass was ploughed in on 7 September 1965. The weights of crop were not recorded.

Trefoil. Trefoil was undersown on 2 November 1965 in winter wheat which was severely damaged by wheat bulb fly (*Leptohylemyia coarctata* Fall.). The crop was killed with paraquat on 28 April 1966 and trefoil was undersown in barley on 30 April. Samples of tops and roots were dug from one area, 0·84 m², from each sub-plot on 27 September, washed free from soil and weighed. Barley stubble and trefoil were ploughed in on 30 November and 1 December.

Red clover. Late-flowering red clover was undersown in winter wheat on 29 March 1968, sampled in the same way as the trefoil on 23 October and the wheat stubble and

TABLE 3

Amounts of dry matter (tonnes/ha) and nitrogen (kg N/ha) ploughed in as green manures in 1966, 1968 and 1971

1966			1968			1971			Total in 3 crops	
	Trefoil			Red clover			Red clover			
N to barley (kg/ha)	Total DM	Total N	N to winter wheat (kg/ha)	Total DM	Total N	N to winter rye (kg/ha)	Total DM	Total N	Total DM	Total N
0	3·57	88·4	25	1·93	64·8	31	1·43	37·9	6·93	191
25	3·49	87·0	75	1·27	44·3	31	1·54	38·9	6·30	170
50	3·83	85·4	125	1·17	40·2	31	1·31	32·3	6·31	158
75	2·86	67·5	175	0·60	21·7	31	1·29	33·0	4·75	122
Mean	3·44	82·1		1·24	42·8		1·39	35·5	6·07	160

clover ploughed in on 29 November. The same variety was undersown in winter rye on 22 April 1971, sampled on 15 September and ploughed in on 28 October.

Table 3 gives total amounts of dry matter in tops and roots of trefoil (1966) and red clover (1968 and 1971) and the total N contained in the crops. Total weights of trefoil and red clover decreased slightly as the amounts of N applied to barley and winter wheat increased. Uniform N was given to rye in 1971 and the weights of clover were almost independent of the amounts of N given two years earlier to sugar beet. Mean amounts of dry matter and N added to soil in the three legume crops were 6·1 tonnes/ha and 160 kg N/ha respectively.

Leys with nitrogen or white clover. The leys were sown in May 1964 but, due to weed infestation, both were resown (like the green manure crop) on 23 April 1965. In 1964 and 1965 the ley plots were given 27 kg P/ha and 52 kg K/ha in the seedbed, together with 63 kg N/ha to the plots growing grass leys with inorganic N. The seed mixtures used and amounts sown are in Table 4.

TABLE 4

Seed mixtures used for leys with clover and leys with nitrogen

Species	Amount sown (kg/ha) Leys with clover	Leys with nitrogen
Timothy S48	7	10
Meadow fescue S215	12	15
Smooth-stalked meadow grass	5	7
Kersey white clover	4	—
Wild white clover	1	—
Total	29	32

Both leys established well and persisted for seven years before they were ploughed up on 28 October 1971 (Blocks I and III) and on 30 November 1972 (Blocks II and IV). The grass was cut between one and four times a year and removed from the plots. No bare patches developed, all species survived and the drought-resistant smooth-stalked meadow grass (*Poa pratensis*) was prominent when the leys were sampled in 1971. Nitrogen was given to the grass ley (Ln) each spring and after each cut, except the last. From 1965–69 the amount of each dressing was restricted to 63 kg N/ha in order to limit growth and prolong the life of the ley. More nitrogen, 126 kg N/ha, was given in 1970–71 to increase the N content of the grass and avoid ploughing in N-deficient material before the sequence of arable test crops started.

The leys were grown in the 'build-up' phase of this experiment entirely to provide soils containing known amounts of organic matter and nitrogen. Table 5 gives the total dry matter produced and the amounts of N and other nutrients removed between 1965–71. In all years except 1965, the ley given inorganic N produced more dry matter than the clover ley. Differences between the yields of the two leys were largest in 1970 and 1971 when N rates were doubled. Between 1965–71, average yields of the clover and grass leys were 4·3 and 6·6 tonnes/ha respectively. From 1965–68 more N was removed from the clover ley (Lc) than from the grass ley (Ln) but 199 kg/ha more N was removed from the grass than from the clover ley in the harvests of 1970–71. The mean amounts of N removed each year between 1965–71 were 99 and 106 kg N/ha from the clover and grass leys respectively.

In most years, and particularly 1966 and 1971, much more K was removed by leys than by arable crops. Balancing dressings, calculated from crop yields and analyses were given, partly in autumn and partly in spring (Appendix Table 1), to compensate for the

TABLE 5

Total dry matter produced and nutrients removed by leys with clover(Lc) and leys with nitrogen (Ln), 1965–71

Year	Ley	Number of cuts	Total dry matter (tonnes/ha)	Nutrients removed (kg/ha) N	P	K	Na	Ca	Mg
1965	Lc	2	3·98	103	14·0	131	4·3	61	7·0
	Ln	2	3·34	65	11·4	118	2·1	25	5·2
1966	Lc	4	6·74	193	20·3	145	5·1	91	11·6
	Ln	3	9·65	140	21·3	196	2·4	50	13·0
1967	Lc	2	4·51	98	15·3	122	1·8	36	7·0
	Ln	1	5·28	64	14·9	125	0·3	19	5·6
1968	Lc	2	4·97	116	15·8	137	1·2	35	9·1
	Ln	2	6·53	85	16·3	129	0·7	26	8·5
1969	Lc	2	3·78	55	9·3	98	0·8	20	4·1
	Ln	2	5·58	63	13·0	138	0·5	22	5·7
1970	Lc	2	0·96	21	2·1	20	0·2	10	1·3
	Ln	2	4·73	117	11·1	118	0·8	28	7·1
1971	Lc	2	4·28	105	14·5	145	1·4	39	7·0
	Ln	2	10·91	208	35·0	355	1·9	55	13·4
Total	Lc	16	29·22	691	91·3	798	14·8	292	47·1
	Ln	14	46·02	742	123·0	1179	8·7	225	58·5

Note: N applied at 63 kg N/ha (1965–69) and 126 kg N/ha (1970–71) to grass leys with nitrogen (Ln) in spring and before all cuts except the last.

extra P, K and Mg removed by the leys. More Na and Ca were removed by the clover ley than by the grass ley. Differences between uptakes from the two leys were largest between 1965–68 when the clover ley removed about twice as much Na and Ca as the grass ley. Over one-half of the Na taken up by both leys between 1965–71 was removed in the first two years. No attempt was made to balance the removals of Na and Ca by the leys or arable crops.

Total weights of dry matter (stems plus roots) in the top 10 cm of the leys were measured, after the last cut and before they were ploughed, in October 1971 and 1972. The weights

TABLE 6

Total grass, clover and nitrogen in leys ploughed up in 1971 and 1972

(Means of 8 sampling units/plot)

	Leys with clover (Lc) Blocks I & III (1971)	Blocks II & IV (1972)	Mean	Leys with nitrogen (Ln) Blocks I & III (1971)	Blocks II & IV (1972)	Mean
Grass, dry matter (tonnes/ha)	0·93	1·11	1·02	1·15	3·50	2·32
Clover, dry matter (tonnes/ha)	0·34	0·34	0·34	0	0	0
% clover in sward	26·9	29·8	28·4	0	0	0
Total roots, ash-free (tonnes/ha)	7·94	7·60	7·77	7·10	7·00	7·05
N in grass (kg N/ha)	14·3	17·4	15·8	23·9	58·0	40·9
N in clover (kg N/ha)	11·8	10·0	10·9	0	0	0
N in roots (kg N/ha)	126·1	135·0	130·6	129·3	126·6	128·0
Total, tops and roots (kg N/ha)	152·2	162·4	157·3	153·2	184·6	168·9

were obtained by removing a block of soil, 20 cm × 20 cm × 10 cm deep; stems of grass and clover were cut at ground level and dried, weighed and analysed separately. The crowns and roots were separated from the soil by sieving and washing and their organic matter contents measured. Table 6 gives the total amounts of grass, clover and nitrogen in the leys ploughed up in 1971 and 1972 before the start of the 'testing' phase of the experiment. The proportions of clover in the sward, based on the dry weights of the crops, were almost the same (27–30%) in all blocks of the experiment. Total roots from the clover ley were slightly more than from the grass ley. The mean amounts of N in tops and roots before ploughing were 157 and 169 kg N/ha for the clover and grass leys respectively.

Yields of arable crops and effects of nitrogen, 1966–72

The sequence of crops in this phase of the experiment was chosen to avoid those which, if grown frequently, could act as host plants for soil-borne pathogens and therefore increase the incidence of either fungal diseases or nematode infestation in the second phase of the experiment. The cropping sequence (Table 7) also ensured that little N was needed in the fifth and sixth years of the experiment, when beans and rye were grown. This allowed the residual value of N given during the first four years to be measured and avoided the accumulation of residues of inorganic N in the last two years of the 'build-up' phase of the experiment.

TABLE 7

Summary of arable cropping and spring manuring, 1966–72[a]

Year	Crop	Spring manuring,[b] kg/ha N	P	K	Mg	Date sown	Date harvested	Notes
1966	Barley (Maris Badger)	0, 25, 50, 75	none	none	none	28 Apr. 1966	9 Sept. 1966	PKMg applied in autumn for winter wheat (failed)
1967	Potatoes (Majestic)	25, 75, 125, 175	55	104	15	5–7 Apr. 1967	12–13 Sept. 1967	Basal manuring adjusted to allow for variations in autumn dressings
1968	Winter wheat (Cappelle)	25, 75, 125, 175	none	none	none	25 Oct. 1967	23 Aug. 1968	
1969	Sugar beet (Klein E)	25, 75, 125, 175	55	104	none	11 Apr. 1969	29–30 Oct. 1969	Site limed with 4·8 tonnes/ha ground chalk on 10–14 February 1969
1970	Beans (Maris Bead)	none	55	104	none	20 Mar. 1970	1 Sept. 1970	PK combine-drilled as fertiliser containing 6·1% P and 23·2% K
1971	Winter rye (King II)	31	none	none	none	17 Oct. 1970	31 Aug. 1971	
1972	Winter rye (King II) (Blocks II & IV only)	40	25	100	25	23 Oct. 1971	29 Aug. 1972	PK broadcsat as fertiliser containing 6·1% P and 23·2% K

(a) Full details of cultivations, herbicides, insecticides are in Rothamsted Experimental Station: Numerical results of the field experiments. Woburn Organic Manuring 66/C/31; 67/C/23; 68/C/18; 69/W/RN/12; 70/W/RN/12; 71/W/RN/12; 72/W/RN/12.
(b) In addition to autumn applications

Winter wheat, the first crop in the proposed rotation, failed and was replaced by barley in spring 1966, which was followed by potatoes (1967), winter wheat (1968), sugar beet (1969), beans (1970) and winter rye, 1971 (all blocks) and 1972 (Blocks II and IV only). Table 7 gives the varieties grown and summarises the spring manuring from 1966–72. Nitrogen was applied at four rates to the first four crops in the rotation to measure the immediate effects of N in each of the four years. The amounts applied to each sub-plot varied from year to year to avoid differential accumulations of N throughout this stage of the experiment. The experiment was also designed to estimate residual effects of N for potatoes, winter wheat and sugar beet but boron deficiency developed in 1969 on

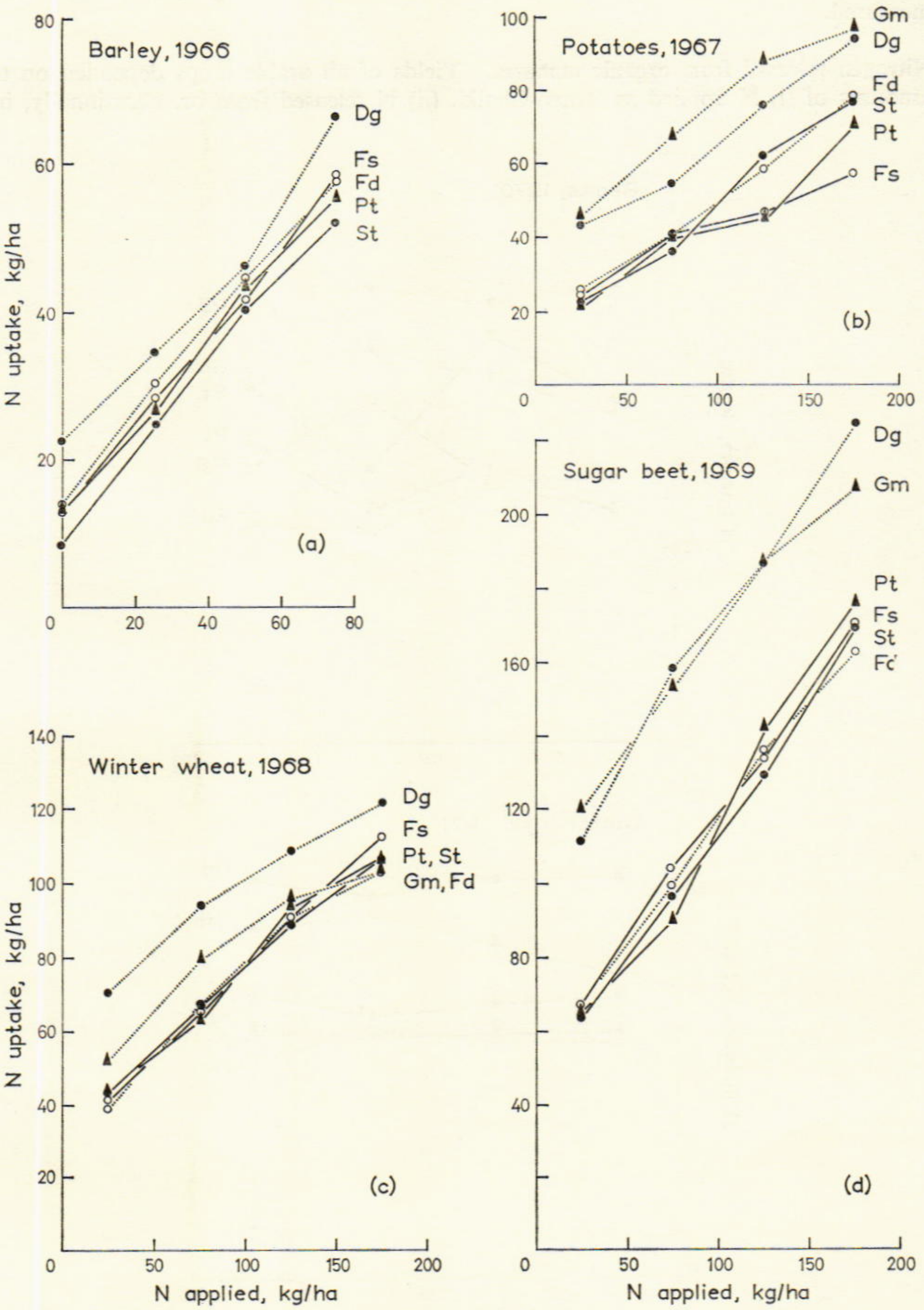

FIG. 1. Relationships between nitrogen uptakes by (a) barley (grain + straw), (b) potatoes (total tubers), (c) winter wheat (grain + straw) and (d) sugar beet (tops + roots) and N applied as 'Nitro-Chalk' in the presence of peat (Pt), straw (St), green manures (Gm), farmyard manure (Dg) or fertilisers equivalent to PKMg in straw + supplementary P (Fs) or to farmyard manure (Fd). N uptakes by barley grown with green manures (Gm) are omitted because the straw was contaminated by trefoil.

parts of the sugar beet crop and the residual values of N for sugar beet could not be measured.

Nitrogen released from organic manures. Yields of all arable crops depended on the amounts of (i) N applied as 'Nitro-Chalk', (ii) N released from or, occasionally, im-

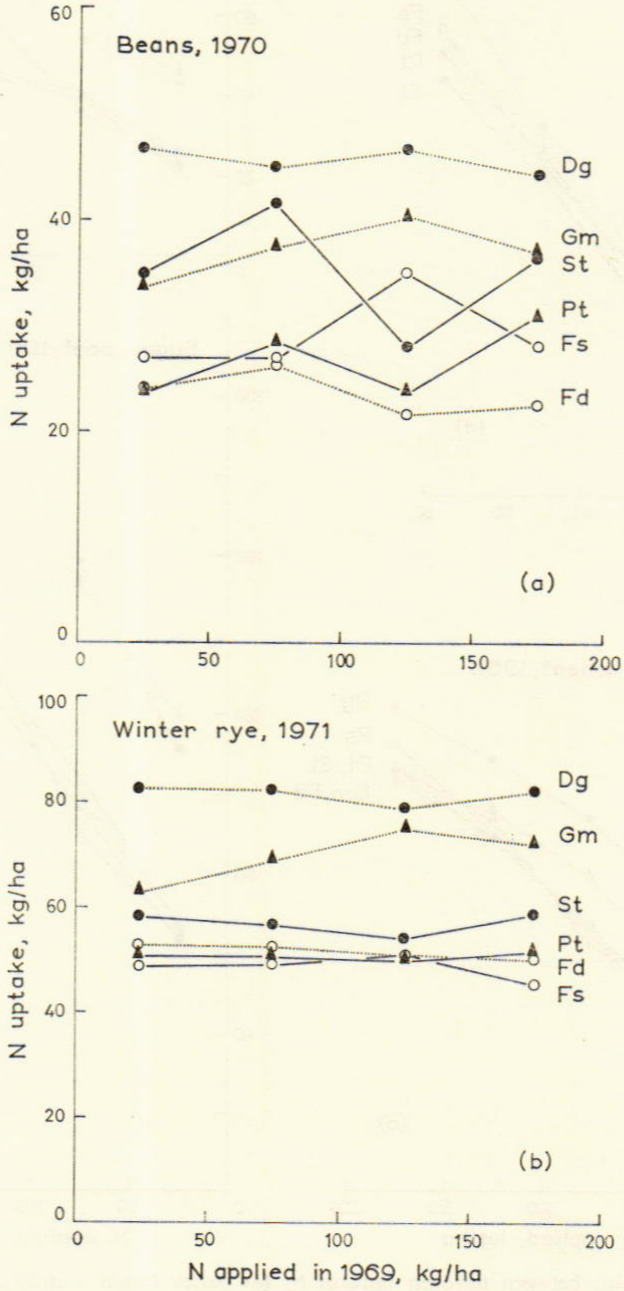

FIG. 2. Relationships between nitrogen uptakes by (a) beans (grain + straw) and (b) winter rye (grain + straw) and N applied as 'Nitro-Chalk' to sugar beet in 1969 in the presence of Pt, St, Gm, Dg, Fs and Fd (for key to symbols, see Fig. 1).

mobilised by the organic manures and (iii) P, K and Mg applied in organic manures or fertilisers. It is impossible, however, to assess benefits from the organic manures unless some estimate is also made of the N they release and all yields of crops between 1966–69 are discussed in relation to the 'adjusted N' supply. These 'adjustments' were made by estimating, from linear regressions of the total N uptake by the crops against N applied, the amounts of N removed from soils to which no N was given (Fig. 1). The extra N removed from soils given organic or green manures was then calculated from differences between uptakes from Pt, St and Gm *minus* Fs and uptakes from Dg *minus* Fd (Table 8). 'Adjustments' for beans in 1970 were calculated from differences between total N uptakes (no inorganic N was given) and those for rye in 1971 from differences between N uptakes from soils with and without organic or green manures, all given a uniform dressing of 31 kg N/ha (Fig. 2).

TABLE 8

Nitrogen removed from soils given only fertilisers and extra nitrogen removed from soils given organic manures, 1966–71

(All results in kg N/ha)

		N removed from soils given fertilisers[a]		Extra N removed from soils given organic manures[b]			
Crop	Year	Fertilisers equivalent to straw + P	Fertilisers equivalent to FYM	Peat	Straw	Green manures	Farmyard manure
Barley	1966	13·0	14·5	0·1	−3·8	10·0[c]	6·5
Potatoes	1967	19·6	16·5	−5·9	−7·7	21·2	16·0
Winter wheat	1968	29·6	31·7	2·9	4·3	18·8	33·9
Sugar beet	1969	48·7	50·0	−7·3	−4·0	59·8	47·6
Beans	1970	29·1	23·5	−2·3	6·0	8·1	22·3
Winter rye	1971	49·0[d]	51·8[d]	2·4	7·9	21·0	29·8
Total	1966–71	189·0	188·0	−10·1	2·7	138·9	156·1

(a) Values by extrapolation (see Figs 1 and 2)
(b) Differences between values for Pt, St and Gm *minus* Fs and Dg *minus* Fd
(c) Interpolated value because barley straw was contaminated with trefoil
(d) Includes N recovered from a uniform application (31 kg N/ha) of 'Nitro-Chalk'

Peat and straw released or immobilised negligible amounts of N but green manures released N to all crops, the largest amount being 59·8 kg N/ha to sugar beet in 1969. Three green manure crops were grown between 1965–68 and they contained 122–191 kg N/ha (Table 3), together with N in ryegrass grown in 1965, which was not measured. Total N recovered by arable crops from green manures grown between 1966–71 was 139 kg N/ha (Table 8). The total amounts of N recovered from cumulative dressings of FYM between 1966–68 and 1969–71 were 56 and 100 kg N/ha respectively and totalled about 10% of the N in FYM applied between 1966–71.

Effects of organic manures on the recovery of N from 'Nitro-Chalk'. Table 9 gives the apparent recoveries of N, applied as 'Nitro-Chalk', (i) in the years of application and (ii) in subsequent years. These recoveries were estimated from the mean uptakes from the three largest amounts of N tested (given in Table 7) *minus* uptakes from the smallest amount of N tested, i.e. $\frac{1}{3}(N_2 + N_3 + N_4) - N_1$. Apparent recoveries of N were measured from uptakes by barley, potatoes, winter wheat and sugar beet in the years 'Nitro-Chalk' was applied (1966–69). Apparent recoveries of residues of 'Nitro-Chalk', applied in 1966 and 1967, were measured from N uptakes by potatoes (1967) and winter wheat (1968). Beans (1970) and winter rye (1971) measured residues of the nitrogen given to sugar beet in 1969.

The first four arable crops (1966–69) removed 155–179 kg N/ha, about 44–51% of

TABLE 9

Apparent recoveries of nitrogen,[a] applied as 'Nitro-Chalk', in the years of application and in subsequent years, 1966–71

Crop	Year: Crop grown	Year: N applied	Amounts of N[b] (kg N/ha)	PKMg equivalent to straw + P: Peat	Straw	Green manures	Fertiliers only	PKMg equivalent to FYM: Fertilisers only	FYM	S.E.
				Recoveries of N in the years of application, kg/ha						
Barley	1966	1966	50	29	31	14[c]	30	31	27	±2·6
Potatoes	1967	1967	100	31	36	38	23	32	31	±5·3
Winter wheat	1968	1968	100	45	44	41	49	48	37	±3·9
Sugar beet	1969	1969	100	71	68	62	72	67	78	±11·6
				Recoveries of N in subsequent years, kg/ha						
Potatoes	1967	1966	50	−7	0	7	−5	−2	−3	±5·2
Winter wheat	1968	1967	100	2	3	18	8	7	10	±3·9
Beans	1970	1969	100	4	1	5	3	0	−1	±4·2
Winter rye	1971	1969	100	0	−2	9	−1	0	−1	±2·4
				Total N recoveries, kg/ha						
In the years of application				176	179	155	174	178	173	—
In subsequent years				−1	2	39	5	5	5	—
Total			350	175	181	194	179	183	178	—

(a) Total N in grain + straw (barley, winter wheat, beans and rye); tops + roots (sugar beet); tubers (potatoes)
(b) Apparent recoveries were calculated from $\frac{1}{3}(N_2 + N_3 + N_4)$ *minus* N_1 (for N rates, see Table 7)
(c) Calculated using an interpolated value (23·0 kg N/ha) for N_1, because barley straw was contaminated with trefoil.

the total applied. Cumulative dressings of peat, straw or farmyard manure did not affect the recovery of N from 'Nitro-Chalk' but green manures (in 1966 and 1968) decreased the apparent recovery of N by about 20 kg N/ha. Potatoes (in 1967) recovered negligible amounts of N given to the preceding barley crop. Winter wheat (in 1968), however, recovered 2–18% of the N given to potatoes in 1967 and the largest recovery (18 kg N/ha), on plots growing green manures in 1966 and 1968, increased wheat yields by 0·58 ± 0·318 tonnes/ha. Beans (in 1970) and winter rye (in 1971) recovered insignificant amounts of N from 'Nitro-Chalk' given to sugar beet in 1969, partly because sugar beet removed 62–78% of the nitrogen applied to it. Green manures increased the recoveries of nitrogen from residues of 'Nitro-Chalk' in all four years in which they were measured. Between 1966–71 green manures released about 140 kg N/ha to the soil (Table 8), decreased the recovery of N from 'Nitro-Chalk' by about 20 kg N/ha in the years it was applied and increased the recovery of N from 'Nitro-Chalk' by about 40 kg N/ha in subsequent years (Table 9).

Yields of arable crops from 'adjusted' N dressings. Yields of barley grain, potato tubers, wheat grain and sugar are given in Figs 3a–d in relation to the inorganic N applied to Fs and Fd plots and to the 'adjusted' N supply from green manures and farmyard manure. ('Adjustments' for straw and peat (Table 8) were too small to show graphically.) Appendix Tables 3 to 9 give grain yields of cereals and beans, total tubers of potatoes and roots of sugar beet and total dry matter of each crop harvested. Table 10 summarises yields of all the arable crops (1966–72) grown at the highest rate of N tested. Some relationships between cumulative dry matter production and cumulative N supply between 1966–71 are discussed later (pp. 118–120).

TABLE 10

Yields of arable crops, 1966–72, at the highest rate of nitrogen tested

(All results in tonnes/ha)

Year	Crop	N applied (kg/ha)	PKMg equivalent to straw + P: Peat	Straw	Green manures	Fertilisers only	PKMg equivalent to FYM: Fertilisers only	FYM	Mean	S.E.
1966	Barley (grain at 85% DM)	75	3·93	3·50	3·49	4·13	3·93	4·46	3·91	±0·133
1967	Potatoes (total tubers)	175	19·7	22·4	27·8	17·5	24·2	26·2	23·0	±1·96
1968	Winter wheat (grain at 85% DM)	175	4·71	4·80	4·46	4·82	4·62	4·47	4·65	±0·205
1969	Sugar beet (sugar)	175	7·40	7·02	6·75	6·60	6·57	7·94	7·05	±0·448
1970	Beans (grain at 85% DM)	0	0·80	0·96	0·90	0·71	0·55	1·11	0·84	±0·105
1971	Rye (grain at 85% DM)	31	3·58	3·76	3·44	3·03	3·32	4·63	3·63	±0·158
1972	Rye (grain at 85% DM)	40	2·83	3·18	3·73	2·70	2·54	3·71	3·12	±0·192

Barley 1966. Grain yields (Appendix Table 3) ranged widely (from 0·51–4·46 tonnes/ha) and nitrogen consistently increased yields. The largest amounts tested (75 kg N/ha) were insufficient for maximum yields both in the presence and absence of organic manures (Fig. 3a). Yields were independent of the amounts of PKMg fertilisers tested. Peat did not affect yields but both straw and green manures lessened grain yields, probably for different reasons. Straw immobilised some nitrogen (about 4 kg N/ha) which partly accounts for the smaller yields it produced. Although the green manures released about 10 kg N/ha to the crop (Table 8), barley appeared to suffer from competition with the trefoil which grew very vigorously and, unlike other green manuring experiments at Woburn (Barnes & Clarke, 1963; Dyke, 1973), trefoil depressed mean barley yields by 0·40 ± 0·126 tonnes/ha (Appendix Table 3). Farmyard manure produced larger yields than equivalent amounts of PKMg fertilisers but they were wholly accounted for by the extra nitrogen it released (Fig. 3a). Barley derived no benefits from organic manures, other than from nitrogen released from FYM.

Potatoes 1967. Potatoes grew poorly during a dry summer and tuber yields ranged from 9·1–27·8 tonnes/ha (Appendix Table 4). Yields increased almost linearly with the amounts of N applied (Fig. 3b) and the largest amounts tested (175 kg N/ha) were insufficient for maximum yields. The larger amounts of PKMg fertilisers gave larger yields than the smaller PKMg dressings, particularly when 125–175 kg N/ha were applied.

N applied (kg N/ha)	tonnes/ha: Tuber yields with PKMg manuring equivalent to straw + P	Extra yield from PKMg manuring equivalent to FYM	S.E. of increase in yield
25	9·2	+2·0	±2·77
75	12·6	+2·1	
125	15·2	+5·5	
175	17·5	+6·7	
Mean	13·6	+4·1	±2·38

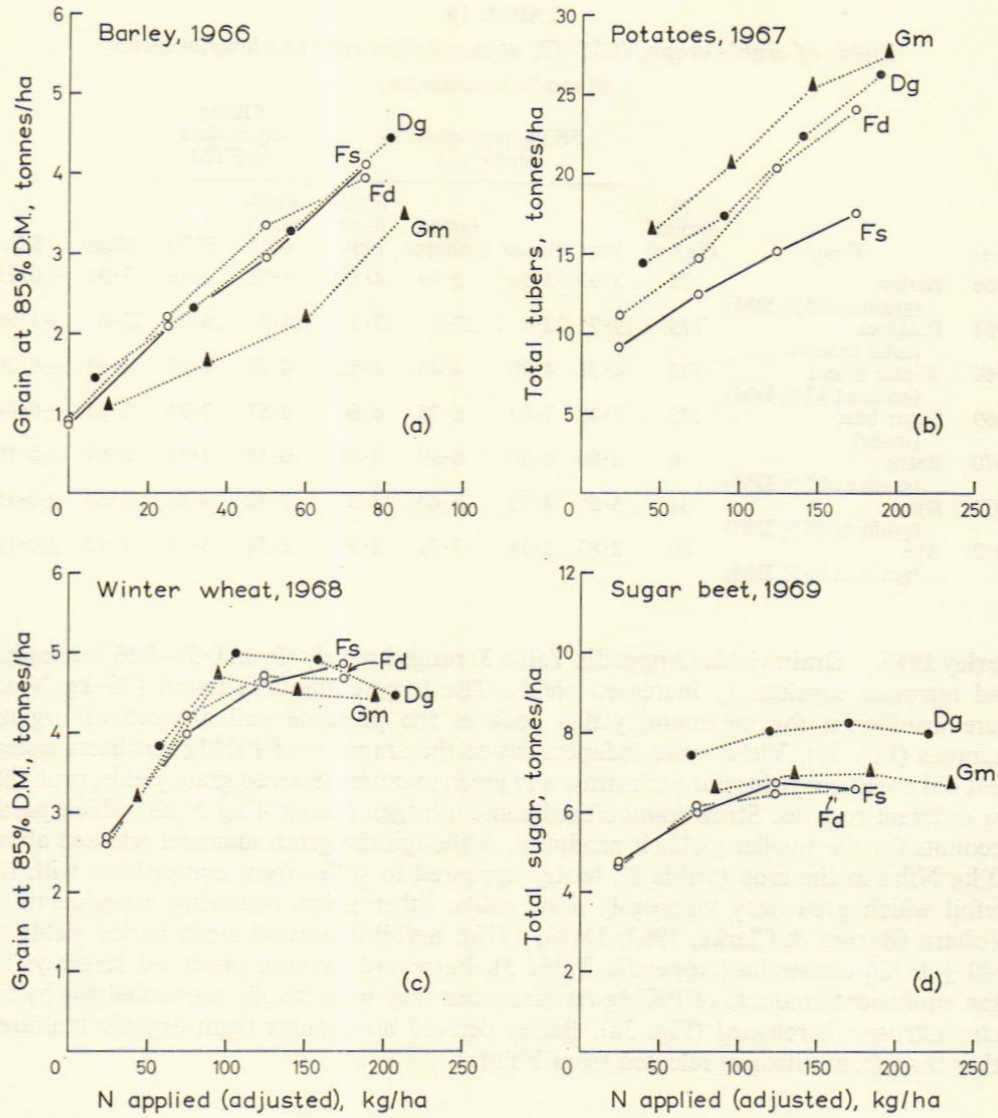

FIG. 3. Relationships between yields of barley (grain), potatoes (tubers), winter wheat (grain) and sugar and 'adjusted' N applied. ('Adjusted' N = N applied as 'Nitro-Chalk' + N taken up from green manures (Gm) or farmyard manure (Dg).)

Peat and straw increased tuber yields by 1·0 and 3·0 tonnes/ha more than fertilisers alone. Residues from trefoil, undersown in barley in 1966, increased mean tuber yields by 9·1 ± 2·38 tonnes/ha (Appendix Table 4) and they benefited the crop much more than can reasonably be explained by the N they released (Fig. 3b). Trefoil residues (between 2·9–3·8 tonnes/ha, Table 3) remained at the bottom of the plough furrows throughout the growing season and were still visible when the potatoes were lifted in autumn. Their value is tentatively attributed to the soil water they conserved and to the N they released slowly throughout the year. Farmyard manure also produced slightly larger tuber yields than equivalent fertilisers but, unlike the trefoil residues, almost all of the extra yield it produced was adequately explained by the extra N (16 kg N/ha) it supplied (Fig. 3b).

Winter wheat 1968. Winter wheat grew well and grain yields ranged from 2·57–5·00 tonnes/ha (Appendix Table 5). Nitrogen, given as 'Nitro-Chalk', consistently increased yields, except on plots given FYM or growing green manures, on which optimum amounts of fertiliser N were 75–125 kg N/ha. Yields were the same with both amounts of PKMg fertilisers (Fs and Fs). Neither peat nor straw improved yields and, unlike barley grown in 1966, the straw did not immobilise any nitrogen. After allowing for the nitrogen they released, both green manures and farmyard manure produced the same maximum yields (about 5 tonnes/ha) of winter wheat (Fig. 3c).

Sugar beet 1969. The crop grew well for most of the season and sugar yields ranged from 4·57–8·17 tonnes/ha, and averaged 6·55 tonnes/ha. Autumn 1969 was exceptionally dry and heart-rot, due to boron deficiency, developed during October on many plots, mostly in Blocks I and II. The mean yields and N uptakes are briefly discussed here without reference to the effects of boron deficiency which will be described more fully elsewhere.

Yields of clean beet, sugar, tops and total dry matter were independent of the amounts of PKMg applied as fertilisers (Fig. 3d; Appendix Table 6). Peat and straw did not benefit the crop and both gave the same yields of sugar and tops as equivalent amounts of fertilisers. Green manures and farmyard manure, however, both produced more sugar than fertilisers alone. Most of the value of the residues from green manures derives from the nitrogen they release because differences between sugar yields (Gm *minus* Fs), but not yields of tops, decreased with increasing amounts of N given as 'Nitro-Chalk'.

	Yields, tonnes/ha					
	With fertilisers only (Fs)		Extra yields from green manures			
N applied (kg N/ha)	Sugar	Tops (DM)	Sugar	S.E. of increase	Tops (DM)	S.E. of increase
25	4·75	1·7	+1·86	±0·633	+1·4	±0·45
75	6·10	2·7	+0·87		+0·9	
125	6·80	3·2	+0·24		+1·1	
175	6·60	4·0	+0·15		+1·0	
Mean	6·06	2·9	+0·78	±0·471	+1·1	±0·28

Farmyard manure increased the yields of sugar much more than equivalent amounts of PKMg fertilisers and differences between sugar yields with FYM (Dg *minus* Fd) decreased less than after green manures as the amounts of N given as 'Nitro-Chalk' increased from 25 to 175 kg N/ha.

	Yields, tonnes/ha					
	With fertilisers only (Fd)		Extra yields from FYM			
N applied (kg N/ha)	Sugar	Tops (DM)	Sugar	S.E. of increase	Tops (DM)	S.E. of increase
25	4·57	1·9	+2·84	±0·633	+0·9	±0·45
75	6·14	2·5	+1·86		+1·0	
125	6·51	3·1	+1·66		+1·0	
175	6·57	3·5	+1·37		+1·1	
Mean	5·95	2·7	+1·93	±0·471	+1·0	±0·28

The extra nitrogen removed by sugar beet from residues of green manures (60 kg N/ha) and from cumulative dressings of farmyard manure (48 kg N/ha) increased yields of dry matter in tops by about 1 tonne/ha. The extra nitrogen from green manure residues did not increase sugar yields (Fig. 3d) whereas farmyard manure produced about 1·5 tonnes/ha more sugar than equivalent fertilisers after adjusting the N supply for the N it released. Part of the benefit from farmyard manure may be due to the boron it contains. It is unlikely, however, that boron is solely responsible, because peat, which contains as much, or more, boron (Appendix Table 2), also increased the B content of the leaves, and prevented heart-rot (*Rothamsted Report for 1970*, Part 1, pp. 56–57), but did *not* increase sugar yields (Appendix Table 6).

Beans 1970. Beans were sown on 20 March after a wet winter and the seedbed was prepared by power harrowing; some rows, corresponding with tractor wheelings, had failed to germinate by 20 May. The summer was drier than average and the crop grew poorly, grain yields at harvest (Appendix Table 7) ranging from 0·50 to 1·19 tonnes/ha. Mean yields from farmyard manure (1·14 tonnes/ha) were about twice those from equivalent amounts of PKMg as fertilisers (0·56 tonnes/ha). Straw and green manures, but not peat, gave slightly more beans (0·13 $\pm$ 0·088 tonnes/ha) than equivalent amounts of PKMg fertilisers. Beans recovered very little N remaining from the previous sugar beet crop (Table 9) and yields were independent of the amounts of N applied a year earlier. No N scale was tested, so it is impossible to assess unambiguously whether the better crop on FYM plots was due solely to the N (about 22 kg N/ha) it released (Table 8).

Winter rye 1971. Rye grew well and grain yields ranged from 3·18 to 4·76 tonnes/ha. Residues from N applied two years earlier to sugar beet were negligible (Table 9) and they did not affect yields of grain or total dry matter (Appendix Table 8). Cumulative dressings of straw gave slightly more grain (0·33 $\pm$ 0·188 tonnes/ha) than equivalent fertilisers but neither peat nor red clover (Gm), undersown in the rye, improved yields. There was no difference between the larger (Fd) and smaller (Fs) amounts of fertiliser. Rye grown on FYM plots took up more nitrogen (31·0 kg N/ha) than from plots given equivalent fertilisers (Fig. 2b) and both grain yields and total dry matter were largest with farmyard manure, which gave 1·25 $\pm$ 0·188 tonnes/ha more grain than equivalent fertilisers. As there was no N scale to measure yield increases from inorganic N, it is impossible to assess whether the large benefit from FYM was due solely to the N it released.

Winter rye 1972. A second crop of rye was grown in 1972 only on Blocks II and IV. Mean grain yields (Appendix Table 9) were smaller than in 1971 but they confirm that no residues remained from N given to sugar beet in 1969. Straw again improved grain yields a little more (0·25 $\pm$ 0·208 tonnes/ha) than equivalent fertilisers but peat did not. Green manuring was much more effective in 1972 than in 1971; yields of grain and dry matter were the same as with FYM, probably because red clover was undersown in rye on plots which already contained residues (36 kg N/ha, Table 3) from red clover grown in 1971. The extra amounts of N taken up by rye grown after green manures (in 1971 and 1972) and from cumulative dressings of FYM, last given in autumn 1970, were 16·0 and 18·6 kg N/ha respectively.

Effects of N on uptakes of P, K, Na, Ca and Mg, 1966–71

Appendix Table 10 gives the amounts of N, P, K, Na, Ca and Mg removed by the six crops as means of the four amounts of N applied between 1966–69. Balancing dressings to compensate for differential removals of P, K and Mg (Appendix Table 1) were based on these mean removals. (Small discrepancies between uptakes in these two tables arise from the conversion of Imperial to metric units and from rounding errors.) Figs 4–7

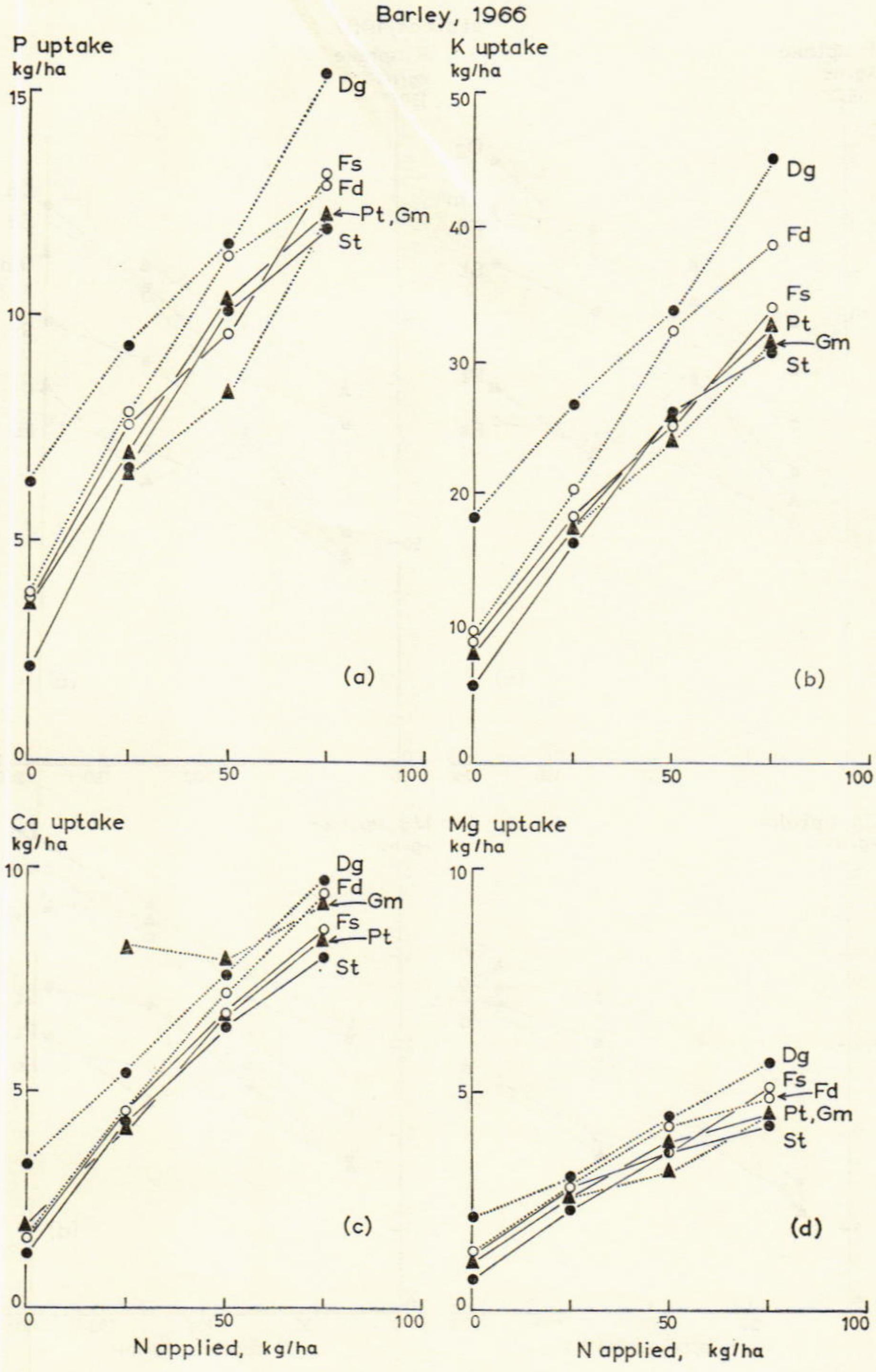

FIG. 4. Effects of nitrogen, applied as 'Nitro-Chalk', on P, K, Ca and Mg uptakes by barley (grain + straw) in the presence of Pt, St, Gm, Dg, Fs and Fd (for key to symbols, see Fig. 1).

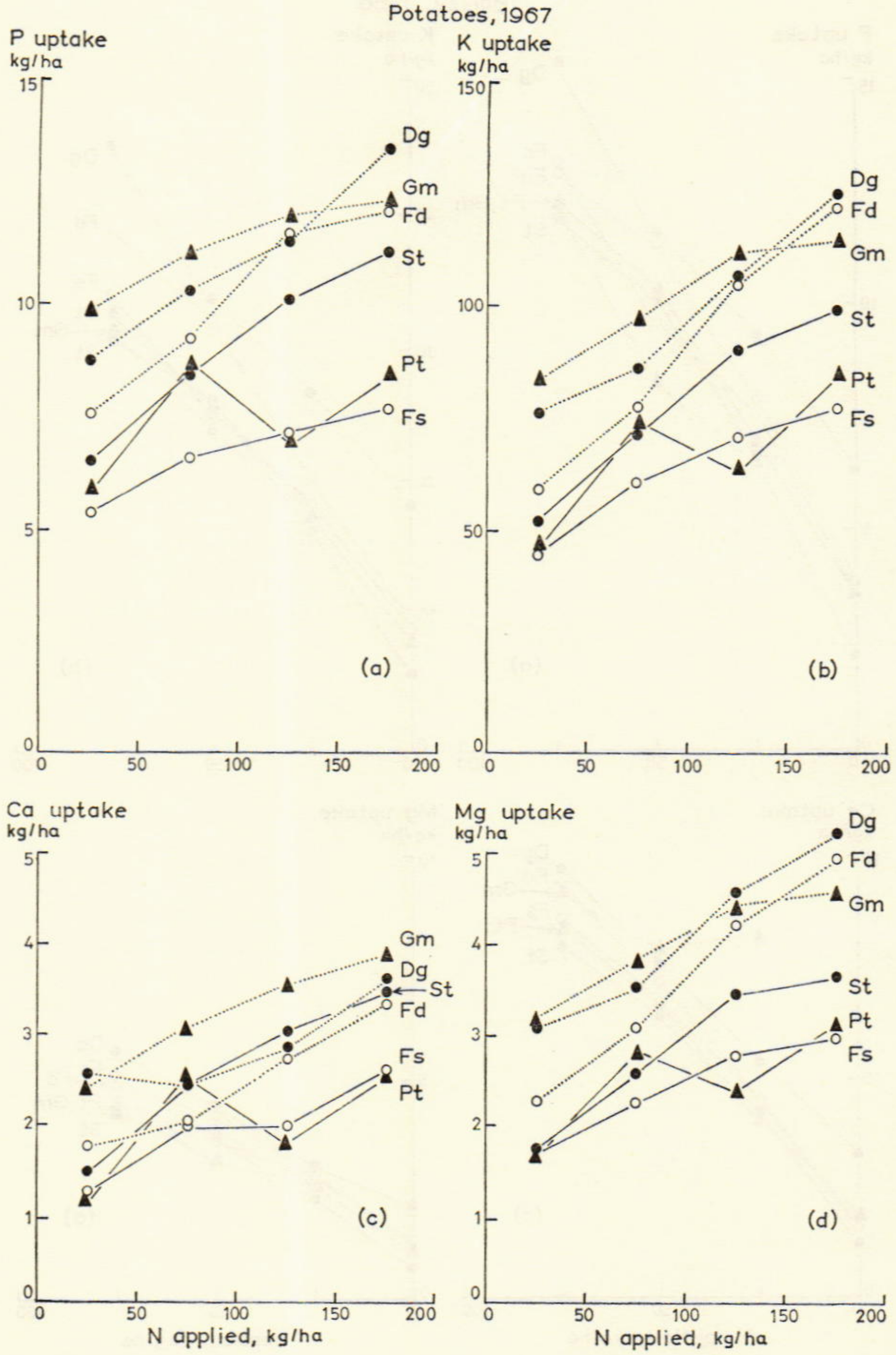

FIG. 5. Effects of nitrogen, applied as 'Nitro-Chalk', on P, K, Ca and Mg uptakes by potatoes (tubers only) in the presence of Pt, St, Gm, Dg, Fs and Fd (for key to symbols, see Fig. 1).

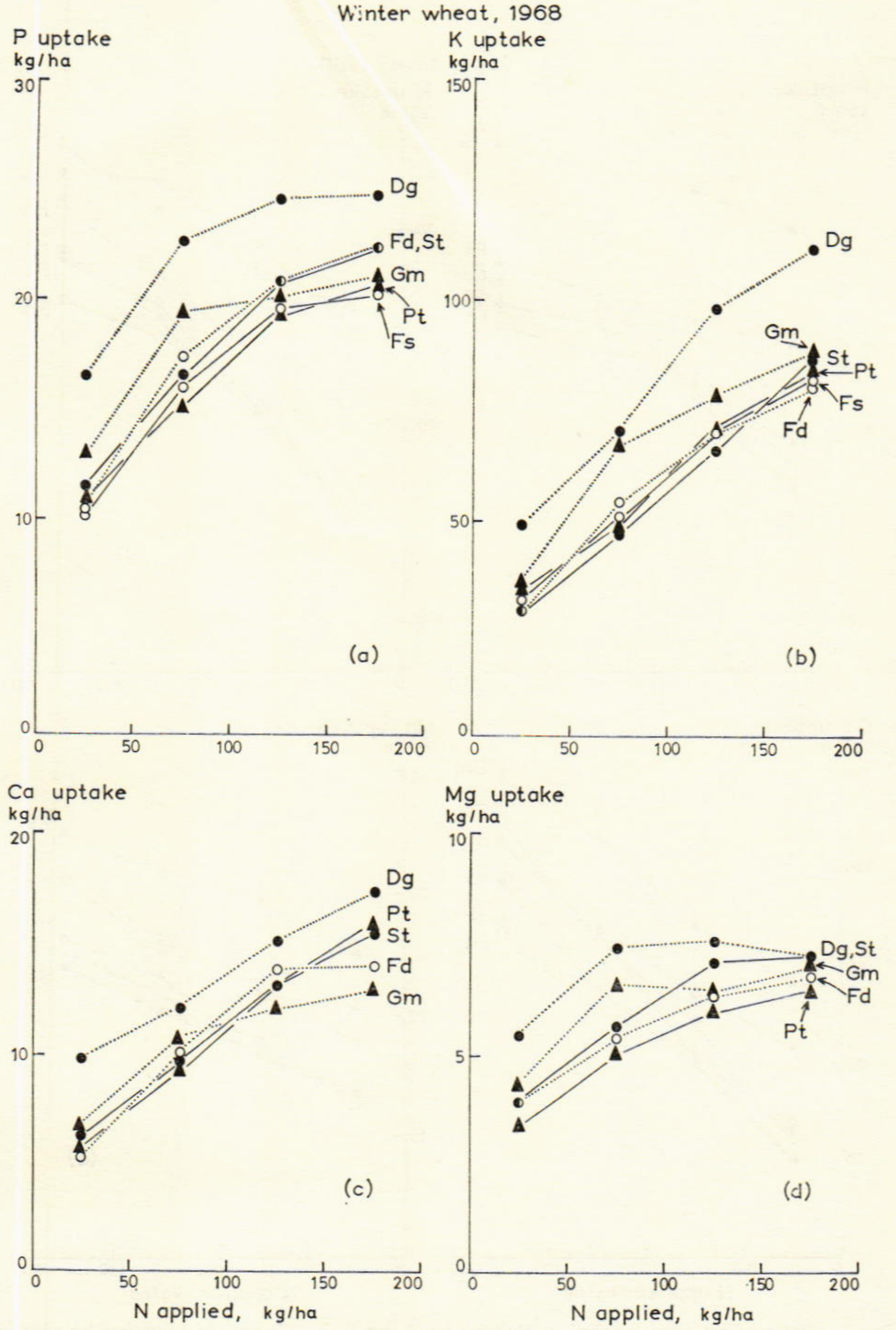

FIG. 6. Effects of nitrogen, applied as 'Nitro-Chalk', on P, K, Ca and Mg uptakes by winter wheat (grain + straw) in the presence of Pt, St, Gm, Dg, Fs and Fd (for key to symbols, see Fig. 1). Ca and Mg uptakes from fertilisers (Fd and Fs) were indistinguishable and values for Fs are omitted from this figure.

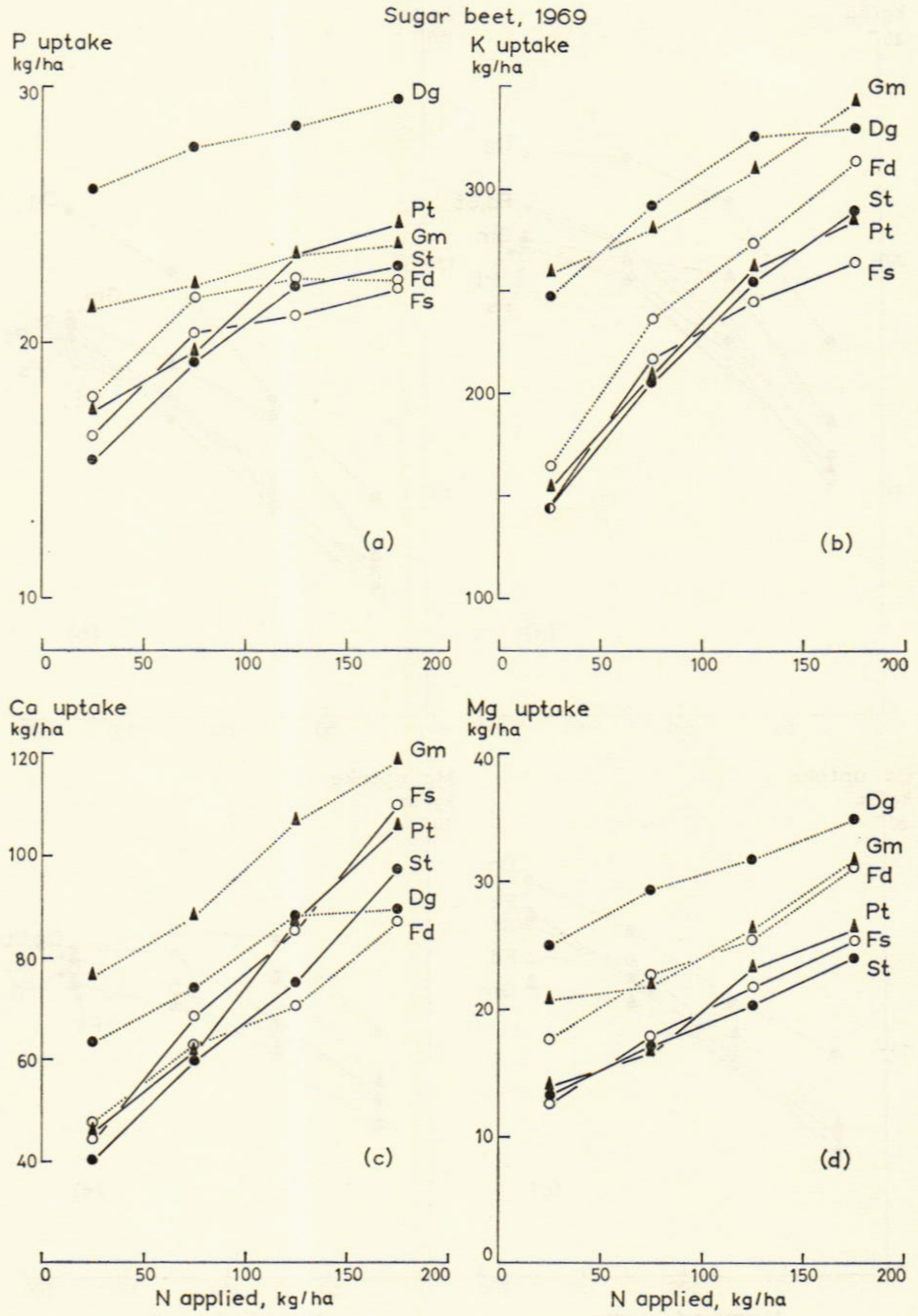

FIG. 7. Effects of nitrogen, applied as 'Nitro-Chalk', on P, K, Ca and Mg uptakes by sugar beet (tops + roots) in the presence of Pt, St, Gm, Dg, Fs and Fd (for key to symbols, see Fig. 1).

show the relationships between uptakes of P, K, Ca and Mg and the N applied to arable crops between 1966–69. Uptakes by sugar beet include nutrients in the tops, which were sampled and analysed but, as they were ploughed in on plots, no balancing dressings were needed to compensate for the large amounts of P, K and Mg they contained (Fig. 7). The amounts of P, K, Ca and Mg removed by arable crops between 1966–71 depended on the amounts of (i) inorganic N applied (1966–69), (ii) N released from organic manures and (iii) P, K and Mg given as fertilisers.

Uptakes of P, K, Ca and Mg were approximately linearly related to the amounts of N applied and several results are relevant to the design and purpose of the present experiment. Arable crops grown with green manures or FYM removed more N (about 56 and 67 kg N/ha respectively) between 1966–69 than crops grown with fertilisers (Fs and Fd). The extra uptakes were about 7·5 kg P, 61 kg K and 3·3 kg Mg/ha (green manures) and 11·5 kg P, 56 kg K and 6·0 kg Mg/ha (FYM), and they were balanced by extra fertiliser given each winter or early spring. Differences between the amounts of P, K and Mg removed from Fs and Fd plots in six crops were small (6·2, 42·1 and 2·3 kg/ha respectively) despite two- to three-fold differences in the amounts applied (Appendix Table 1). The balancing dressings of PKMg fertilisers used in this experiment compensated more for differences in the amounts of P, K and Mg removed by crops due to the amounts of nitrogen given (either as 'Nitro-Chalk' or as organic or green manures) than for differences in the amounts of P, K and Mg applied.

TABLE 11

Amounts of P, K, Na, Ca and Mg removed by arable crops, 1966–71, as percentages of the total N removed by cropping

(Means of all rates of N)

	PKMg equivalent to straw + P				PKMg equivalent to FYM		
Nutrient	Peat	Straw	Green manures	Fertilisers only	Fertilisers only	FYM	Mean
Phosphorus	21·4	21·7	18·7	20·7	22·6	21·0	21·0
Potassium	93·8	92·7	93·3	89·5	102·8	95·8	94·6
Sodium	1·4	1·2	1·3	1·3	1·3	1·5	1·3
Calcium	17·9	17·1	19·6	17·7	16·3	15·6	17·4
Magnesium	8·3	8·3	7·8	8·3	9·0	8·5	8·4

Table 11 summarises uptakes of P, K, Na, Ca and Mg between 1966–71, in the presence and absence of organic or green manures, as percentages of the total N removed by cropping. Uptakes of nutrients, expressed in this way, were almost independent of the amounts and type of organic manures tested. Slightly more Ca was taken up from Gm than from Fs plots, perhaps because cereal straws (barley, winter wheat and rye) were contaminated with the legumes. Rather less P was removed from Gm than from Fs plots and more K from Fd than Dg plots but there are no obvious explanations for these small differences.

Cumulative removal of nitrogen from soils

Fig. 8 shows the cumulative amounts of N, calculated from data in Table 8, taken up from soils between 1966–71, Throughout this period, the N removed by arable crops from soils given about 7 tonnes organic matter/ha each year as peat or straw was almost the same as from soils given only fertilisers. Much more N was, however, removed from soils after three legume crops (trefoil, 1966 and red clover, 1968 and 1971) or after cumulative dressings of farmyard manure. This experiment provides evidence, not previously established at Woburn, that trefoil and clover residues release amounts of

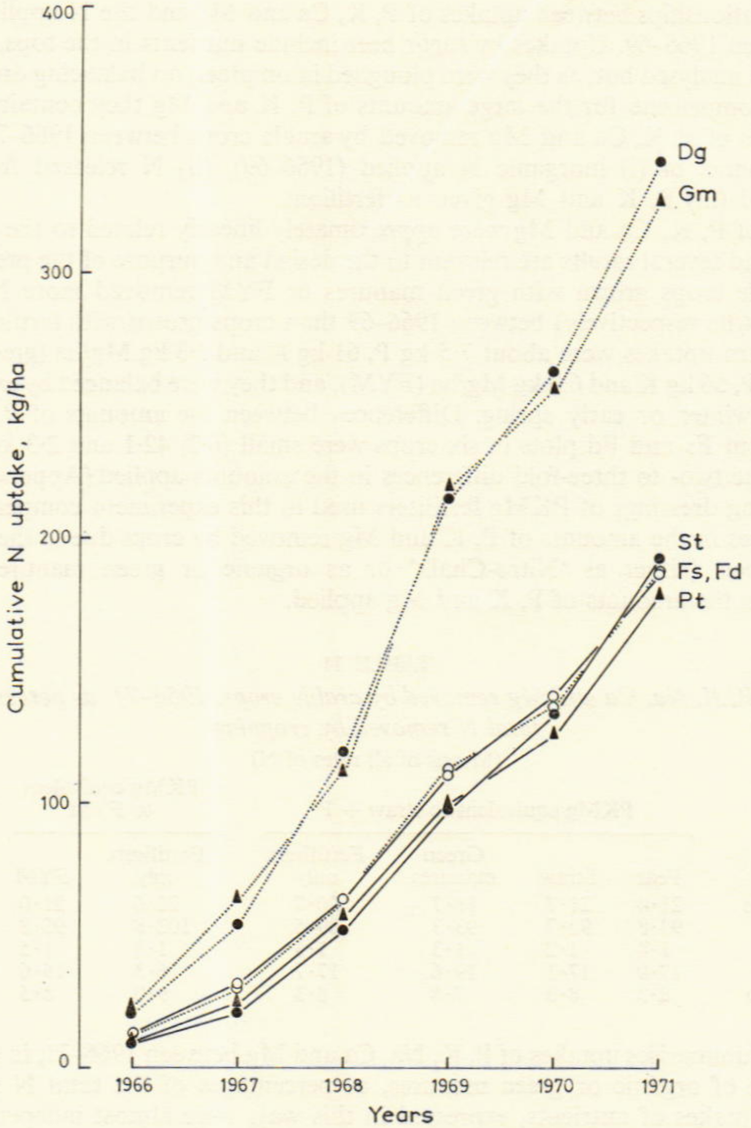

FIG. 8. Cumulative uptakes of nitrogen, 1966–71, from soils enriched with peat (Pt), straw (St), green manures (Gm), farmyard manure (Dg) or given only fertilisers equivalent to PKMg in straw + supplementary P (Fs) or to farmyard manure (Fd).

nitrogen over a period of six years which are comparable with those released from a total of 250 tonnes FYM/ha. The exceptionally close agreement between the amounts released from green manures and FYM (Fig. 8) is obviously partly fortuitous.

Cumulative yields of dry matter, 1966–71

Most arable crops, and particularly potatoes (Appendix Table 4), winter wheat (Appendix Table 5) and sugar beet (Appendix Table 6) yielded better when given FYM or when they followed green manures. Much of the benefit from these organics was explained by the extra nitrogen they supplied (Fig. 3a–d). Cumulative dry matter production, derived from Appendix Tables 3–8, provides better evidence for cumulative effects of organic manures

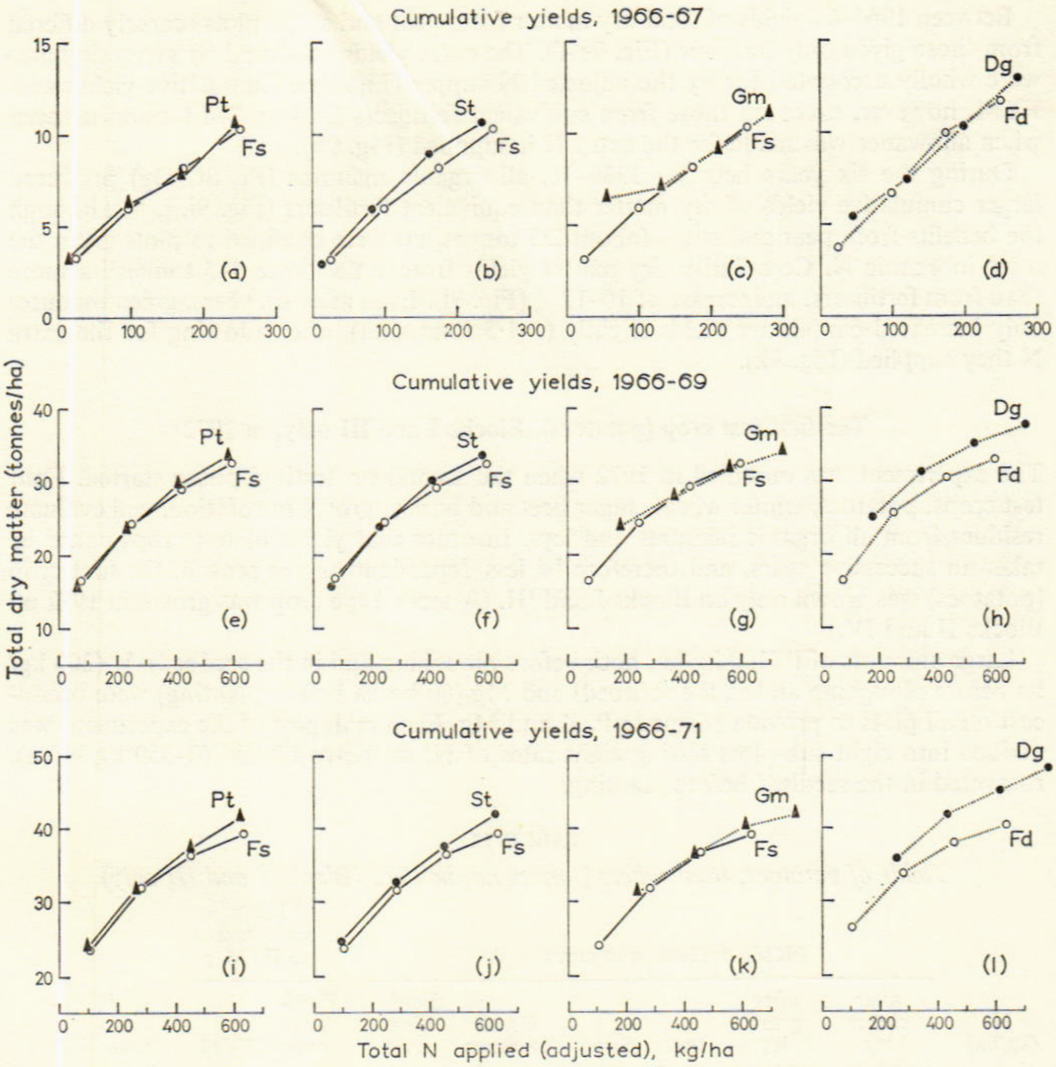

FIG. 9. Relationships between cumulative yields of dry matter, 1966–67, 1966–69 and 1966–71 and total 'adjusted' N applied. ('Adjusted' N = N applied as 'Nitro-Chalk' + N taken up from peat, straw, green manures or farmyard manure.)

on crop growth other than those directly due to nitrogen. Fig. 9a–l shows the cumulative yields of dry matter from the arable crops for 1966–67, 1966–69 and 1966–71, plotted against 'adjusted' amounts of N applied. The 'adjustments' were made by adding the amounts of N released from, or subtracting the amounts immobilised by, the organic manures (Table 8) to the cumulative additions of N given as 'Nitro-Chalk' (Table 7).

Between 1966–67, cumulative yields of dry matter were the same with peat and straw as with fertilisers only (Fig. 9a–b). Green manures gave identical yields to the fertiliser plots, except where the smallest amounts of inorganic N were applied (Fig. 9c). The estimate of the amount of N released from green manures in 1966 (Table 8) is probably too small but cannot be obtained more accurately because the barley 'straw' was much contaminated with trefoil, especially on plots given no nitrogen. Cumulative yields from FYM and equivalent fertilisers (Fd) were very similar (Fig. 9d) although 100 tonnes FYM/ha were applied between 1966–67.

Between 1966–69 yields of total dry matter from peat and straw plots scarcely differed from those given only fertiliser (Fig. 9e–f). The extra yields produced by green manures were wholly accounted for by the adjusted N supply (Fig. 9g). Cumulative yields with FYM, however, exceeded those from equivalent fertilisers (Fd) by 3–4 tonnes/ha, even when allowance was made for the extra N it supplied (Fig. 9h).

During the six years between 1966–71, all organic manures (Pt, St, Dg) produced larger cumulative yields of dry matter than equivalent fertilisers (Fig. 9i, j, l), although the benefits from peat and straw (about 2·5 tonnes/ha) were confined to plots given the most inorganic N. Cumulative dry matter yields from FYM were 4–5 tonnes/ha more than from fertilisers, an increase of 10–12% (Fig. 9l). Even after six years, green manures only increased cumulative yields slightly (1–1·5 tonnes/ha), after allowing for the extra N they supplied (Fig. 9k).

The first test crop (potatoes), Blocks I and III only, in 1972

The experiment was modified in 1972 when the second or 'testing' phase started. Four test crops, potatoes, winter wheat, sugar beet and barley, grown in rotation, will evaluate residues from all organic manures and leys. In order that yields of test crops could be taken in successive years, and therefore be less dependent on the season, the first crop (potatoes) was grown only on Blocks I and III. (A second rye crop was grown in 1972 on Blocks II and IV.)

Large amounts of P (100 kg/ha, both before ploughing and in the seedbed), K (200 kg/ha before ploughing and in the seedbed) and Mg (60 kg/ha before planting) were broadcast on all plots to provide adequate P, K and Mg. Each mainplot of the experiment was divided into eight sub-plots testing eight rates of N, as 'Nitro-Chalk' (0–350 kg N/ha), rotavated in the seedbed before planting.

TABLE 12

Yields of potatoes, total tubers (tonnes/ha) in 1972 (Blocks I and III only)

	PKMg equivalent to straw + P						PKMg equivalent to FYM		
N (kg/ha)	after clover ley	after grass ley	Peat	Straw	Green manures	Fertilisers only	Fertilisers only	FYM	Mean
0	29·4	26·7	18·6	21·2	27·7	19·9	20·3	27·6	23·9
50	30·3	25·5	30·7	27·0	33·2	25·6	24·7	31·2	28·5
100	37·7	31·0	29·5	31·5	33·4	28·1	25·0	35·0	31·4
150	34·9	33·2	37·6	31·5	37·5	30·3	28·1	34·5	33·4
200	36·6	28·7	40·3	31·9	37·5	32·6	32·1	41·2	35·1
250	35·7	34·2	45·2	32·8	39·8	33·7	32·9	45·2	37·5
300	39·9	38·1	44·8	37·5	43·7	35·8	35·5	40·4	39·5
350	45·8	36·9	47·1	38·3	43·6	37·9	41·7	47·5	42·4
Mean	36·3	31·8	36·7	31·5	37·0	30·5	30·0	37·8	34·0
									±0·076 (for Mean column, N 0–350)

±2·17 (for Means, after clover ley to FYM)

S.E. for use in vertical and interaction comparisons ±2·16
S.E. for use in horizontal comparisons ±2·96

Table 12 gives yields of potatoes (Pentland Crown) in 1972. Full discussion and evaluation must await the results on Blocks II and IV in 1973, but the preliminary indications fully support the evidence from cumulative yields (Fig. 9) that some organic matter treatments between 1966–71 increased yields, even when the most N was given. Yields on plots given FYM were more, by 4·9 to 12·3 ± 4·19 tonnes/ha, at *all* levels of nitrogen than on plots (Fd) given equivalent amounts of P, K and Mg from 1965–70.

Discussion and conclusions

Balancing dressings of PKMg fertilisers. This paper is largely a descriptive and factual account of the yields from the experiment between 1966–72. The main objective of the first phase of the experiment was to produce soils containing different amounts and forms of organic matter. The cropping sequence was chosen to avoid the build-up of soil-borne pathogens and balancing dressings of P, K and Mg were applied, both in spring and autumn, to compensate for the differential removals of these nutrients. Crop analyses, summarised for the leys in Table 5 and for the arable crops in Figs 4–7 and Appendix Table 10, show that the amounts of P, K and Mg removed depended more on the amounts of N applied as 'Nitro-Chalk', or released from the clover ley, the green manures or farmyard manure, than on the amounts given as PKMg fertilisers. Soil analyses, which give the amounts and vertical distribution of exchangeable K and Mg, and of $NaHCO_3$-soluble P, confirm that the nutrient status of the soils in 1972/3 was almost independent of the amounts and types of organic matter added between 1965–71/2 (Mattingly, Chater & Poulton, 1974).

'Adjusted' N dressings. The amounts of N released from, or occasionally immobilised by, the organic manures were estimated from the amounts taken up from soils in the absence of inorganic N (Table 8). Brockman (1969) used a similar adjustment to measure the N released from soils under grass. These amounts, together with those added as fertilisers, are called 'adjusted' N dressings and were used (Fig. 3a–d) to assess how much of the benefits from the green or organic manures could be reasonably explained by the N they released.

Soil-borne diseases. No assays were made for 'take-all' or for other soil-borne cereal pathogens but visual evidence suggested that both barley (1966) and winter wheat (1968) were virtually free from 'take-all'. Soils were sampled in May 1970 for eggs of cereal cyst nematodes (*Heterodera avenae*) and counted by T. D. Williams. Most plots contained empty cysts of unknown age and a few contained $<1{\cdot}0$ egg/g air-dry soil, which is many less than required to affect yield. All arable plots in Blocks I and III were assayed by A. G. Whitehead for cysts of potato cyst nematode (*Heterodera rostochiensis*) in autumn 1971, before potatoes were grown as a test crop. Most plots contained no eggs or cysts; the largest populations were 5 cysts/200 g soil and 300 eggs/200 g soil in plot 4 (Gm), which are too small to affect potato yields. The long rotation, following 30 years under a six-course rotation, makes it unlikely that soil-borne diseases will affect yields in the 'testing' phase of this experiment.

Peat. The cumulative additions of peat between 1965–70 scarcely affected yields of any crop. Almost all the C and N added as peat remained in the soil in 1971 and the nitrogen was inert (Part II). The effects of peat on cumulative yields appeared, however, to increase during the experiment, especially where the most N was given. Even so, it improved total yields of dry matter by only 5% (Fig. 9i). Johnston and Warren (1965), who tested peat and a polyacrilonitrile soil conditioner on poor soils at Woburn, found little benefit from either material alone, although in combination they increased yields of globe beet. The yields from first test crop (potatoes) in 1972 (Table 12) support the view that benefits from peat increase consistently with the amounts of N applied. When no N was given, yields on soils given peat were the same ($-1{\cdot}3 \pm 4{\cdot}19$ tonnes/ha) as on soils given only fertilisers. When 200–350 kg N/ha were tested, mean yields on peat plots out-yielded equivalent fertiliser plots by $9{\cdot}2 \pm 1{\cdot}52$ tonnes/ha, probably because peat increases the available water in soils (Salter & Williams, 1968).

Straw. Most of the field experiments in Britain on the use of straw as an organic manure, reviewed critically by Cooke (1967), provide no evidence for its value as an organic manure. The interpretation of many (indeed almost all) of the earlier experiments was complicated by the small but variable amounts of K it contained. Precautions taken in the design and conduct of the Woburn Organic Manuring experiment ensured that residues from six cumulative dressings of straw (totalling 46 tonnes/ha of dry matter) were evaluated relative to soils maintained at equal PKMg levels. Straw increased cumulative yields of the arable crops between 1965–71 by about the same amount (5%) as comparable amounts of peat. The yields from the first test crop of potatoes (Table 12), however, were the same ($+1{\cdot}3 \pm 4{\cdot}19$ tonnes/ha) as from equivalent fertilisers when no N was given, and were consistently less than on plots given peat at all rates of N from 50–350 kg N/ha. The results from this experiment so far show negligible benefits from cumulative dressings of straw at Woburn when the nutrients it contains (P, K and Mg) are balanced by equivalent amounts of fertilisers.

Green manures. The effects of the green manures were much larger and more consistent than those from the additions of peat or straw. Many previous experiments at Woburn show some benefits from green manuring (Crowther & Mann, 1933; Mann, 1959; Barnes & Clarke, 1963; Dyke, 1973), but few experiments were designed to evaluate them unambiguously. Legumes (trefoil and the clovers) provide more N than ryegrass (Barnes & Clarke, 1963) and green manures were more effective when ploughed under in autumn than in the following spring, probably because some of the green crop died during the winter. However, if green manures are incorporated in warm moist soils in autumn some N may be leached by winter rain (Crowther & Mirchandani, 1931). Green manures were ploughed down late in autumn (in October or November) in the Organic Manuring experiment to delay mineralisation and minimise losses of nitrogen by winter rainfall.

Most of the value of the green manure crops grown between 1966–71, except for potatoes (1967), was attributed to the N they released. Total amounts of N added ranged from 120–190 kg N/ha (Table 3) and were least on sub-plots given the most 'Nitro-Chalk'. The cumulative amounts of N released from green manures (Fig. 8), averaging values from all sub-plots, totalled 139 kg N/ha, about 87% of the mean amount added. This value from cumulative recoveries of N over six years, is greater than the nitrogen equivalent of trefoil N (65%) quoted by Barnes and Clarke (1963) for autumn-ploughed trefoil grown in the Green Manuring experiment on Stackyard in 1955–62.

The sequence of green manure crops (Table 3) maintained soil carbon almost constant between 1964–71, during which period soils given only inorganic fertilisers lost carbon at $-0{\cdot}008 \pm 0{\cdot}0026\%$ C each year (Part II). Residues from green manures released about the same amounts of N, at similar rates, as residues from cumulative dressings of FYM (Fig. 8). The better yields of potatoes in 1967, after trefoil grown in 1966, cannot be explained by the N it released (Fig. 3b) and yields of the first test crop of potatoes in 1972 confirm this result. Yields of potatoes, following rye undersown with red clover (Table 12) averaged $6{\cdot}5 \pm 3{\cdot}07$ tonnes/ha more than on plots given equivalent fertilisers. Evidence from this experiment so far confirms that green manure crops (trefoil and red clover), undersown in the cereals, increased yields of the potatoes that followed them by more than can be explained by the N the green crops released. Further work is needed to explain their action, which is tentatively attributed to better moisture retention and N supply in soils containing legume residues, particularly during the spring. Green manures only slightly increased cumulative dry matter yields between 1966–71, after allowing for the N they contained (Fig. 9k).

Farmyard manure. There was reasonable evidence that cumulative dressings of FYM, totalling 250 tonnes/ha in six years, benefited root crops and beans more than can be attributed to the nutrients it contained. Cumulative yields of dry matter between 1965–71 were 10% more from FYM than from equivalent fertilisers (Fig. 9l) after allowing for the N it released. The increased yields of sugar in 1969 were the largest effects of FYM which were not accounted for by the NPKMg is supplied. Boyd (1968) summarised results from the Woburn Ley–Arable experiment, after major nutrient imbalances had been corrected and concluded 'Although, given enough N for maximum yield, responses to FYM in the period 1965–67 were much less, there was still some effect of FYM not obtainable by fertilisers alone. This was small in the grazed ley and arable (hay) rotations, but considerable after lucerne (3·6 cwt sugar/acre) and after arable (roots) (5·6 cwt sugar/acre)'. The yields of sugar in the Organic Manuring experiment in 1969 were much larger, about 1·5 tonnes/ha (12 cwt/acre), with FYM than with equivalent fertilisers, even allowing for the N it released (Fig. 3d). Part of the benefit from FYM may be due to the boron it supplies (Appendix Table 2). Sugar beet grown on FYM plots showed few symptoms of heart-rot (*Rothamsted Report for 1970*, Part 1, pp. 56–57), and their leaves contained more boron (27 ppm) than plants grown with equivalent fertilisers (16 ppm). No boron deficiency was detected, however, in sugar beet grown on plots given peat and their leaves contained 30 ppm B. They yielded no better than beet grown with fertilisers so it is unlikely that much of the larger sugar yields with FYM can be unequivocally attributed to the boron it supplied. Sugar beet grown in the testing phase of the experiment (1974/5) and in other experiments on Stackyard Field need soluble boron to eliminate the possibility of B deficiency. Yields of the first test crop (potatoes) grown only in one year, 1972, confirm benefits from FYM which cannot be attributed to inadequate NPKMg manuring (Table 12).

In the testing phase of this experiment (1972–76) more analyses for micronutrients in crops and soils will be made to establish whether the occasional benefits of organic or green manures observed so far are due to the addition or release of micronutrients rather than to improvements in soil physical properties and water-holding capacity.

Summary

1. The Organic Manuring experiment, started in 1964 on Stackyard Field (Series B) compares most of the treatments to increase soil organic matter previously tested in separate experiments at Woburn. The experiment evaluates, from crop yields and soil analyses (described in Part II) the cumulative effects of leys, peat, straw, farmyard manure and green manures, grown or applied from 1965–71/2 to a light soil with a long history of arable cropping. The experiment is divided into two phases (i) arable cropping (1966–71/2) or continuous leys (1965–71/2) followed by an arable rotation (potatoes–winter wheat–sugar beet–barley) to evaluate, between 1972–76, the organic matter accumulated during the first phase. In the first phase, described in this paper, eight treatments were tested on four blocks. The treatments were (i) continuous leys with clover (Lc) or inorganic N (Ln), (ii) annual arable cropping on plots given sedge peat (Pt), straw (St), green manure crops (Gm) or farmyard manure (Dg) or no organics (Fs and Fd). P, K and Mg fertilisers were applied at two rates, one equivalent to the nutrients in straw + supplementary P (Fs) and the other equivalent to the nutrients in farmyard manure (Fd). The sequence of arable crops was barley (1966), potatoes (1967), winter wheat (1968), sugar beet (1969), beans (1970), winter rye (1971) and (on two blocks only) in 1972.

2. Balancing dressings of P, K and Mg, given each year, ensured that the organic and green manures were evaluated in soils maintained at the same nutrient status as the plots

given only fertilisers (Fs and Fd) which acted as controls. Net gains of P, K and Mg between 1966–71 on all plots growing grass–clover leys or leys with nitrogen, and on plots given peat, straw, green manures or fertilisers only (Fs) were 220 kg P/ha, 680 kg K/ha and 90 kg Mg/ha. Net gains on plots given farmyard manure or equivalent fertilisers (Fd), were 540 kg P/ha, 2000 kg K/ha and 260 kg Mg/ha.

3. The total amounts of organic matter (tops + roots) added to soils under the clover ley and ley with nitrogen were 9·1 and 9·4 tonnes/ha; the amounts of nitrogen added were 157 and 169 kg N/ha respectively. Dry matter and nitrogen added in three green manure crops (trefoil 1966; red clover 1968 and 1971) were 6·1 tonnes/ha and 160 kg N/ha. The amounts of organic matter added as peat, straw and farmyard manure were 42, 43 and 36 tonnes/ha respectively; they supplied 535, 290 and 1580 kg N/ha.

4. The amounts of N released from the organic and green manures, estimated by extrapolating 'yield of N' curves, showed that little N was released from peat and straw between 1966–71. Green manures released 8–60 kg N/ha each year and 139 kg N/ha in six years. Farmyard manure released 6–48 kg N/ha each year, and 156 kg N/ha in six years, about 10% of the total applied. Yields of barley (1966), potatoes (1967), winter wheat (1968) and sugar (1969) are discussed in relation to the total N applied as 'Nitro-Chalk' and released from the green and organic manures.

5. When differences between treatments due to the differential additions and removals of P, K and Mg were eliminated, yields of barley and winter wheat were reasonably explained by the N released from green manures or farmyard manure. (Undersown trefoil slightly decreased barley yields.) Residues from trefoil increased potato yields more (by 5–9 tonnes/ha) and sugar yields slightly more (by 0·5 tonnes/ha) than expected from the N they released. The N released from FYM accounted well for the larger yields of potatoes it produced in 1967. FYM gave 1·0–1·5 tonnes/ha more sugar in 1969 than equivalent PKMg, even when yields were adjusted for the N it released. Yield of all crops on plots given peat or straw were about the same as with equivalent fertilisers, although peat almost doubled the amount of soil C between 1966–71.

6. All organic manures produced larger cumulative yields of dry matter (1966–71) than equivalent fertilisers after allowing for the extra N they released. The extra yield (2·5 tonnes/ha) from peat and straw was only obtained on plots given the most inorganic N. Farmyard manure (250 tonnes/ha) increased total yields by 4–5 tonnes/ha more than equivalent fertilisers, an increase of 10–12%. Green manures increased cumulative yields by only 1·0–1·5 tonnes/ha after allowing for the N they released.

7. Potatoes grown on two blocks in 1972 produced more tubers on soils previously enriched with peat, green manures or FYM, or following the grass–clover leys, than on plots given only fertilisers from 1966–71. Organic matter from the grass ley or straw hardly increased yields. The mean increases in tuber yields, averaged over eight rates of N, were 5·8 (clover ley), 1·3 (grass ley), 6·2 (peat), 1·0 (straw), 6·5 (green manures) and 7·8 (FYM) tonnes/ha.

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APPENDIX

Methods of crop analysis

Nitrogen was estimated by Kjeldahl digestion using Cu and Se as catalysts. Ammonia was determined on the 'Technicon AutoAnalyzer' by the method described by Varley (1966), modified by adding a citrate–tartrate buffer.

Phosphorus was measured, after dry ashing, on the 'Technicon AutoAnalyzer' using the method of Fogg and Wilkinson (1958).

Potassium, sodium, calcium and magnesium were measured, after dry ashing, by emission (K, Na, Ca) or atomic absorption (Mg) spectrophotometry.

Boron in organic manures was measured colorimetrically, after dry ashing with $Ca(OH)_2$, using 1,1′-dianthrimide (Gorfinkiel & Pollard, 1952).

Organic matter in peat, straw, FYM and the roots of the leys was measured from loss on ignition at 500–550°C. (Organic matter was not measured on samples of green manures or cut grass.)

APPENDIX TABLE 1

Total amounts of P, K and Mg applied as organic manures and fertilisers and removed in crops, 1965–72

(All values in kg/ha)

		Clover ley			Grass ley			Peat			Straw			Green manures			Fertilisers (Fs)			Fertilisers (Fd)			Farmyard manure		
		P	K	Mg	P	K	Mg	P	K	Mg	P	K	Mg	P	K	Mg	P	K	Mg	P	K	Mg	P	K	Mg
1965	Spring	(e) 54·8	(e) 104·2	—	(e) 54·8	(e) 104·2	—	—	—	—	—	—	—	(e) 54·8	(e) 104·2	—	—	—	—	—	—	—	—	—	—
	Autumn (a)	—	—	—	—	—	—	1·1	1·0	9·1	6·0	122·9	3·8	—	—	—	—	—	—	—	—	—	49·9	445·9	31·8
	(b)	—	—	11·4	—	—	11·4	27·4	104·2	11·4	21·9	—	—	—	—	11·4	27·4	104·2	11·4	54·8	312·6	30·3	—	—	—
	Removed in crops	14·3	131·3	6·8	11·5	117·7	5·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1966	Spring	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Autumn (a)	—	—	—	—	—	—	0·5	1·0	10·6	7·1	89·6	4·5	—	—	—	—	—	—	—	—	—	250·0	312·6	88·6
	(b)	27·4	208·4	11·4	27·4	208·4	11·4	27·4	104·2	—	21·9	—	18·9	—	104·2	11·4	27·4	104·2	11·4	109·7	312·6	60·6	—	—	—
	Removed in crops	20·3	144·8	11·4	21·4	195·9	12·9	8·2	20·8	3·0	7·7	19·8	2·3	8·8	27·1	3·0	8·2	21·9	3·0	8·8	25·0	3·0	10·4	31·3	3·8
1967	Spring	54·8	260·5	37·9	54·8	312·6	37·9	(d) 55·3	(d) 105·2	(d) 10·6	54·8	104·2	15·1	54·8	104·2	18·9	54·8	104·2	18·9	137·1	125·0	30·3	—	—	—
	Autumn (a)	—	—	—	—	—	—	1·1	1·0	13·6	6·0	101·1	4·5	—	—	—	—	—	—	—	—	—	102·0	192·8	52·3
	(b)	27·4	208·4	15·1	27·4	208·4	15·1	27·4	104·2	—	21·9	—	11·4	27·4	104·2	15·1	27·4	104·2	15·1	120·6	166·7	60·6	—	—	—
	Removed in crops	15·4	121·9	6·8	14·8	125·0	5·3	7·7	66·7	2·3	8·8	78·1	3·0	11·5	101·1	3·8	6·6	62·5	2·3	10·4	90·6	3·8	11·0	97·9	3·8
1968	Spring	—	—	—	—	—	—	—	—	—	—	—	—	—	41·7	—	—	—	—	—	—	—	—	—	—
	Autumn (a)	—	—	—	—	—	—	1·1	1·0	18·2	7·1	52·1	4·5	—	—	—	—	—	—	—	—	—	76·2	483·4	60·6
	(b)	43·9	104·2	15·1	43·9	104·2	15·1	27·4	104·2	—	21·9	—	11·4	27·4	104·2	15·1	27·4	104·2	15·1	54·8	312·6	60·6	—	—	—
	Removed in crops	15·9	137·5	9·1	16·4	129·2	8·3	16·4	58·3	5·3	17·5	57·3	6·1	18·1	65·6	6·1	16·4	57·3	5·3	17·5	57·3	5·3	21·9	81·3	6·8
1969	Spring	21·9	125·0	—	21·9	104·2	—	27·4	104·2	—	27·4	156·3	—	38·4	114·6	—	27·4	104·2	—	—	166·7	—	—	—	—
	Autumn (a)	—	—	—	—	—	—	1·6	2·1	22·7	4·4	86·5	3·8	—	—	—	—	—	—	—	—	—	63·6	468·9	29·5
	(b)	27·4	104·2	22·7	27·4	104·2	22·7	27·4	104·2	—	21·9	—	15·1	27·4	104·2	22·7	27·4	104·2	22·7	54·8	416·8	22·7	—	—	—
	Removed in crops (c)	9·3	97·9	3·8	13·2	137·5	6·1	11·5	65·6	7·6	11·5	67·7	7·6	12·1	72·9	8·3	11·0	63·6	7·6	12·1	69·8	8·3	16·4	90·6	12·1
1970	Spring	—	41·7	—	—	83·4	—	27·4	104·2	—	27·4	135·4	—	27·4	104·2	—	27·4	104·2	—	27·4	135·4	—	27·4	104·2	—
	Autumn (a)	—	—	—	—	—	—	1·6	4·2	13·6	4·9	63·6	5·3	—	—	—	—	—	—	—	—	—	48·2	349·0	30·3
	(b)	27·4	104·2	22·7	27·4	104·2	22·7	27·4	104·2	—	27·4	—	15·1	27·4	114·6	22·7	32·9	104·2	22·7	49·3	354·2	22·7	—	—	—
	Removed in crops	2·2	18·8	1·5	11·0	117·7	6·8	3·3	15·6	1·5	4·4	17·7	1·5	4·4	20·8	1·5	3·8	16·7	1·5	3·3	15·6	1·5	6·0	27·1	2·3
1971	Spring	27·4	104·2	—	38·4	208·4	—	—	—	—	—	41·7	—	—	—	—	—	—	—	—	—	—	—	—	—
	Autumn (a)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	(b)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Removed in crops	14·3	142·0	6·8	34·5	357·0	13·6	13·7	38·6	3·8	14·8	39·6	3·8	14·8	58·4	5·3	12·6	33·4	3·8	13·7	37·6	3·8	20·3	63·6	6·0
1972	Spring	—	104·2	—	21·9	312·6	15·1	—	—	7·6	—	—	—	—	31·3	—	—	—	—	—	—	—	11·0	41·7	—
	Balance (f)	221	675	90	223	675	93	221	684	94	217	673	89	215	686	89	221	682	94	543	2007	262	542	2007	258

(a) As organic manures; (b) As fertilisers; (c) Sugar beet tops ploughed in; (d) Includes P, K and Mg applied in peat; (e) Includes 27 kg P/ha and 52 kg K/ha to ryegrass (Gm) and Leys (Lc and Ln) in 1964; (f) Blocks I and III only.

APPENDIX TABLE 2

Analyses of farmyard manure, straw and peat applied, 1965–70

Year	Dry matter (%)	% in dry matter N	P	K	Na	Ca	Mg	µg/g dry matter B
		Farmyard manure						
1965	19·4	3·00	0·51	4·58	0·30	1·50	0·33	24·6
1966	24·9	2·78	2·00	2·50	0·36	2·82	0·71	18·2
1967	31·2	2·37	1·30	2·46	0·30	2·84	0·66	29·7
1968	22·4	2·68	0·68	4·29	0·32	1·82	0·54	21·1
1969	21·1	2·37	0·60	4·43	0·25	1·20	0·28	13·6
1970	37·5	2·16	0·51	3·70	0·24	1·48	0·32	16·6
Mean	26·1	2·56	0·93	3·66	0·30	1·94	0·47	20·6
		Barley straw						
1965	80·4	0·58	0·087	1·72	0·067	0·35	0·049	—
1966	76·0	0·68	0·103	1·26	0·093	0·43	0·062	4·8
1967	87·0	0·55	0·075	1·22	0·059	0·38	0·052	4·0
1968	81·9	0·67	0·095	0·68	0·169	0·33	0·056	3·9
1969	80·6	0·40	0·060	1·14	0·050	0·40	0·050	3·0
1970	86·1	0·88	0·063	0·79	0·232	0·37	0·068	3·6
Mean	82·0	0·63	0·080	1·14	0·112	0·38	0·056	3·9
		Sedge peat						
1965	35·0	1·00	0·021	0·025	0·042	1·41	0·187	21·4
1966	35·0	1·06	0·020	0·014	0·034	1·66	0·261	49·3
1967[a]	35·5	1·45	0·022	0·014	0·032	1·64	0·202	—
1967[b]	44·0	0·94	0·019	0·016	0·036	1·49	0·210	28·7
1968	30·4	1·53	0·021	0·014	0·035	1·60	0·276	28·9
1969	41·8	1·30	0·020	0·020	0·027	1·50	0·250	27·6
1970	34·5	1·14	0·025	0·050	0·028	1·12	0·186	17·6
Mean	36·6	1·20	0·021	0·022	0·033	1·49	0·225	28·9

(a) Applied in spring
(b) Applied in autumn

APPENDIX TABLE 3

Yields of barley (tonnes/ha) in 1966

N (kg/ha)	PKMg equivalent to straw + P: Peat	Straw	Green manures	Fertilisers only	PKMg equivalent to FYM: Fertilisers only	FYM	Mean	
				Grain at 85% dry matter				
0	0·89	0·51	1·10	0·88	0·92	1·44	0·96	±0·046
25	1·93	1·75	1·66	2·10	2·20	2·32	1·99	
50	3·10	2·81	2·22	2·98	3·35	3·30	2·96	
75	3·93	3·50	3·49	4·13	3·93	4·46	3·91	
Mean	2·46	2·14	2·12	2·52	2·60	2·88	2·45	
S.E.	±0·089							
				Total dry matter (grain plus straw)				
0	1·22	0·72	2·77	1·15	1·32	2·14	1·57	±0·080
25	2·89	2·62	2·33	3·12	3·33	3·61	2·98	
50	4·58	4·33	3·24	4·63	5·20	5·23	4·53	
75	6·06	5·25	4·72	6·24	6·17	6·89	5·89	
Mean	3·69	3·23	3·26	3·81	4·01	4·47	3·74	
S.E.	±0·126							

S.E. for use in vertical and interaction comparisons ±0·114 (grain) ±0·196 (total DM)
S.E. for use in horizontal comparisons ±0·133 (grain) ±0·212 (total DM)

APPENDIX TABLE 4

Yields of potatoes (tonnes/ha) in 1967

N (kg/ha)	Peat	Straw	Green manures	Fertilisers only	Fertilisers only	FYM	Mean	
	PKMg equivalent to straw + P				PKMg equivalent to FYM			
	Total tubers (fresh weights)							
25	9·1	9·9	16·7	9·2	11·2	14·5	11·8	±0·47
75	15·3	14·3	20·8	12·6	14·7	17·4	15·8	
125	14·3	19·8	25·6	15·2	20·7	22·5	19·7	
175	19·7	22·4	27·8	17·5	24·2	26·2	23·0	
Mean	14·6	16·6	22·7	13·6	17·7	20·2	17·6	
S.E.	±1·68							
	Total dry matter (tubers only)							
25	2·03	2·23	3·84	2·01	2·49	3·36	2·66	±0·121
75	3·54	3·34	4·85	2·86	3·34	3·87	3·63	
125	3·29	4·70	5·88	3·49	4·75	5·10	4·54	
175	4·65	5·35	6·50	4·04	5·42	5·98	5·32	
Mean	3·38	3·90	5·27	3·10	4·00	4·58	4·04	
S.E.	±0·399							

S.E. for use in vertical and interaction comparisons ±1·16 (total tubers) ±0·291 (total DM)
S.E. for use in horizontal comparisons ±1·96 (total tubers) ±0·472 (total DM)

APPENDIX TABLE 5

Yields of winter wheat (tonnes/ha) in 1968

N (kg/ha)	Peat	Straw	Green manures	Fertilisers only	Fertilisers only	FYM	Mean	
	PKMg equivalent to straw + P				PKMg equivalent to FYM			
	Grain at 85% dry matter							
25	2·65	2·57	3·20	2·64	2·59	3·80	2·91	±0·072
75	3·82	3·92	4·73	3·97	4·19	5·00	4·27	
125	4·58	4·57	4·52	4·65	4·71	4·90	4·66	
175	4·71	4·80	4·46	4·82	4·62	4·47	4·65	
Mean	3·94	3·96	4·23	4·02	4·03	4·54	4·12	
S.E.	±0·137							
	Total dry matter (grain plus straw)							
25	4·81	4·52	4·93	4·87	4·55	6·75	5·07	±0·119
75	6·98	7·09	7·76	7·22	7·59	8·97	7·60	
125	8·45	8·40	8·25	8·46	8·38	9·16	8·52	
175	8·64	8·98	8·24	8·70	8·44	9·12	8·68	
Mean	7·22	7·25	7·30	7·31	7·24	8·50	7·47	
S.E.	±0·230							

S.E. for use in vertical and interaction comparisons ±0·175 (grain) ±0·291 (total DM)
S.E. for use in horizontal comparisons ±0·205 (grain) ±0·341 (total DM)

APPENDIX TABLE 6

Yields of sugar beet (tonnes/ha) in 1969

	PKMg equivalent to straw + P				PKMg equivalent to FYM			
N (kg/ha)	Peat	Straw	Green manures	Fertilisers only	Fertilisers only	FYM	Mean	
				Clean beet				
25	24·3	24·6	33·5	24·2	22·9	36·9	27·7	±0·69
75	29·0	31·1	35·4	31·0	31·0	40·1	32·9	
125	36·6	34·6	36·9	33·9	33·3	41·9	36·2	
175	37·9	36·3	36·2	34·3	34·5	41·4	36·8	
Mean	32·0	31·6	35·5	30·8	30·4	40·1	33·4	
S.E.				±1·49				
				Total sugar				
25	4·82	4·88	6·61	4·75	4·57	7·41	5·51	±0·141
75	5·85	6·21	6·97	6·10	6·14	8·00	6·55	
125	7·09	6·95	7·04	6·80	6·51	8·17	7·09	
175	7·40	7·02	6·75	6·60	6·57	7·94	7·05	
Mean	6·29	6·27	6·84	6·06	5·95	7·88	6·55	
S.E.				±0·333				
				Total tops (dry matter)				
25	1·8	1·5	3·1	1·7	1·9	2·8	2·2	±0·12
75	2·6	2·4	3·6	2·7	2·5	3·5	2·9	
125	3·7	3·2	4·3	3·2	3·1	4·1	3·6	
175	4·3	3·9	5·0	4·0	3·5	4·6	4·2	
Mean	3·1	2·8	4·0	2·9	2·7	3·7	3·2	
S.E.				±0·20				
				Total dry matter (tops plus roots)				
25	8·4	8·2	12·2	8·3	8·1	12·6	9·6	±0·27
75	10·6	10·9	13·2	11·0	10·9	14·4	11·8	
125	13·5	12·7	14·1	12·4	12·0	15·1	13·3	
175	14·4	13·6	14·5	13·2	12·6	15·4	14·0	
Mean	11·7	11·3	13·5	11·2	10·9	14·4	12·2	
S.E.				±0·60				

S.E. for use in vertical and interaction comparisons ±1·68 (clean beet), ±0·345 (sugar), ±0·29 (tops), ±0·66 (total DM)

S.E. for use in horizontal comparisons ±2·08 (clean beet), ±0·448 (sugar), ±0·32 (tops), ±0·82 (total DM)

APPENDIX TABLE 7

Yields of beans (tonnes/ha) in 1970

N[a] (kg/ha)	PKMg equivalent to straw + P: Peat	Straw	Green manures	Fertilisers only	PKMg equivalent to FYM: Fertilisers only	FYM	Mean	
	Grain at 85% dry matter							
25	0·63	0·89	0·80	0·70	0·56	1·18	0·79	±0·040
75	0·73	1·04	0·91	0·71	0·64	1·09	0·85	
125	0·61	0·72	0·98	0·93	0·50	1·19	0·82	
175	0·80	0·96	0·90	0·71	0·55	1·11	0·84	
Mean	0·69	0·90	0·90	0·77	0·56	1·14	0·83	
S.E.	±0·062							
	Total dry matter (grain plus straw)							
25	0·94	1·20	1·25	1·06	0·96	1·67	1·18	±0·050
75	1·17	1·48	1·35	1·09	1·03	1·67	1·30	
125	0·99	1·00	1·53	1·32	0·90	1·66	1·23	
175	1·26	1·30	1·42	1·09	0·92	1·61	1·27	
Mean	1·09	1·25	1·39	1·14	0·95	1·65	1·24	
S.E.	±0·079							

S.E. for use in vertical and interaction comparisons ±0·097 (grain) ±0·124 (total DM)
S.E. for use in horizontal comparisons ±0·105 (grain) ±0·133 (total DM)
(a) N rates applied to sugar beet in 1969; no N in 1970

APPENDIX TABLE 8

Yields of rye (tonnes/ha) in 1971

N[a] (kg/ha)	PKMg equivalent to straw + P: Peat	Straw	Green manures	Fertilisers only	PKMg equivalent to FYM: Fertilisers only	FYM	Mean	
	Grain at 85% dry matter							
25	3·48	3·61	3·33	3·33	3·29	4·76	3·63	±0·041
75	3·43	3·63	3·18	3·46	3·38	4·63	3·62	
125	3·48	3·48	3·46	3·36	3·48	4·46	3·62	
175	3·58	3·76	3·44	3·03	3·32	4·63	3·63	
Mean	3·49	3·62	3·35	3·29	3·37	4·62	3·62	
S.E.	±0·133							
	Total dry matter (grain plus straw)							
25	6·69	6·92	6·44	6·27	6·39	9·38	7·01	±0·071
75	6·53	6·88	6·70	6·42	6·63	9·33	7·08	
125	6·69	6·51	7·36	6·29	6·63	8·62	7·02	
175	6·72	7·07	6·77	6·02	6·63	9·13	7·06	
Mean	6·66	6·84	6·82	6·25	6·57	9·12	7·04	
S.E.	±0·223							

S.E. for use in vertical and interaction comparisons ±0·099 (grain) ±0·175 (total DM)
S.E. for use in horizontal comparisons ±0·158 (grain) ±0·270 (total DM)
(a) N rates applied to sugar beet in 1969; 31 kg N/ha to rye (all plots) in 1971

APPENDIX TABLE 9

Yields of rye (tonnes/ha) in 1972

(Blocks II and IV only)

N[a] (kg/ha)	PKMg equivalent to straw + P: Peat	Straw	Green manures	Fertilisers only	PKMg equivalent to FYM: Fertilisers only	FYM	Mean	
				Grain at 85% dry matter				
25	2·74	2·83	3·60	2·69	2·45	3·73	3·00	±0·058
75	2·54	2·96	3·69	2·77	2·84	3·63	3·07	
125	2·51	2·97	3·97	2·76	2·58	3·84	3·10	
175	2·83	3·18	3·73	2·70	2·54	3·71	3·12	
Mean	2·66	2·98	3·75	2·73	2·60	3·73	3·07	
S.E.	±0·147							
				Total dry matter (grain plus straw)				
25	5·79	6·04	7·20	5·71	4·98	7·81	6·26	±0·171
75	5·43	6·50	7·39	5·97	5·91	7·84	6·51	
125	5·22	6·19	7·57	5·88	4·90	7·85	6·27	
175	5·91	6·93	7·18	5·83	5·76	7·36	6·49	
Mean	5·59	6·41	7·34	5·85	5·39	7·71	6·38	
S.E.	±0·313							

S.E. for use in vertical and interaction comparisons ±0·143 (grain) ±0·419 (total DM)
S.E. for use in horizontal comparisons ±0·192 (grain) ±0·479 (total DM)
(a) N rates applied to sugar beet in 1969; 40 kg N/ha to rye (all plots) in 1972

APPENDIX TABLE 10

Amounts of N, P, K, Na, Ca and Mg (kg/ha) removed by arable crops, 1966–71

(Means of all rates of N)

Nutrient	Year	Peat	Straw	Green manures	Fertilisers (Fs)	Fertilisers (Fd)	Farmyard manure	S.E.
Nitrogen	1966	34·8	31·3	39·5	35·2	36·4	42·9	±1·65
	1967	44·4	49·4	72·2	41·4	50·8	67·0	±4·88
	1968	76·6	76·3	82·7	78·0	74·9	99·0	±1·72
	1969	50·3	52·0	68·9	52·2	51·7	72·0	±2·42
	1970	26·8	35·1	37·2	29·1	23·5	45·8	±2·06
	1971	51·4	56·9	70·0	49·0	51·8	81·6	±2·44
	Total	284·3	301·0	370·5	284·9	289·1	408·3	
Phosphorus	1966	8·2	7·7	8·5	8·4	8·9	10·6	±0·25
	1967	7·4	9·0	11·2	6·7	10·1	11·0	±0·87
	1968	16·4	17·7	18·3	16·4	17·6	22·1	±0·72
	1969	11·4	11·5	11·8	10·8	11·8	16·2	±0·57
	1970	3·5	4·7	4·7	3·8	3·1	5·8	±0·30
	1971	13·8	14·7	14·9	13·0	13·8	20·2	±0·44
	Total	60·7	65·3	69·4	59·1	65·3	85·9	
Potassium	1966	21·2	19·8	26·6	21·7	25·4	30·9	±1·74
	1967	67·1	77·9	101·2	63·0	90·8	97·7	±8·29
	1968	58·6	57·1	65·8	57·3	57·5	81·4	±4·36
	1969	65·7	67·6	72·7	63·7	70·1	90·1	±3·57
	1970	15·7	17·3	21·3	16·3	15·8	27·2	±1·20
	1971	38·3	39·2	58·2	33·1	37·6	63·9	±2·11
	Total	266·6	278·9	345·8	255·1	297·2	391·2	
Sodium	1966	0·68	0·59	0·59	0·67	0·66	0·83	±0·059
	1967	0·22	0·27	0·31	0·19	0·25	0·25	±0·038
	1968	0·62	0·55	0·86	0·59	0·66	0·83	±0·104
	1969	1·69	1·34	1·87	1·34	1·49	2·92	±0·114
	1970	0·22	0·34	0·34	0·22	0·22	0·56	±0·022
	1971	0·61	0·64	0·73	0·65	0·60	0·87	±0·046
	Total	4·04	3·73	4·70	3·66	3·88	6·26	
Calcium	1966	5·2	4·9	9·9	5·3	5·7	6·5	±0·85
	1967	2·0	2·6	3·2	2·0	2·5	2·9	±0·28
	1968	10·9	11·1	10·5	10·9	10·5	13·5	±0·48
	1969	17·1	16·3	21·8	17·5	14·1	18·8	±1·17
	1970	7·5	8·3	10·1	7·8	6·3	9·6	±0·49
	1971	8·1	8·2	17·3	7·1	8·1	12·3	±0·82
	Total	50·8	51·4	72·8	50·6	47·2	63·6	
Magnesium	1966	2·9	2·7	3·3	3·1	3·2	3·8	±0·12
	1967	2·5	2·9	4·0	2·4	3·7	4·1	±0·31
	1968	5·2	5·9	6·1	5·4	5·5	6·9	±0·23
	1969	7·8	7·7	8·5	7·7	8·4	12·0	±0·39
	1970	1·3	1·6	1·8	1·3	1·2	2·2	±0·10
	1971	3·9	4·1	5·2	3·7	3·9	5·8	±0·17
	Total	23·6	24·9	28·9	23·6	25·9	34·8	

Notes: 1966, Barley, grain + straw; 1967, Potatoes, tubers only; 1968, Winter wheat, grain + straw; 1969, Sugar beet, roots only; 1970, Beans, grain + straw; 1971, Winter rye, grain + straw