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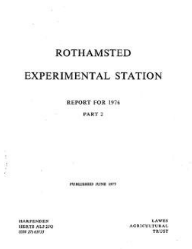
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PART 2

The Woburn Long-term Experiment on Green Manuring, 1936-67; Results With Barley

G. V. Dyke, H. D. Patterson and the Late T. W. Barnes

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The Woburn Long-term Experiment on Green Manuring, 1936–67; Results with Barley

G. V. DYKE, H. D. PATTERSON* and the late T. W. BARNES†

Field experiments on 'green manuring' have been done on the greensand at Woburn since 1892. The phrase 'green manuring' has been used during this period in several different senses. In the earlier experiments the green manures often occupied the land for the whole of a growing season; sometimes they were eaten on the plots by sheep (with additional feeding of cake), sometimes they were ploughed in without grazing. We restrict the use of the term 'green manuring' to the practice of growing a crop of which the whole will be incorporated in the soil to improve the yields of one or more subsequent crops.

We see two economically possible uses for green manuring in farming now. In the reclamation of land that has been out of farming (e.g. land restored after mining or engineering work, or reclaimed from the sea) cash grants may be available that make it possible to devote land for one or more growing seasons to green manure crops which bring no income to the farmer. This use we do not further consider in this paper.

In established farming, where outlay must be matched by expected returns within a reasonable period, it seems to us unlikely that a farmer can afford to forego all income from land for a season, and spend some money on growing a green manure, unless a very great increase of subsequent yields is assured. The Woburn experiments show that no such increase of yield can be expected and we believe that this application of green manuring is quite valueless at present.

It seems therefore that the only important application of green manuring in stable agriculture is the insertion of green manures as catch crops into a system with at least one cash crop each year. Early experiments at Woburn did not deal directly with this practical application of green manuring. Experiments since 1955 have tested two methods:

(a) the sowing of a green crop (trefoil or ryegrass) after early potatoes for ploughing down the following spring before barley,
(b) the undersowing of trefoil or ryegrass in barley; the green crop is ploughed down in autumn or in spring for a following crop of potatoes, sugar beet or barley.

Early experiments

Some of the experiments that were started before 1936 compared different species (mainly rape, tares and mustard) grown as green manures; others tested the effects of roots and tops separately and together (Mann, 1958) but few experiments included plots without green manures. In most of these experiments the green crops occupied the land for the whole of a growing season. The early experiments used winter wheat (without fertiliser) as test-crop alternating with the summer green crops which were grown repeatedly on the

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† Barnes worked as chemist at Woburn from 1928 to 1966 when he retired. He contributed much to the Green Manuring experiment (among others) in the field and in the laboratory and he took part in the early stages of the preparation of this paper. He died in 1974.

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same plots. For a summary of the wheat experiments see Crowther and Mann (1933).

Garrett and Mann (1948) studied the effect of undersowing trefoil (*Medicago lupulina*) in a sequence of crops of barley—a practical use of a green manure similar to that used by some farmers on light soils in the Chiltern Hills ('the Chamberlain system').

Where trefoil had been ploughed down the incidence of take-all (*Gaeumannomyces graminis*) was slightly lessened and yields of grain were increased by 0·4 t ha^{-1}; on plots without trefoil ploughing in spring gave slightly more grain than ploughing in autumn. The best yields, from plots with trefoil ploughed down and also given some ammonium sulphate in autumn, were only about 2 t ha^{-1}—very poor by present standards.

Long-term experiment—first period 1936–53

In 1936 a major long-term experiment was started on the subject of green manuring. The site was in Stackyard Field Series A, one of the areas previously used for many years for the experiment on the manurial value of cake and corn fed to sheep and bullocks (Russell & Voelcker, 1936). The surface soil is mainly sand to loamy sand over resorted lower greensand; it is classified as Cottenham Series.

Conventions adopted in this paper are:

1. The word 'fallow' is used for plots not sown with green manure crops. The sequence of harvested crops was the same on all plots compared but the 'fallow' plots were ploughed and cultivated independently while the green manures were growing. From the time of ploughing-down the green manures cultivations were the same on all plots. As this is a rather special use of the word 'fallow' the quotation marks will be used throughout this paper.
2. When a rate of N applied to a crop is mentioned this refers to 'Nitro-Chalk' unless otherwise stated.
3. The phrase 'test-crop' is used to indicate the crop whose yield is being discussed or tabulated. 'Nurse-crop' means the crop (barley in this experiment) which is growing in the same season as an undersown green manure. In this experiment all harvested crops were test-crops.

From 1936 to 1953 barley (B) and kale (K) (winter cabbages from 1946) were grown in alternation on adjacent areas (the 'Upper Half' and 'Lower Half'), 40 plots of each crop each year. Four green manures were tested in comparison with 'fallow' plots (F)

V: vetches or lupins
M: mustard or rape
R: ryegrass
C: red clover

Of these V and M were sown in the spring of the year after barley, R and C were undersown in the barley. All green crops were ploughed down about June and kale was sown (in 1946 and later years, cabbages were planted out) soon afterwards. Each of the treatments F, V and M was repeated on the same plots in successive two-year periods; R and C alternated. The sequences, with approximate dates, are shown in Fig. 1.

Additional factors and minor changes:

D: farmyard manure (FYM) at 0 *v.* 25 t ha^{-1} to kale (later to cabbages).
S: chaffed barley straw at 0 *v.* 3·8 t ha^{-1} applied in autumn after barley harvest.
N: 26 *v.* 53 kg N ha^{-1}, applied as ammonium sulphate to kale/cabbages (N1, N2 respectively).

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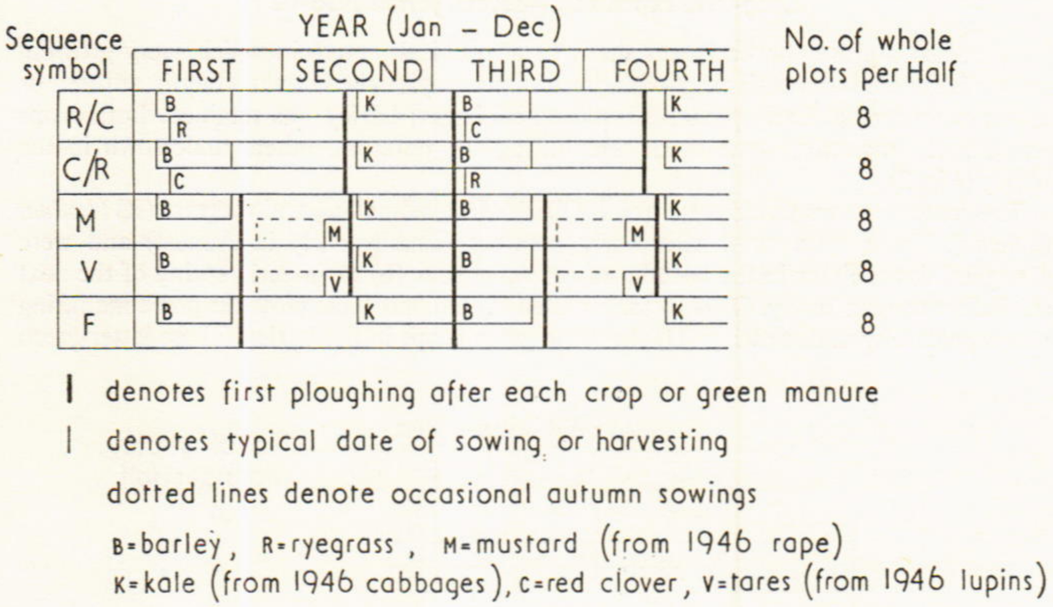

FIG. 1. Long-term experiment. Crop sequences 1936–53.

The design was $5 \times 2^3 = 40$ treatments. There were two replicates ('Halves'), each arranged as one randomised block of 40 plots. One Half was in each phase of the two-year rotation.

From 1944 an additional factor was included:

A: 0 *v.* 38 (50 in 1944 only) kg N ha^{-1} top-dressed to barley (A1 *v.* A2).
The design was now a half-replicate with identity

$$I \equiv (R/C + C/R - M - V - F)\ DSNA$$

From 1946 A2 plots received 38 kg N ha^{-1} (A1, none) when they carried green manures (including 'fallow').
From 1949 the rates of N applied to the green manures and 'fallow' were 38, 75, kg N ha^{-1}, on A1, A2 plots respectively. All N was applied as sulphate of ammonia.
From 1950 to 1952 two dates of planting of cabbages were compared on half plots.

Mann (1959) summarised the results of this experiment up to 1953. He emphasised that, in years of little summer rainfall (May to August inclusive) the green manures did not rot satisfactorily and, because the soil was drier where they had been grown than on 'fallow' plots, they lessened yields of the cabbages. In seasons of greater summer rainfall clover (C) and vetches or lupins (V) increased the yield of cabbages but ryegrass (R) and rape or mustard (M) decreased them. The percentage differences in yields of barley were smaller than in cabbages but each green manure, when ploughed down in a dry season, on average slightly decreased the yield of barley in the following season, but when ploughed down in a wet season each gave a small mean increase. Because of these disappointing results the experiment was modified in 1954; the changes were made to ensure that green manures were ploughed down when the soil was wet enough for immediate rotting and that differences in soil wetness would not affect the yields of the following crop.

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Long-term experiment—second period 1955–62

Now at last a close approach was made to a practical system in which every growing season is devoted to a cash crop, with green manures ploughed down either in autumn or in the early spring. Early potatoes replaced cabbages; barley was retained. Both crops tested green manures, some sown after lifting the potatoes, others undersown in the barley (Fig. 2).

The green manures tested were trefoil (T) (*Medicago lupulina*) and ryegrass (R) (*Lolium italicum*). These were sown after early potatoes (usually early in August) and were ploughed down either in the autumn of the same year (E) or in early spring of the next (L) before sowing barley. (This factor is called P.) On half these plots the green manuring was repeated by undersowing (U) the same green crops in the barley. These latter green

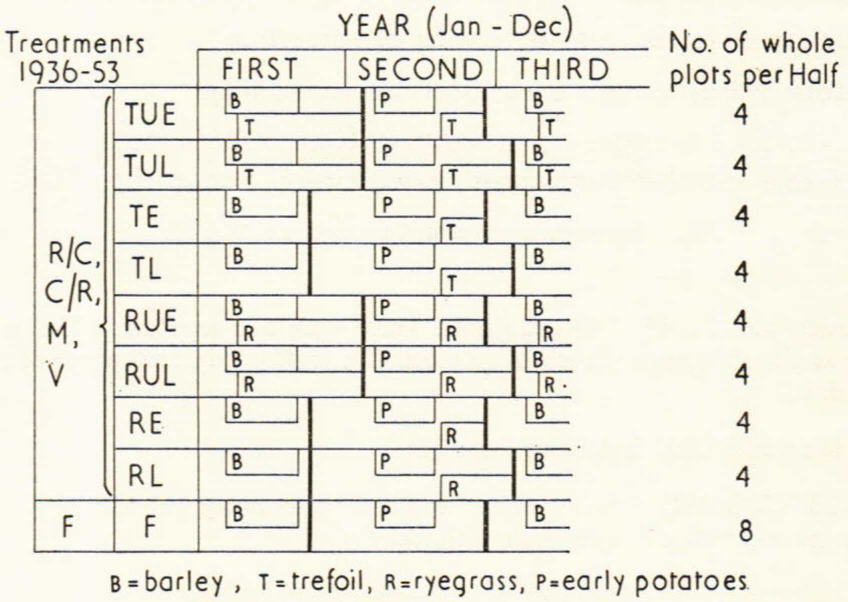

FIG. 2. Long-term experiment. Crop sequences 1955–62 (conventions as in Fig. 1).

manures were all ploughed down in spring. The eight systems of green manuring given by the combination of these three factors were applied to the plots of the former R/C, C/R, V and M treatments of which there were 32 per Half. The 'fallow' plots continued without green manures; they were ploughed in autumn before barley, at the same time as the E plots (Fig. 2).

The test of 0 *v.* straw (S) spread after barley harvest continued on the same plots as formerly, but a new test (N) of 'Nitro-Chalk' was introduced:

	kg N ha^{-1}	
Treatment	N1	N2
to barley	29	58
to potatoes	75	151

The new treatments were allocated to the plots so that the residual effects of FYM, denoted by (D), and of one contrast of the earlier green manures (R/C and C/R–V–M), denoted by (X), could be estimated; other residual effects were eliminated by randomisation. Each Half now comprised:

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(i) 'fallow' plots—single replicate of 2^3 with factors (D), S, N
(ii) remainder—quarter replicate of 2^7 with identities

$$
\begin{aligned}
I &\equiv (D)(X)UN \\
&\equiv S(X)PG \\
&\equiv (D)SPUGN
\end{aligned}
$$

Details of crop varieties, basal manuring etc, throughout the period can be found in '*Details*' (Rothamsted, 1970) and dates of sowing, harvest etc., together with annual summaries of crop yields from 1939 onwards in '*Yields*' (Rothamsted, published annually); earlier yields were reported annually in Station *Reports*. The results for this period were summarised by Barnes and Clarke (1963).

Long-term experiment—third period 1963–67

In 1962 the early potatoes on the Upper Half showed signs of damage by potato cyst-nematode (*Globodera rostochiensis*) and potatoes were not grown after that year. Sugar beet was sown on the Lower Half in 1963; otherwise barley was grown on both Halves each year. The sequences of main crops and of green manures, with approximate dates of sowing etc. are shown in Fig. 3.

In 1964 and 1965 trefoil was undersown on four plots per Half that had carried trefoil in earlier years and on four that had carried ryegrass; similarly for ryegrass. The remaining eight plots were left without undersown green crops. In 1966 no green manures were undersown on the Upper Half and this part of the experiment ended at harvest 1966. On the Lower Half in 1966 new treatments were applied, including the undersowing of trefoil and ryegrass, each on four plots of those hitherto without green manures (F).

From 1963 comparisons were made in each test-crop of 'Nitro-Chalk' at four or five rates. For this purpose each plot was split into two by halving the length and the rates of N were paired, the first and third being applied to the halves of some plots, the second and fourth to the halves of others. The following were applied as separate factors, all combinations occurring on equal numbers of plots:

Upper Half 1963 (to barley) 0, 38, 75, 113 kg N ha^{-1}
Lower Half 1963 (to sugar beet) 0, 84, 166, 251 kg N ha^{-1}
Upper and Lower Halves 1964 and 1965 (to barley; dressings repeated on same plots)
  38, 75, 113, 151 kg N ha^{-1} to F plots
  0, 38, 75, 113 kg N ha^{-1} to remainder
Upper Half 1966 (to barley) 38, 75, 113, 151 kg N ha^{-1}
Lower Half 1966 (to barley) plots undersown, 38, 113 kg N ha^{-1}
  plots not undersown, 0, 38, 75, 113 kg N ha^{-1}
Lower Half 1967 (to barley) 38, 75, 113, 151 kg N ha^{-1}

Chemical analysis of green manures

The green manures were sampled just before ploughing, the tops and as much as possible of the roots were recovered, freed from soil and dried. The amounts of dry material calculated from these samples are given in Table 1. Each year the percentage of N was determined for bulked samples as indicated in the table.

Ryegrass provided more dry matter than trefoil at each of the three occasions of ploughing down. Ryegrass provided about equal amounts of dry matter and N whether ploughed down in autumn or spring for barley; trefoil, by contrast, provided much less dry matter and N when ploughed down in spring than in autumn. Damage by frost and by birds probably caused most of the loss during the winter. Ryegrass ploughed down in

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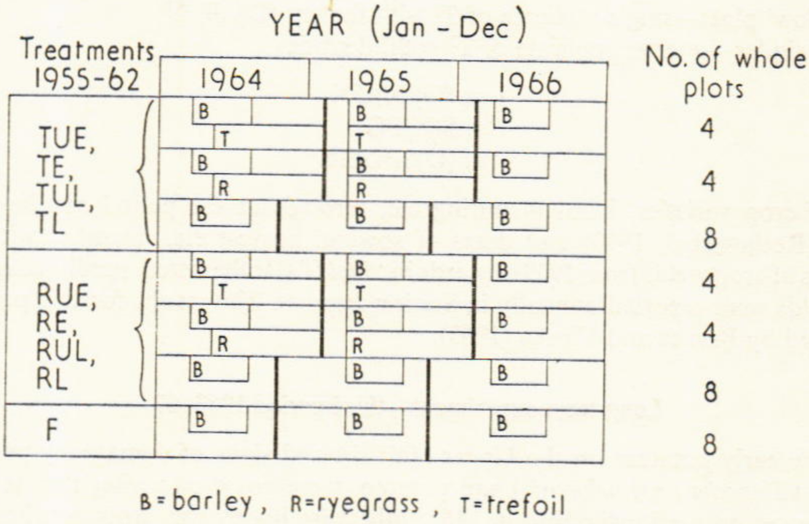

FIG. 3a. Long-term experiment. Crop sequences, Upper Half 1964–67 (conventions as in Fig. 1).

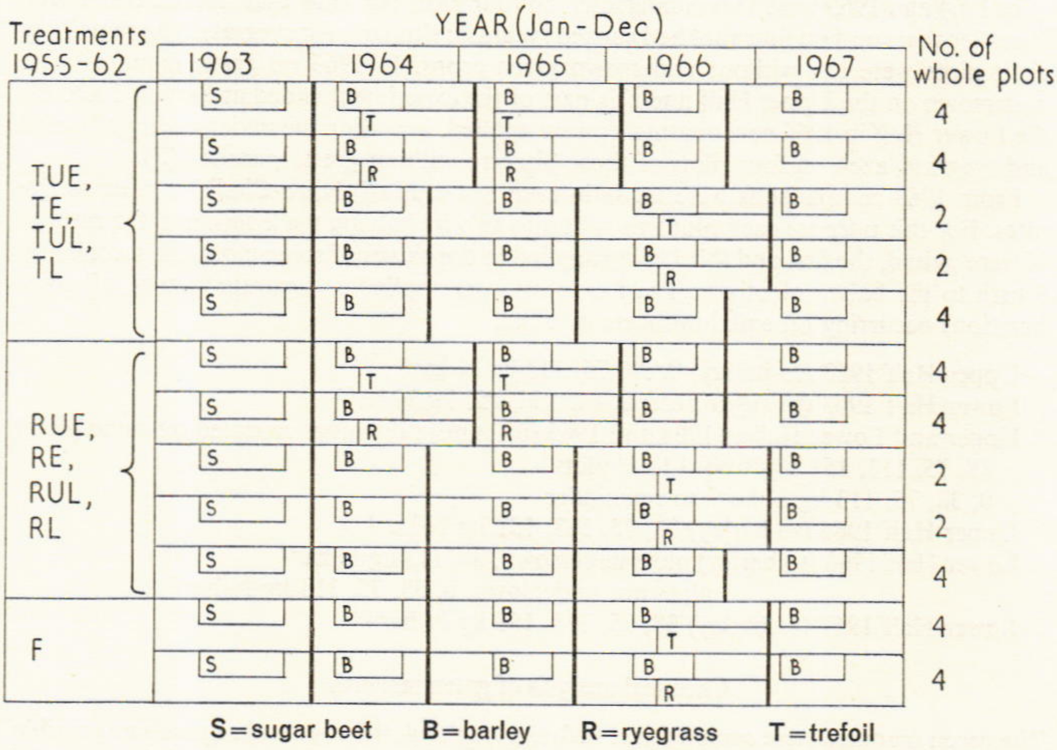

FIG. 3b. Long-term experiment. Crop sequences, Lower Half 1963–67 (conventions as in Fig. 1).

spring for potatoes had a smaller percentage of N than ryegrass for barley (autumn or spring); in trefoil the percentage of N was about equal on all three occasions.

Trefoil ploughed down in autumn for barley provided much more N than either dressing of 'Nitro-Chalk'; the other green manures for barley provided about the equivalent of the heavier dressing of 'Nitro-Chalk' (58 kg N ha^{-1}) or a little less. For potatoes

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TABLE 1

Dry matter and N in green manures ploughed down for test-crops grown in 1955–62

(Means of results for eight seasons)

	Trefoil			Ryegrass		
	No FYM*	FYM*	Mean	No FYM*	FYM*	Mean
			(a) Before barley, ploughed down in autumn			
			Dry matter ($t\ ha^{-1}$)			
N1	2·49	2·89	2·69	2·82	3·35	3·09
N2	3·24	2·74	2·99	3·59	3·54	3·56
Mean	2·86	2·81	2·84	3·21	3·44	3·33
	%N		3·22			1·74
	N ($kg\ ha^{-1}$)		92			57
			(b) Before barley, ploughed down in spring			
			Dry matter ($t\ ha^{-1}$)			
N1	1·28	1·27	1·28	2·50	2·99	2·74
N2	1·47	1·58	1·53	2·87	3·51	3·20
Mean	1·38	1·43	1·41	2·69	3·25	2·97
	%N		3·04			1·82
	N ($kg\ ha^{-1}$)		43			54
			(c) Before potatoes, ploughed down in spring			
			Dry matter ($t\ ha^{-1}$)			
N1	2·21	1·93	2·07	2·67	2·43	2·56
N2	2·21	2·06	2·13	2·32	2·41	2·37
Mean	2·21	2·00	2·11	2·50	2·42	2·46
	%N		2·96			1·48
	N ($kg\ ha^{-1}$)		63			36

* FYM last applied 1953

Standard errors of dry matter figures

	Trefoil	Ryegrass
Body of each table	±0·188	±0·193
Marginal means	±0·133	±0·138

N1: 'Nitro-Chalk' at 29 kg N ha^{-1} to barley, 75 kg N ha^{-1} to potatoes
N2: 'Nitro-Chalk' at 58 kg N ha^{-1} to barley, 151 kg N ha^{-1} to potatoes (none to green manures)

each green manure provided much less N than the lighter dressing of 'Nitro-Chalk' (75 kg N ha^{-1}).

On plots that received the heavier dressing of N to the test-crops the green manures sown after potatoes provided 15–20% more dry matter than on plots with less N, but those undersown in barley gave about the same (trefoil) or less (ryegrass), presumably because of increased competition by the nurse-crop. The residual effect of FYM was, on average, a slight increase in the amount of dry matter in green manures sown in the open after early potatoes, but a small decrease in those undersown in the barley, probably because of increased competition by the barley.

The application of straw to the barley stubble after harvest had negligible effects on the green crops undersown in the barley; residual effects of straw on green crops sown after potatoes were small and not significant.

Table 2 shows the estimated amounts of dry matter and N in green manures ploughed down for barley in the later years of the experiment. Comparison with Table 1 indicates that, where 0 or 38 kg N ha^{-1} were applied to the barley nurse-crop, amounts of dry matter and N were similar to those given by undersown green manures in 1955–62; trefoil gave about 2 t dry matter and 54 kg N ha^{-1}, ryegrass about 2·1 t dry matter and

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TABLE 2

Dry matter and N in green manures ploughed down for barley 1964–67

Dry matter (DM), t ha^{-1}; N, kg ha^{-1}

Year of test-crop	'Half'		Trefoil 0	Trefoil 38	Trefoil 75	Trefoil 113	Ryegrass 0	Ryegrass 38	Ryegrass 75	Ryegrass 113
			N to nurse-crop barley (kg ha^{-1})							
1964	Upper	DM	2·60	3·06	2·25	1·92	3·43	2·74	2·50	2·17
		N	88*	104*	76*	65*	57†	45†	41†	36†
1965	Upper	DM	1·87	1·34	0·98	0·65	0·70	0·54	0·51	0·38
		%N	2·78	2·62	2·07	2·43	1·38	1·43	1·55	1·69
		N	52	35	20	16	10	8	8	6
	Lower	DM	1·98	1·58	1·03	0·73	0·85	0·82	0·70	0·45
		%N	2·84	2·54	2·24	2·26	1·10	1·12	1·24	1·48
		N	56	40	23	16	9	9	9	7
1966	Upper	DM	1·96	1·20	1·03	0·53	3·04	2·71	3·21	2·89
		%N	3·08	2·91	2·98	2·52	0·95	0·96	1·03	1·40
		N	60	35	31	13	29	26	33	40
	Lower	DM	2·00	1·86	0·82	0·55	4·32	2·50	3·34	2·69
		%N	3·09	3·20	3·08	3·18	1·04	1·08	1·12	1·21
		N	62	59	25	18	45	27	37	33
1967	Lower A+	DM	—	2·54	—	1·84	—	2·26	—	2·26
		%N	—	3·07	—	3·05	—	1·73	—	1·08
		N	—	78	—	56	—	39	—	24
	Lower B+	DM	—	1·05	—	2·16	—	2·62	—	2·71
		%N	—	3·01	—	3·05	—	1·04	—	1·20
		N	—	70	—	66	—	27	—	33
Mean (excl. 1967)		DM	2·08	1·81	1·22	0·88	2·47	1·86	2·56	1·72
		N	64	43	35	26	30	23	26	24
Mean of all		DM	—	1·80	—	1·20	—	2·03	—	1·94
		N	—	52	—	36	—	26	—	26

* Based on bulked sample of trefoil (3·40% N)
† Based on bulked sample of ryegrass (1·66% N)
A+ Plots previously 'fallow'
B+ Plots previously green-manured

26 kg N ha^{-1}. But in 1964–67 in contrast to the earlier period, the dry matter and N in trefoil were decreased by each increment of N to the nurse-crop. With 113 kg N trefoil gave less than half its yield without N; ryegrass varied rather erratically with the rate of N and its yield of N was about equal to that of trefoil with 75 or 113 kg N; with none or 38 kg N trefoil gave roughly double the N of ryegrass.

Soil samples 1961 and 1966

In February 1961 the soil of each plot was sampled to 23 cm depth for the determination of N (Tables 3a and 3b).

Comparison of the first and second lines of Table 3a shows that green manuring over a period of 25 years (mainly in alternate years) had increased the percentage of N by 0·010—an accumulation of about 340 kg N ha^{-1} in the 23 cm ploughed layer. The effect of the green maures was less where FYM had been applied in the past, but the variation of the effect is small in comparison with the standard error. On the average over all crop-sequences straw and residual FYM each increased the amounts of N significantly ($+ 0{\cdot}006 \pm 0{\cdot}0017$ and $+ 0{\cdot}008 \pm 0{\cdot}0017$ %N respectively).

Ryegrass on average left less N in the soil than trefoil (Table 3b) and green manures grown every year (TU, RU) gave substantially greater increases than those grown every second year (T, R).

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TABLE 3(a)

% N in oven-dry soil: February 1961

Crop sequence	No FYM*		FYM*		Mean	Effect of:				
	No straw	Straw	No straw	Straw		FYM*	Straw	N	Ploughing date†	Green manure‡
		(±0·0038)			(±0·0019)			(±0·0038)		
(i) F	0·078	0·088	0·094	0·096	0·089	+0·012	+0·006	+0·002	—	—
		(±0·0019)			(±0·0010)			(±0·0019)		
(ii) Mean R, TU, R, RU	0·092	0·099	0·100	0·105	0·099	+0·008	+0·006	+0·004	+0·002	+0·006
		(±0·0017)								
Mean of all	0·089	0·097	0·099	0·103						
		(±0·0043)			(±0·0022)			(±0·0043)		
Difference (ii) minus (i)	+0·014	+0·011	+0·006	+0·009	+0·010	−0·004	0·000	0·002	—	—

* Last applied 1953
† Spring minus autumn
‡ Clover and ryegrass minus rape and lupins, 1936–53

TABLE 3(b)

Crop sequence	No FYM	FYM*	Mean	Increase over F
	(±0·0027)		(±0·0019)	(±0·0027)
F	0·083	0·095	0·089	—
T	0·094	0·104	0·099	+0·010
TU	0·101	0·106	0·104	+0·015
R	0·096	0·096	0·096	+0·007
RU	0·092	0·105	0·098	+0·009

* Last applied 1953

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TABLE 4

Woburn Ley–Arable experiment; % N in oven-dry soil: means of five blocks, one sampled each year 1956–60

(Plots without FYM)

	Mean	Increase over A
A	0·097	—
AH	0·099	+0·002
Lu	0·105	+0·008
L	0·111	+0·014

Five-year rotations:
A: arable (potatoes, rye, roots)
AH: arable with hay (potatoes, rye (undersown), one year hay)
Lu: lucerne (three years, cut)
L: ley (three years, grazed)
All followed by test-crops: potatoes, barley

For comparison, Table 4 shows the results of determinations of N in the soils of certain plots of the Woburn Ley-Arable experiment, also in Stackyard field, which was started in 1938. These determinations were made by one of us (TWB) and were quoted in part by Mann and Boyd (1958). They refer to plots that carried the same crop-rotations in each five-year period throughout the period and received no FYM; plots with 'alternating' rotations were not sampled. It is of interest that the largest difference ('grazed ley' minus 'arable with roots') is 0·014%, less than the difference (0·018%) between TU and F (both without FYM) in the green manuring experiment.

Chater and Gasser (1970) showed that differences in %N in soil in 1966 caused by green manures, FYM and straw were similar to those in 1961. Mineralisable N was increased by trefoil but decreased by ryegrass.

Yields of crops

First period 1936–53. These have been mentioned briefly in describing the evolution of the experiment; see p. 121.

Second period 1955–62. Yields of early potatoes have been discussed by Barnes and Clarke (1963).

Yields of barley. Table 5 presents mean yields of barley for the years 1955–62 and standard errors. These were produced on the Rothamsted Orion computer by a general program for analysing long-term experiments. The standard errors were calculated from components of years × treatments that were judged to be unimportant; the program makes due allowance for correlations between yield values recurring on the same plots in different years, as recommended by Patterson and Lowe (1970).

Each system of green manuring gave an increase in the yield of barley (Table 5). Ryegrass sown once (R) or twice (RU) in each two-year cycle and ploughed down in autumn or spring for barley gave an average increase of $0·59 \pm 0·088$ t ha^{-1} barley (23% of the 'fallow' yield); the means for the eight seasons varied from $-$ 0·02 to $+$ 1·13 t ha^{-1}. Trefoil gave an average increase of $0·88 \pm 0·088$ t ha^{-1} (33% of the 'fallow' yield); annual means varied from $+$ 0·17 to $+$ 1·87 t ha^{-1}. Undersowing the barley each year had no significant effect on the yield of the nurse-crop; if anything it increased it very slightly (by $0·09 \pm 0·072$). We conclude that any effect of competition between seeds and nurse-crop is at least balanced by the residual effect of the additional green manure ploughed down for the preceding potatoes.

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TABLE 5

Mean yields of barley 1955–62 (eight seasons)

t ha⁻¹, at 85% dry matter

	F	T	TU	R	RU	TE	TL	RE	RL	Mean excluding F
Mean	(1) 2·65	3·51	3·56	(1) 3·18	3·31	3·36	3·70	(1) 2·97	3·51	(2) 3·39
N1	(3) 2·35	3·36	3·46	(3) 2·90	3·02	3·24	3·60	(3) 2·72	3·21	(4) 3·19
N2	2·95	3·66	3·65	3·45	3·60	3·50	3·82	3·24	3·82	3·59
N2–N1	(5) +0·60	+0·30	+0·19	(5) +0·55	+0·58	+0·26	+0·21	(5) +0·51	+0·60	(1) +0·40
Without S	(3) 2·64	3·44	3·50	(3) 3·18	3·21	3·31	3·64	(3) 2·86	3·53	(4) 3·33
With S	2·67	3·59	3·61	3·18	3·43	3·43	3·78	3·10	3·49	3·45
Effect of S	(5) +0·04	+0·15	+0·11	(5) 0·00	+0·21	+0·11	+0·14	(5) +0·24	−0·04	(1) +0·11
Without D	(3) 2·60	3·40	3·58	(3) 3·16	3·02	3·34	3·64	(3) 2·75	3·45	(4) 3·29
With D	2·70	3·64	3·54	3·19	3·60	3·39	3·78	3·21	3·58	3·49
Effect of D	(5) +0·10	+0·24	−0·04	(5) +0·03	0·58	+0·05	+0·14	(5) +0·40	+0·13	(1) +0·20
E	—	3·42	3·31	(3) 2·90	3·06	—	—	—	—	(4) 3·17
L	—	3·60	3·81	3·45	3·57	—	—	—	—	3·61
E–L	—	+0·18	+0·50	(5) +0·55	+0·51	—	—	—	—	(1) +0·44

Standard errors: (1) ±0·072
(2) ±0·036
(3) ±0·102
(4) ±0·051
(5) ±0·144

For symbols see pp. 120–122

5

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Green manures ploughed down in spring gave more barley than those ploughed down in autumn; for trefoil the difference was 0·34 ± 0·102 t ha⁻¹, for ryegrass 0·54 ± 0·102 t ha⁻¹. What little evidence we have (Dyke, 1973) suggests that, where no green manure is grown before barley, ploughing in autumn and ploughing in spring give about equal yields, so the differences between treatments E and L in Table 5 may be attributed to differences in the efficiency of the green manures applied at different times. It is remarkable that trefoil when ploughed down in spring, although it provided less N, gave more barley than when ploughed down in autumn (Tables 1 and 5).

The interpretation of the effects of the green manures in terms of N and other factors will be dealt with below. The effect of straw on yield of barley was small, and varied little with the different green manure treatments. The residual effect of FYM was + 0·20 ± 0·072 t ha⁻¹ after green manures but smaller after fallow.

Third period 1963–67. The yields of barley recorded in this period are summarised in Appendix Tables 1 to 8; most of the tables that follow in the text can be derived from the Appendix Tables (Table 10 is an exception). Note that, in all these tables, where four rates of N were applied, the first and third are based on half-plots in the same whole plots, the second and fourth on half-plots in other whole plots. Whole-plot errors were consistently larger than subplot errors but for ease of interpretation we present standard errors based on the average variance applicable to comparison of any two rates of N. All comparisons between green-manuring treatments involve whole-plot differences and the tabulated SEs take this into account.

TABLE 6

Mean yields of barley. Cumulative effects of green manures

t ha⁻¹, at 85% dry matter

Green manure		N to test crop, kg ha⁻¹ 0	38	75	113	151	Mean*
None since 1936		—	2·11	3·37	4·05	4·55	3·18
Various since 1936 to tabulated crop	trefoil	2·91	4·25	4·55	4·90	—	4·57
	ryegrass	2·03	3·12	4·31	4·67	—	4·03
Increase for:	trefoil	—	+2·14	+1·18	+0·85	—	+1·39
	ryegrass	—	+1·01	+0·94	+0·62	—	+0·85

The yields tabulated are unweighted means of the means of 1963, 1964 and 1966, all Upper Half. An estimated value (3·56) has been used for 'None since 1936', 151 kg N ha⁻¹ in 1963

* Excluding 0, 151 kg N ha⁻¹

Table 6 and Fig. 4 show the yields of barley on plots where trefoil or ryegrass were ploughed down since the growing of the last cash crop; these plots had all had green manuring treatments regularly since 1936. The table includes yields from plots 'fallow' since 1936. These are presented to show the effects achieved by long-continued green manuring, where residual benefits from earlier treatments reinforce benefits of current treatments. In the next section we give a more detailed analysis of effects, choosing results free from residual effects.

Where the barley was given 38 kg ha⁻¹ fertiliser N trefoil gave an increase of 2·14 t grain ha⁻¹; with more fertiliser N the effect of trefoil diminished but even with 113 kg N ha⁻¹ trefoil gave 0·85 t ha⁻¹ extra grain. The yield with trefoil plus 38 kg N ha⁻¹ exceeded that with 113 kg N ha⁻¹ but no green manure. Ryegrass gave an increase of 1·01 t ha⁻¹ with 38 kg N ha⁻¹, decreasing to 0·62 t ha⁻¹ with 113 kg N ha⁻¹. Ryegrass plus 75 kg N ha⁻¹ gave a greater yield than 113 kg N ha⁻¹ alone. Trefoil gave better yields of barley than ryegrass but with 113 kg N ha⁻¹ the difference was small.

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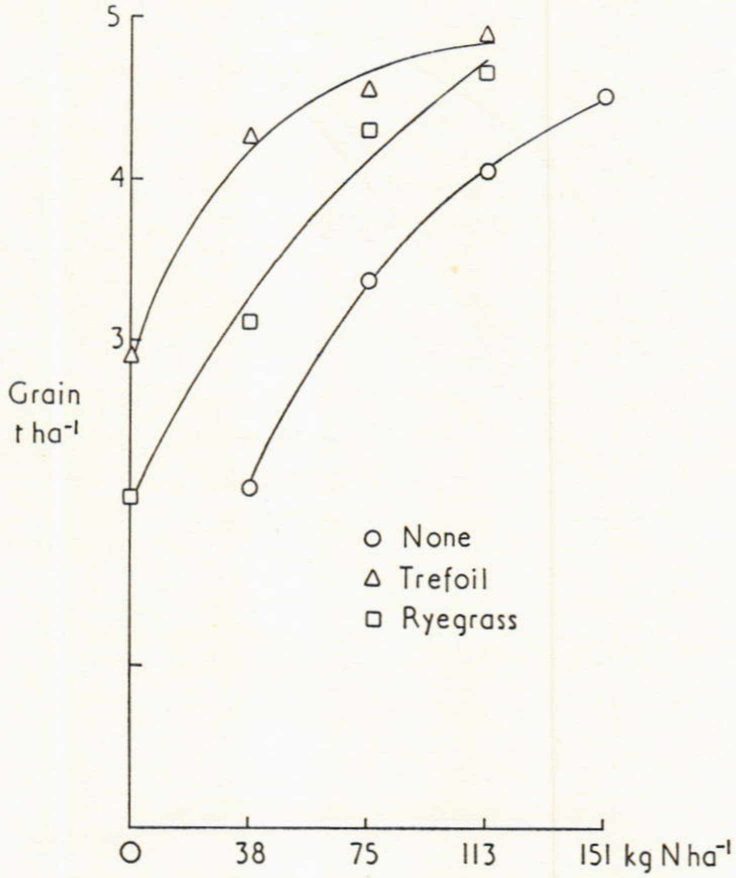

FIG. 4. Effects of long-term green manuring on barley (see Table 6).

TABLE 7

Effects of short-term green manuring on yields of barley

t ha^{-1}, at 85% dry matter

Means of 1964 Upper, 1965 Upper, 1965 Lower, 1966 Upper, 1966 Lower, and 1967 Lower Halves (All after V, C, R, M 1936–53)

This table shows the direct effects of green manures ploughed down once (for 1966 crops, twice) for the test-crops.

Recent green manure	N to barley, kg ha^{-1} 0	38	75	113	Mean
None	1·70	2·70	4·01	4·55	3·24
Trefoil	3·44	4·28	4·75	4·85	4·33
Ryegrass	1·74	2·94	4·15	4·81	3·41
Increase for:					
Trefoil	+1·74	+1·58	+0·74	+0·30	+1·09
Ryegrass	+0·04	+0·24	+0·14	+0·26	+0·17

Table 7 and Fig. 5 show the yields of barley in years and Halves in which there were plots with and without recent green manures, each set of plots having the same combinations of earlier treatments. The increases from trefoil are rather smaller, averaging + 1·09 t ha^{-1}, those for ryegrass are much smaller, than those of Table 6, averaging only + 0·17 t ha^{-1}. Figs. 4 and 5 show the yields tabulated in Tables 6 and 7 respectively. In

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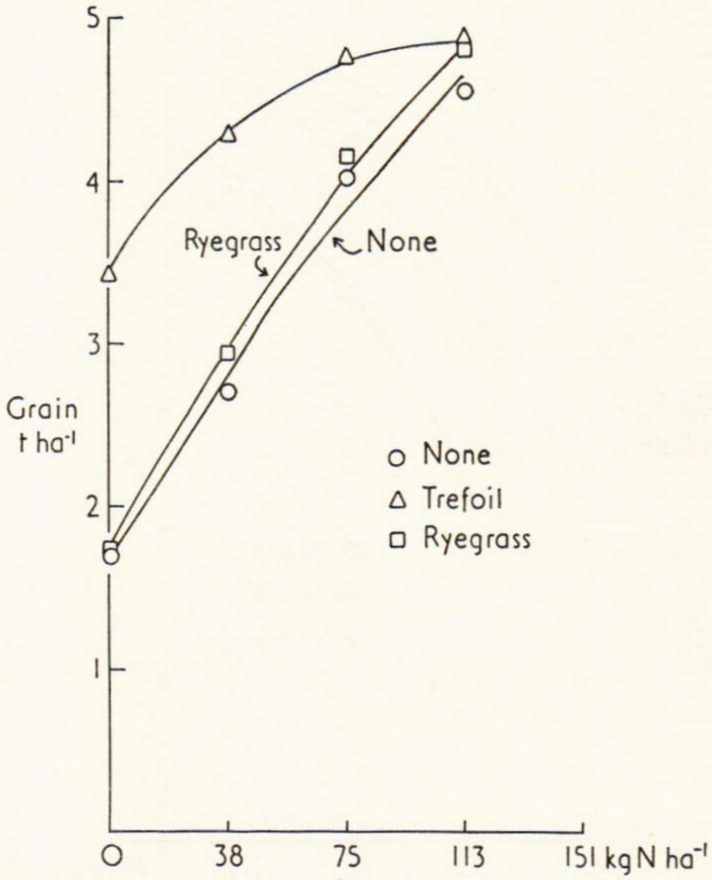

FIG. 5. Effects of short-term green manuring on barley (see Table 7).

addition the figures show smooth curves fitted to the mean yields using a Mitscherlich or exponential model of the form

$$y = \alpha + \beta\rho^x$$

(y = yield, t ha^{-1}, $x = 0, 1, 2, 3, 4$ for rates 0, 38, 75, 113, 151 kg N ha^{-1} as fertiliser). In this model ρ is the ratio of between increments of yield due to successive increments of 38 kg ha^{-1} of fertiliser N. In both sets of means fitting a common value of ρ (with independent estimates of α and β for 'none', 'trefoil' and 'ryegrass') is not satisfactory. This implies that one curve cannot be obtained from another by any combination of a horizontal shift (implying a difference in effective N) and a vertical shift (implying a difference in yield independent of N). The curves shown are based on independent estimates of α, β and ρ for each treatment. The estimates are as follows:

	Cumulative (Table 6)			Short-term (Table 7)		
	α	β	ρ	α	β	ρ
F	5·19	—3·08	0·599	9·36	—7·69	0·850
T	4·95	—2·04	0·376	5·03	—1·59	0·452
R	6·09	—4·10	0·691	8·20	—6·48	0·802

Using these curves we can estimate the amounts of fertiliser N required to give equal yields as follows:

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TABLE 8

Effects of green manures grown once compared with those of green manures grown in two successive seasons, on first succeeding barley crop

t ha^{-1}, at 85% dry matter

Increase for:		Trefoil						Ryegrass					
N to barley, kg ha^{-1} Year	Half	0	38	75	113	151	Mean	0	38	75	113	151	Mean
		Green manures grown once											
1964	Upper	+1·52	+2·14	+0·88	+0·33	—	+1·22	+0·11	+0·40	+0·53	+0·21	—	+0·32
1965	Upper	+1·74	+1·20	+0·11	+0·04	—	+0·78	−0·31	−0·63	−0·05	+0·05	—	−0·23
1965	Lower	+2·96	+1·30	+0·80	+0·31	—	+1·35	−0·43	−0·30	−0·33	+0·09	—	−0·24
1967	Lower	—	+1·19	+1·76	+0·67	+0·38	+1·00	—	+0·41	+0·98	+0·25	+1·15	+0·69
	Mean	(+2·07)	+1·46	+0·88	+0·34	(+0·38)	+1·09	(−0·21)	−0·03	+0·28	+0·15	(+1·15)	+0·14
		Green manures grown twice											
1966	Upper	+1·40	+1·33	+0·55	+0·46	—	+0·94	+0·12	+0·30	−0·10	+0·26	—	+0·15
1966	Lower	+1·64	+1·75	+1·45	+0·27	—	+1·27	+0·29	+0·63	+0·55	−0·22	—	+0·31
	Mean	+1·52	+1·54	+1·00	+0·36	—	+1·10	+0·20	+0·46	+0·22	+0·02	—	+0·23

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	Cumulative kg N ha⁻¹				Short-term kg N ha⁻¹			
T	0	38	75	112	0	38	75	113
F	59	119	166	196	61	97	116	125
R	0	38	75	113	0	38	75	113
F	35	72	116	178	2	44	85	123

Table 8 shows short-term effects of green manures free from long-term effects; effects of green manures sown once (in the season immediately preceding the test-crop) are compared with those of green manures sown in two successive seasons.

Although average effects of repeated green manuring are generally a little greater than those of a single green manure the differences are small in relation to those between seasons and between Halves in the same season. Table 9 shows the residual effects of long-term green manuring discontinued one or more seasons beforehand; these are differences between plots which had had varied green manures at least every second year since 1936 and comparable plots which had no green manures since 1936. (In 1966 and 1967 on the Lower Half effects of trefoil and ryegrass cannot be separately estimated because these contrasts were confounded with randomly chosen contrasts of the later treatments.)

TABLE 9

Residual effects of long-term green manuring recently discontinued; barley, increase in yield t ha^{-1}, at 85% dry matter

Year	Half	Treatment 1955–63	Crop after last green manure	N to barley, kg ha^{-1} 38	75	113	151	Mean
1964	Upper	T	2nd	+0·33	+0·22	−0·18	—	+0·13
		R	2nd	+0·38	+0·42	+0·21	—	+0·34
1964	Lower	TU	2nd	+1·06	+1·16	+0·16	—	+0·79
		RU	2nd	+0·52	−0·25	+0·39	—	+0·22
		T	3rd	+0·38	+0·03	−0·10	—	+0·10
		R	3rd	+0·12	+1·05	−0·99	—	+0·06
1965	Upper	T, TU	part 2nd, part 3rd	+0·57	+0·42	−0·34	—	+0·22
		R, RU	part 2nd, part 3rd	+0·54	+0·23	+0·08	—	+0·28
1965	Lower	T, TU	part 3rd, part 4th	+0·43	+0·05	−0·18	—	+0·10
		R, RU	part 3rd, part 4th	+0·60	+0·21	−0·38	—	+0·15
1966	Upper	T, TU	part 3rd, part 4th	+0·15	+0·75	+0·79	—	+0·56
		R, RU	part 3rd, part 4th	+0·81	+0·64	+0·90	—	+0·78
1966	Lower	T, TU / R, RU	part 4th, part 5th	+0·32	—	+0·19	—	(+0·25)
1967	Lower	T, TU / R, RU	part 5th, part 6th	+0·29	+0·52	−0·48	+0·08	(+0·11)
Mean		T, TU		+0·49	+0·44	+0·02	—	+0·32
Mean		R, RU		+0·50	+0·38	+0·04	—	+0·31
Mean* (excluding 1966 Lower)				+0·44	+0·46	−0·02		+0·29

* Giving equal weight to each annual mean

The average residual effect was + 0·29 t ha^{-1}. With 38 or 75 kg N to the barley the residual effects were about + 0·45 t ha^{-1} but with 113 kg N the average effect was negligible. The decreases in yield due to green manuring in some seasons where 113 kg N ha^{-1} were applied may be ascribed to lodging. Variation of the mean effect between seasons was erratic, with no clear decrease as the period since the last green manuring increased.

From 1965 onward the residual effect of ryegrass was greater than that of trefoil whereas in 1964, in the second crops after green manures, trefoil gave 0·46 t ha^{-1} more barley against 0·28 t ha^{-1} for ryegrass.

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Tables 7, 8 and 9 together suggest that although green manures grown twice in successive years do little more to improve yields than single green crops, long-continued green manuring has an appreciably greater effect and, when discontinued, leaves residues which increase barley yields for at least five years. The effects of short-term green manuring are lessened but not eliminated where N is applied at 75 or 113 kg ha^{-1} and the same is true of the effects of repeated green manuring continued up to the season of the test-crop but residual effects, though similar where 38 or 75kg N ha^{-1} are used, are eliminated by applying 113 kg N ha^{-1}. Although the direct effect of trefoil (grown once or many times) is greater than that of ryegrass the residual effect of ryegrass seems to last longer than that of trefoil. This may reflect the larger amounts of dry matter (but less of N) supplied by ryegrass than trefoil (Tables 1 and 2).

Effects of undersown green manures on their nurse-crops. The average effect of undersown trefoil on the nurse-crop (barley) was a decrease of 0·32 t ha^{-1} (nearly 10% of the yield) (Table 10). The decrease was much smaller where 113 kg N ha^{-1} was applied but this may be a chance effect.

Ryegrass had a negligible average effect on its nurse-crop but there was an indication that it decreased yield where 38 or 75 kg N ha^{-1} was applied but increased yield with 113 kg N.

Effect of N applied to the preceding crop. The residual effects of N applied to barley not undersown with a green manure, measured in the following barley crop, were small and irregular; there was, if anything, a small decrease in yield with increasing N (Table 11).

Where trefoil was undersown, N applied to the nurse-crop lessened the growth of trefoil (see Table 2) and caused a corresponding decrease in the yield of the succeeding

TABLE 10

Effects of undersown green manures on their nurse-crops

Barley, t ha^{-1}, at 85% dry matter

(All yields from plots green-manured 1936–62)

Season and Half	N kg ha^{-1} 0	38	75	113	Mean
	1. Yields without undersown crops				
1964 Upper	2·28	3·54	4·76	5·07	3·91
1964 Lower	1·63	2·36	3·68	4·07	2·94
1966 Lower	—	2·00	—	4·62	(3·31)
Mean	(1·96)	2·63	(4·22)	4·59	—
Mean*	1·96	2·95	4·22	4·57	3·42
	2. Yield increase produced by effect of undersown trefoil				
1964 Upper	−0·44	−0·45	−0·96	−0·11	−0·49
1964 Lower	−0·22	−0·31	−0·09	+0·05	−0·14
1966 Lower	—	+0·13	—	−0·40	(−0·13)
Mean	(−0·33)	−0·21	(−0·52)	−0·15	—
Mean*	−0·33	−0·38	−0·52	−0·03	−0·32
	3. Yield increase produced by effect of undersown ryegrass				
1964 Upper	−0·01	−0·21	+0·11	−0·06	−0·04
1964 Lower	−0·35	+0·15	−0·37	+0·34	−0·06
1966 Lower	—	+0·11	—	−0·27	(−0·08)
Mean	(−0·18)	+0·02	(−0·13)	0·00	—
Mean*	−0·18	−0·03	−0·13	+0·14	−0·05

* Excluding 1966 Lower Half

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TABLE 11

Residual effects of fertiliser N applied to the crop preceding barley

Barley, t ha^{-1}, at 85% dry matter

Means of 1964 Upper, 1966 Upper and Lower Halves
Barley after barley

Green manure undersown in previous crop	N to preceding crop, kg ha^{-1} 0	38	75	113
None	3·51	3·20	3·30	3·21
Trefoil	4·83	4·35	4·24	3·77
Ryegrass	3·43	3·32	3·39	3·51

1964 Lower Half, Barley after sugar beet

	N to preceding crop, kg ha^{-1} 0	84	166	251
No green manure	2·95	2·86	3·00	2·74

Note: Vertical comparisons within years and Halves are confounded with differences in rates of N applied to the tabulated crop; for this reason marginal means are not shown

barley; 113 kg N ha^{-1} decreased yield by 1·06 t ha^{-1}. Where ryegrass was undersown N to the nurse-crop caused no decrease in the subsequent crop.

'Farming systems'. The conclusions of the preceding two sections suggest that if a farmer grows barley for several successive seasons and compares two systems, one without, the other with, annual undersowing of trefoil he will find in the second and later years:

(i) if he applies little N: a considerable increase in yield due to ploughed-down trefoil will amply outweigh the loss of yield due to competition by the trefoil (0·32 t ha^{-1} see Table 10),

(ii) if he applies much N (e.g. 113 kg ha^{-1}): his trefoil will be suppressed to some extent by the vigorous barley and will have a smaller effect when ploughed down (Table 11); the trefoil may lessen yield a little by competition (Table 10)

This is a delicate and uncertain balance. In two seasons the long-term experiment (on both Halves) gave results with a direct bearing on this point; they are shown in Table 12 and in Fig. 6.

Ryegrass gave an increase of 0·10 t ha^{-1}, fairly consistent over the rates of N; trefoil

TABLE 12

Yields with and without green manures where N was applied at the same rate to the preceding nurse-crop and to the test-crop

Barley, t ha^{-1}, at 85% dry matter

Means of 1965 Upper, 1965 Lower, 1966 Upper, 1966 Lower Halves

Green manure undersown in preceding crop	N to preceding and test-crop kg ha^{-1} 0	38	75	113	Mean
None	1·44	2·54	4·29	4·54	3·20
T	3·76	4·10	4·64	4·83	4·33
R	1·51	2·67	4·27	4·76	3·30
T minus None	+2·32	+1·56	+0·35	+0·29	+1·13
R minus None	+0·07	+0·13	−0·02	+0·22	+0·10

In 1965 all treatments were repeated on the same plots as in 1964; in 1966 N was applied in all combinations with N 1965 and 1964 and we have selected plots where the rates were the same

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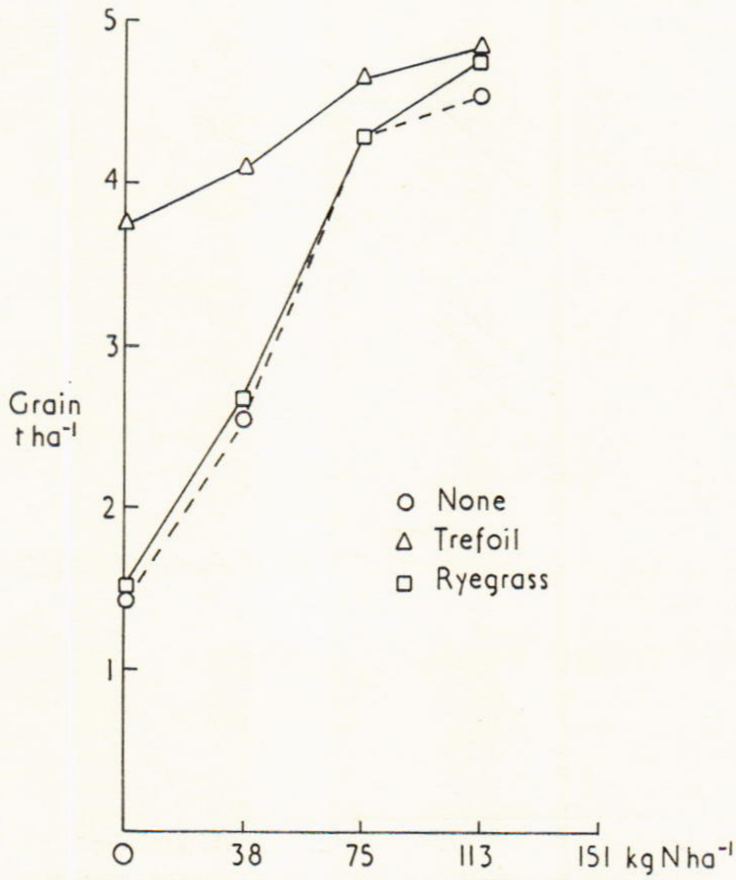

FIG. 6. Effects of repeated green manuring ('farming systems') on barley (see Table 12).

more than doubled yield without N; the effect decreased markedly with increased N but even with 113 kg N ha^{-1} trefoil gave 0·29 t ha^{-1} extra grain.

Discussion

In every season of the tests trefoil used as a green manure supplied appreciable amounts of N which were used by the following crop; ryegrass in general supplied rather less N and gave smaller increases, at any rate where little fertiliser N was applied to the subsequent crop. In some circumstances a green manure ploughed down causes an improvement in the yield of the subsequent crop which cannot be equalled by any amount of N fertiliser applied as a conventional single dressing. This is clearly shown in some sets of results where the final increment of applied N caused a decrease in yields and so we can estimate the maximum attainable yields with and without green manures. Examples are given by Dyke (1965, 1973) and in the present experiment by the results for trefoil of 1967 (Lower Half) which are shown in Appendix Table 8 and in Fig. 7. This diagram also illustrates a feature suggested by other summaries (see Figs. 5 and 6 for examples): where ryegrass has been ploughed down fertiliser N continues to increase yield at greater rates than it does with no green manure or with trefoil. More N can be applied profitably after ryegrass than after trefoil or no green manure and extrapolation to rates greater than we tested suggests that with much N (of the order of 151 kg ha^{-1}) ryegrass will often give greater yields than trefoil or no green manure. We do not know whether differences of

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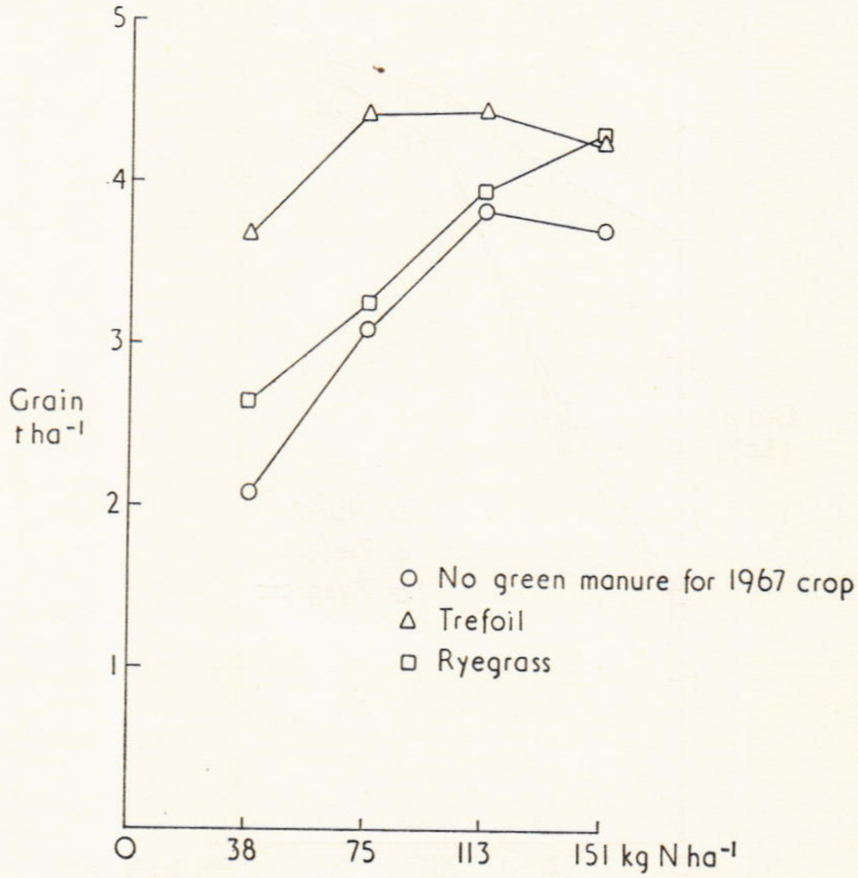

FIG. 7. Yields of barley 1967 (Lower Half) (see Appendix Table 8).

this sort can be eliminated by applying fertiliser N in new ways—perhaps by several small dressings at intervals or by injection of liquid ammonia plus a nitrification inhibitor. Perhaps the implied challenge will be taken up by fertiliser technologists.

Apparently 'impracticable' treatments of this type are fully justified by such consequences and are in keeping with present emphasis on experiments to explore maximum yields attainable with the use of certain treatments which may be at present quite uneconomic. For example, the plot treated annually with farmyard manure in the Broadbalk Wheat experiment at Rothamsted has given more grain in recent years than any fertiliser plot; this has stimulated a test of additional N fertiliser applied in autumn on fertiliser-only plots in an effort to equal the yield of the FYM plot.

In other circumstances (e.g. Dyke, 1965) the effect of a green manure may be explained by supposing that the N that it provides is similar to that supplied by N fertiliser conventionally applied. The present experiment indicates that green manures are most effective in seasons when rainfall in May and June is adequate to keep the soil moist for most or all of the growing season. This is supported by results of the Woburn Irrigation experiment (Table 13). That green manures provide N late in the season is also indicated by the increase in the percentage of N in barley grain recorded in one experiment at Woburn (Dyke, 1973). The percentage of sugar in sugar beet at Woburn was increased by green manures in experiments in which (as is commonly found in many experiments elsewhere) fertiliser N caused a decrease (Dyke, 1965).

To the nation green manuring is attractive if it causes an increase in the nett production

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TABLE 13

Woburn Irrigation Experiment

Barley, t ha^{-1}, at 85% dry matter

Year	Irrigation (cm water)	Yield without trefoil	Increase for trefoil
1961	None	3·46	−0·05
	Full (8·2)	3·92	+0·18
1962	None	2·55	+0·59
	Full (8·9)	3·99	+1·26
1963	None	2·74	+0·45
	Full (7·0)	3·30	+0·26
Mean 1961–63	None	2·91	+0·33
	Full	3·74	+0·56

of food or feedingstuffs. One hectare of suitable land can produce 240–1250 kg trefoil seed (Primrose McConnell, 1968). 250 kg is enough to seed 10 ha of land with trefoil (undersown or as a catch-crop). So one hectare devoted to growing trefoil seed can provide seed for green manuring 10–50 ha. An average increase of yield of 2–10% is required to make good the loss of land in edible crops. (We assume the land devoted to trefoil seed-crops is of equal average initial fertility to the remainder.) The Woburn experiment indicates that, if little or no fertiliser N is applied, yields of both barley and sugar beet are increased by much more than 10%. The average rate of application of fertiliser N to spring barley in England and Wales in 1975 was 77 kg ha^{-1} (Church, 1976). It is possible that more than average N is used on light soils but the Survey shows that, in all sampled areas, only 19% of the area of spring barley received 100 kg N ha^{-1} or more. In the Woburn experiment (Table 7) the average increases due to trefoil were 0·74 t ha^{-1} with 75 kg N ha^{-1} (18% of the yield without trefoil), 0·30 t ha^{-1} with 113 kg N ha^{-1} (6·6%). It seems, therefore, that if the Woburn soil may be taken to represent light land in England and Wales, the nett production of barley is likely to be increased by the adoption of undersown trefoil unless farmers begin to apply more fertiliser N than at present. With 75 kg ha^{-1} of fertiliser N trefoil gave 0·74 t ha^{-1} more barley (Table 7) in the Woburn experiment. This is equivalent to about 24% of the yield without trefoil and amply justifies green manuring on soils similar to those of the light land at Woburn.

To the farmer green manuring is attractive if it seems likely to increase his profit; long-term benefits, which are considered elsewhere in this paper, are hard to assess in terms of money and are disregarded here. A farmer's profit may be increased in either of two ways or by some combination of the two: first green manuring may give an increase of yield sufficient to offset the cost of seed and of sowing and any indirect costs involved, e.g. the use of an expensive weedkiller instead of a cheap one; secondly, N from a green manure may replace some or all of the fertiliser N required to produce a given yield and so lessen the cost of growing the crop.

Trefoil seed costs about £0.66 kg^{-1}. In all our experiments it was sown at 34 kg ha^{-1}, costing £22 ha^{-1}. The cost of sowing may vary from practically nothing (if the seed is sown with the seed of the nurse-crop) to about £4 ha^{-1}. We take the total cost of undersowing as £25 ha^{-1} though we believe the seed rate used was rather generous and could probably be decreased by a quarter or a third without much risk. £25 can buy about 150 kg N as ammonium nitrate/calcium carbonate fertiliser at present prices and so the cost of trefoil, even if sowing rates are lessened, is more than that of any normal dressing of N to a cereal crop. So, at present prices, the practice of undersowing with trefoil cannot be justified solely as a means of saving money on fertilisers, at least if short-term effects only are considered. Sowing trefoil may, however, be justified economically if

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sufficient increase in yields of barley can be obtained with current rates of N fertilisers. To recoup a cost of £25 a farmer needs 0·33 t of barley at £75 t^{-1}. The Woburn experiment shows (Table 8) that the short-term effect of trefoil provides more than double this response where N is applied at 38 or 75 kg ha^{-1} and very nearly this response where 113 kg N ha^{-1} are applied. Since few growers, even on light soils, apply N at more than 100 kg ha^{-1} a profitable response may be expected on a large area. It may well be true that many growers could increase their yields by applying more fertiliser N but our analysis of the Woburn results indicates that trefoil can sometimes be more effective in this way than extra N fertiliser. If the crop following trefoil green manure is sugar beet an increase of 0·70 t sugar ha^{-1} (Dyke, 1965) is worth about £69 (using current 'A' quota prices) and so amply repays the outlay. For early potatoes an increase of 1·1 t total tubers ha^{-1} (Barnes & Clarke, 1963; using means for the greater rate of N) will repay the cost of trefoil provided the potatoes sell for £23 t^{-1}—a price which is likely to be exceeded by a factor of at least five in the foreseeable future.

We now consider some of the implications to a farmer growing tillage crops only who adopts a policy of growing green manures as indicated by the Woburn results. Since trefoil gave generally greater yields of test crops than did ryegrass, we assume he will choose trefoil.

First, he must ensure that his soil is not unduly acid; results at Woburn suggest a pH value of 6·5 is the minimum to ensure good establishment and growth of trefoil (Radulovic & Nutman, 1963). On land that has not recently carried trefoil or closely related species, he must inoculate the trefoil seed with a suitable culture of *Rhizobium meliloti*; in later seasons, if the interval between sowing of trefoil is one or two years he can safely omit this process.

Next, he will need to buy less fertiliser N; as a rough guide he will need about 50 kg N ha^{-1} less.

Finally, he will, in the long run, maintain a greater amount of organic matter in his soil (Table 3); the improvement is comparable to that achieved by putting half his land into short-term grazed leys (Tables 3 and 4). If he believes the dire warnings about the loss of soil organic matter and its consequences given by the Agricultural Advisory Council (1970) he will see green manuring as a means of preventing disaster. If he accepts these official warnings with reserve (as we do) he will see green manuring as a convenient means to keep his land in rather better heart.

In the last 20–30 years yields of crops have increased and unharvested residues (stubble, roots, etc.) have in general increased also; increased burning of the stubble when the straw is burned, and increased use of sugar-beet tops for feeding, may well have counteracted any general increase in crop residues returned to the soil. But crops are now treated with effective weedkillers and practically no organic matter is contributed by weeds, whereas in the past stubbles were often green with weeds (and volunteer cereal plants) which were later ploughed down. Now such green residues are rarer and those that do occur are eliminated by cultivation or by paraquat before they achieve any useful bulk. Our few estimates of the dry matter and N contributed by weeds and stubble (Table 14) suggest that a moderate growth of weeds in a barley stubble can, by February, supply about 0·8 t dry matter ha^{-1} and perhaps retain some N which, at least on light soils, would otherwise be leached during winter. The above-ground stubble of a good crop of winter oats, cut by the combine harvester at a height of about 22 cm, contributed 2·4 t dry matter ha^{-1}; this represents the difference in organic matter contributed to the soil as between baling straw and then working in the stubble (or burning the straw in damp conditions when most of the stubble is unburned) and burning on a very dry field (often seen in 1975 and 1976) when the stubble is entirely burned. Green manures (Tables 1 and 2) can contribute two to four times as much dry matter as our samples of weeds, rather

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TABLE 14

Dry matter and N in weeds and in stubble

Circumstances	Date of test-crop	Season of sampling	DM (t ha^{-1})	N (kg ha^{-1})	(N%)
Weeds after barley (Woburn)	1964	Spring	0·98	19	(1·9)
Weeds after barley (Woburn)	1965	Autumn	0·68	11	(1·7)
		Spring	0·83	16	(2·0)
	Mean		0·83	15	(1·8)
Weeds after early potatoes (Woburn)	1964	Spring	0·20	6	(3·0)
Stubble of combine-harvested winter oats, sample cut to ground level (Rothamsted)	1976	Autumn	2·4	(not determined)	

more than our sample of stubble. We believe, therefore, that killing weeds has appreciably decreased the organic matter in soil and that the balance may be redressed by introducing green manures, especially by undersowing cereals, in their cropping systems. It is better to have a benign species such as trefoil than uncontrolled weeds; 'better the devil you know than the devil you don't'.

The range of weedkillers suitable for use on undersown cereals is limited and so control of certain weeds may be rendered difficult or impossible by an undersown green manure (especially trefoil or another legume); some of the materials that are suitable are more expensive than their counterparts used on cereals not undersown. This difficulty will make some farmers hesitate to adopt undersowing, whether of green manures or of leys for production that include legumes such as clover. They should bear in mind two points. First that recent work by ADAS (Evans 1969) has shown that on many fields of cereals the weedkillers chosen by farmers do not increase yields though, to be fair, it is probable that their application eases harvest and prevents loss of yield because of weeds in later years. Second, that undersown crops have some effect in suppressing the growth of weeds in cereals. Dyke and Barnard (1976) have shown that couch grass (*Agropyron repens*) increases about half as fast in barley undersown with red clover or with Italian ryegrass as in barley not undersown. Stubbles with well established green manure crops may be left over winter without spraying, cultivating or ploughing. This will lessen erosion by winter rain and allow a farmer to concentrate on working land for autumn-sown crops and drilling them in good time.

If straw is left lying on the stubble of a crop that was undersown with a green manure crop the green crop will suffer; the straw should be baled and carted in good time, or spread preferably after chopping (if this is done the green crop may 'anchor' the straw and so help to give good incorporation in the subsequent ploughing). The presence of small seeds undersown affects cereal nurse-crops directly and indirectly. First, the undersown crop may compete directly for light or water. Red clover in a wet season sometimes outgrows barley of a short variety and so causes great difficulty in harvesting. Trefoil and ryegrass seldom if ever grow tall enough to impede harvesting but, in dry seasons, they may steal water and so lessen the yield of the nurse-crop; Dyke and Barnard (1976) noted this effect on beans—a crop not normally undersown.

A farmer who undersows a cereal may judge that, in order to be reasonably sure of a good establishment of the small seeds, he should apply less fertiliser N than he would otherwise do and so accept rather less than the best possible yield of the cereal.

Finally, we note that there are now at least two methods available for sowing green manures that were not practicable in the Woburn experiment. First, small seeds (trefoil or

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ryegrass) may be sown from aircraft (fixed-wing or helicopter) during the growing season of cereals. This practice, which is sometimes called oversowing, enables a farmer to take advantage of an appreciable rainfall in June or July to establish green manures. These will grow slowly before harvest, rapidly if there is enough moisture after harvest. This technique has been used to establish stubble turnips for grazing. Another method used for this purpose can also be used to establish green manures—the use of a suitable drill to put seeds direct into uncultivated stubble. The likely effects of green manures established by these techniques are being investigated in a new experiment at Woburn.

We conclude that:

1. in some circumstances a green manure gives an increase of yield whatever amount of fertiliser N is applied to the test crop; we cannot yet specify these circumstances,
2. green manuring is unlikely to be immediately profitable to many farmers,
3. it offers farmers a means of maintaining or increasing the stock of organic matter in their soils, and
4. it offers the nation a method of lessening its dependence on fertiliser N without loss of production.

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Conventions observed in Appendix Tables 1–8 on following pages

Yields in 'boxes' refer to plots *all* of which had a green manure ploughed down for the test-crop. Dates in brackets, e.g. (1962) indicate the last crop for which a green manure was ploughed down.

U/S: abbreviation for undersown.

(2), (4) etc, printed near the leading entry of the body or margin of a table indicate the number of half-plots involved. Standard errors are tabulated correspondingly; for comparisons between rates of N within the same whole-plot treatment the S.E. given is based on the average variance of comparisons in the same and different whole-plots.

(a) Standard errors for comparisons between rates of N within green manuring treatments (horizontal and interaction comparisons).

(b) Standard errors for comparisons involving different green manuring treatments.

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APPENDIX TABLE 1

Mean yields of barley

t ha^{-1}, at 85% dry matter
Upper Half 1963, after early potatoes

To 1953	1955–62	N in 1962 kg ha^{-1}	N in 1963 kg ha^{-1}: 0	38	75	113	Mean
F	F	75	0·48(2)	1·63	2·60	3·11	1·96(8)
		151	0·65	2·13	2·89	3·41	2·27
		Mean	0·56(4)	1·88	2·75	3·26	2·11(16)
V, M, R, C	T, TU	75	2·69(4)	3·97	3·93	3·99	3·64(16)
		151	2·82	3·80	4·19	3·83	3·66
		Mean	2·76(8)	3·88	4·06	3·91	3·65(32)
	R, RU	75	2·36(4)	3·15	3·90	3·89	3·33(16)
		151	2·41	3·79	3·80	4·24	3·56
		Mean	2·38(8)	3·47	3·85	4·07	3·44(32)
	T	75, 151	2·40(4)	3·64	3·87	3·71	3·40(16)
	TU		3·11	4·13	4·25	4·10	3·90
	R		2·59	3·34	3·74	4·02	3·42
	RU		2·18	3·61	3·97	4·12	3·47
	TE	75, 151	2·92(4)	3·78	4·28	3·65	3·66(16)
	TL		2·59	3·99	3·83	4·17	3·64
	RE		2·11	3·55	3·59	4·34	3·40
	RL		2·66	3·39	4·12	3·79	3·49

Standard errors	(2)	(4)	(8)	(16)	(32)
(a)	0·361	0·256	0·181	0·128	0·091
(b)	0·434	0·306	0·217	0·153	0·109

APPENDIX TABLE 2

Mean yields of barley

t ha^{-1}, at 85% dry matter
Upper Half 1964, second successive barley crop

To 1953	1955–62	N in 1963 kg ha^{-1}	N in 1964 kg ha^{-1}: 0	38	75	113	151	Mean	Mean*
F	F	0	—	1·54(1)	4·27	5·42	5·62	4·21(4)	3·73(3)
		38	—	2·69	3·53	5·25	4·52	4·00	3·82
		75	—	2·74	3·76	3·70	5·47	3·92	3·40
		113	—	2·54	3·90	5·12	5·35	4·23	3·85
		Mean	—	2·38(4)	3·87	4·87	5·24	4·09(16)	3·70(12)
V, M, R, C	T, R (1963)	0	1·84(2)	3·16	3·40	5·32	—	3·43(8)	3·96(6)
		38	1·91	1·86	4·37	5·32	—	3·36	3·85
		75	1·38	3·31	4·25	5·03	—	3·49	4·20
		113	1·88	2·64	4·74	3·87	—	3·28	3·75
		Mean	1·76(8)	2·74	4·19	4·89	—	3·39(32)	3·94(24)
	T (1963)	Mean	1·69(4)	2·71	4·09	4·69	—	3·30(16)	3·83(12)
	R (1963)	Mean	1·83	2·76	4·29	5·08	—	3·49	4·04
	TU (1964)	0	4·12(1)	5·47	5·51	5·31	—	5·10(4)	5·43(3)
		38	2·74	5·07	5·47	5·20	—	4·62	5·25
		75	3·07	4·63	5·61	5·28	—	4·65	5·17
		113	3·19	4·35	3·71	5·07	—	4·08	4·38
		Mean	3·28(4)	4·88	5·07	5·22	—	4·61(16)	5·06(12)
	RU (1964)	0	2·27(1)	2·95	4·67	5·20	—	3·77(4)	4·27(3)
		38	2·23	3·59	4·19	4·83	—	3·71	4·20
		75	1·91	2·89	5·07	4·74	—	3·65	4·23
		113	1·07	3·15	4·97	5·63	—	3·70	4·58
		Mean	1·87(4)	3·14	4·72	5·10	—	3·71(16)	4·32(12)

* Excluding 0 and 151 kg N ha^{-1}

Standard errors	(1)	(2)	(3)	(4)	(6)	(8)	(12)	(16)	(24)	(32)
(a)	0·640	0·453	0·370	0·320	0·261	0·226	0·185	0·159	0·131	0·113
(b)	0·789	0·558	0·456	0·394	0·322	0·279	0·228	0·197	0·161	0·139

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APPENDIX TABLE 3

Mean yields of barley

t ha⁻¹, at 85% dry matter
Lower Half 1964, after sugar beet

To 1953	1955–62	N in 1963, kg ha⁻¹	N in 1964, kg ha⁻¹: 0	38	75	113	151	Mean	Mean*
F	F	0	—	1·52(1)	2·61	4·54	5·47	3·54(4)	2·89(3)
		84	—	2·66	3·24	4·41	4·57	3·72	3·44
		166	—	1·27	3·65	3·14	4·39	3·11	2·69
		251	—	1·74	2·77	5·12	4·52	3·54	3·21
		Mean	—	1·80(4)	3·07	4·30	4·74	3·48(16)	3·06(12)
V, M, R, C	T, R (1962)	0	2·06(2)	2·03	3·51	3·74	—	2·84(8)	3·09(6)
		84	1·52	1·76	3·10	3·87	—	2·56	2·91
		166	0·93	2·64	4·67	3·11	—	2·84	3·47
		251	1·05	1·78	3·14	4·32	—	2·57	3·08
		Mean	1·40(8)	2·05	3·61	3·75	—	2·70(32)	3·14(24)
	T (1962)	Mean	1·38(4)	2·18	3·10	4·20	—	2·71(16)	3·16(12)
	R (1962)	Mean	1·42	1·92	4·12	3·31	—	2·69	3·12
	TU (1963)	0	1·61(1)	3·55	3·55	4·59	—	3·33(4)	3·90(3)
		84	2·38	2·62	4·33	4·23	—	3·39	3·73
		166	1·62	3·06	3·88	5·08	—	3·41	4·01
		251	1·29	2·23	5·15	3·95	—	3·15	3·78
		Mean	1·72(4)	2·86	4·23	4·46	—	3·32(16)	3·85(12)
	RU (1963)	0	1·52(1)	2·87	2·48	4·29	—	2·79(4)	3·21(3)
		84	1·41	1·73	4·14	4·43	—	2·93	3·43
		166	1·38	2·46	2·59	5·26	—	2·92	3·44
		251	1·46	2·20	2·07	4·79	—	2·63	3·02
		Mean	1·44(4)	2·32	2·82	4·69	—	2·82(16)	3·28(12)

* Excluding 0 and 151 kg N ha⁻¹

Standard errors	(1)	(2)	(3)	(4)	(6)	(8)	(12)	(16)	(24)	(32)
(a)	0·640	0·453	0·370	0·320	0·261	0·226	0·185	0·159	0·131	0·113
(b)	0·789	0·558	0·456	0·394	0·322	0·279	0·228	0·197	0·161	0·139

APPENDIX TABLE 4

Mean yields of barley

t ha⁻¹, at 85% dry matter
Upper Half 1965, third successive barley crop

To 1953	1955–62	U/S 1964 and 1965	N in 1964 and 1965, kg ha⁻¹: 0	38	75	113	151	Mean	Mean*
F	F	None	—	2·64(4)	3·98	4·69	4·77	4·02(16)	3·77(12)
V, M, R, C	T, TU, R, RU	None	1·72(8)	3·19	4·30	4·56	—	3·44(32)	4·02(24)
		T	3·46(4)	4·39	4·41	4·61	—	4·22(16)	4·47(12)
		R	1·41	2·56	4·25	4·62	—	3·21	3·81
		Weighted mean	2·08(16)	3·33	4·32	4·59	—	3·58(64)	4·08(48)
	T	Mean†	2·01(4)	3·29	4·27	4·52	—	3·52(16)	4·03(12)
	TU		1·72	3·70	4·23	4·58	—	3·56	4·17
	Mean		1·86(8)	3·49	4·25	4·55	—	3·54(32)	4·10(24)
	R	Mean†	2·16(4)	3·01	4·29	4·67	—	3·53(16)	3·99(12)
	RU		2·41	3·34	4·48	4·57	—	3·70	4·13
	Mean		2·29(8)	3·18	4·39	4·62	—	3·62(32)	4·06(24)
	T, TU	None	1·81(8)	3·21	4·40	4·35	—	3·44(32)	3·99(24)
	R, RU	None	1·63	3·18	4·21	4·77	—	3·45	4·05

* Excluding 0, 151 kg N ha⁻¹
† Mean of 'None, T, and R'

Standard errors	(4)	(8)	(12)	(16)	(32)	(48)	(64)
(a)	0·203	0·143	0·117	0·102	0·072	0·059	0·051
(b)	0·250	0·176	0·144	0·125	0·088	0·072	0·062

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APPENDIX TABLE 5

Mean yields of barley

t ha⁻¹, at 85% dry matter
Lower Half 1965, second successive barley crop

To 1953	1955–62	U/S 1964 and 1965	N in 1965, kg ha⁻¹: 0	38	75	113	151	Mean	Mean*
F	F	None	—	2·52(4)	4·29	5·11	5·10	4·25(16)	3·97(12)
V, M, R, C	T, TU, R, RU	None	1·61(8)	3·04	4·42	4·82	—	3·47(32)	4·09(24)
		T	4·57(4)	4·34	5·22	5·13	—	4·82(16)	4·90(12)
		R	1·18	2·74	4·09	4·91	—	3·23	3·91
		Weighted mean	2·24(16)	3·29	4·54	4·92	—	3·75(64)	4·25(48)
	T (1962)	Mean†	2·05(4)	3·28	4·32	4·99	—	3·66(16)	4·20(12)
	TU (1963)	Mean†	2·25	3·23	4·67	4·92	—	3·77	4·27
	Mean		2·15(8)	3·25	4·49	4·96	—	3·71(32)	4·24(24)
	R (1962)	Mean†	2·38(4)	3·06	4·78	4·78	—	3·75(16)	4·21(12)
	RU (1963)	Mean†	2·30	3·60	4·39	4·98	—	3·82	4·32
	Mean		2·34(8)	3·33	4·59	4·88	—	3·78(32)	4·26(24)
	T, TU	None	1·57(4)	2·95	4·34	4·93	—	3·45(16)	4·07(12)
	R, RU	None	1·64	3·12	4·50	4·73	—	3·50	4·12

* Excluding 0, 151 kg N ha⁻¹
† Mean of 'None, T, and R'

Standard errors	(4)	(8)	(12)	(16)	(24)	(32)	(48)	(64)
(a)	0·203	0·143	0·117	0·102	0·083	0·072	0·059	0·051
(b)	0·250	0·176	0·144	0·125	0·102	0·088	0·072	0·062

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APPENDIX TABLE 6

Mean yields of barley

t ha^{-1}, at 85% dry matter
Upper Half 1966, fourth successive barley crop

To 1953	1955–62	U/S 1964 and 1965	N in 1964 and 1965 kg ha^{-1}	N in 1966, kg ha^{-1} 0	38	75	113	151	Mean	Mean*
F	F	None	38	—	2·26(1)	4·02	4·23	5·05	3·89(4)	3·50(3)
			75	—	2·15	3·64	3·75	4·39	3·48	3·18
			113	—	1·77	4·09	4·32	4·81	3·75	3·39
			151	—	2·07	2·26	3·73	5·12	3·29	2·69
			Mean	—	2·06(4)	3·50	4·01	4·84	3·60(16)	3·19(12)
			Mean*	—	2·06(3)	3·92	4·10	4·75		3·36(9)
V, M, R, C	T, TU, R, RU	None	0	1·28(2)	2·80	4·17	5·15	—	3·35(8)	4·04(6)
			38	1·46	2·38	4·22	4·87	—	3·23	3·82
			75	1·66	2·47	4·22	4·79	—	3·29	3·83
			113	1·41	2·50	4·18	4·63	—	3·18	3·77
			Mean	1·45(8)	2·54	4·20	4·86	—	3·26(32)	
			Mean*	1·51(6)	2·45	4·21	4·76	—		3·81(18)
	T, TU	None	Mean	1·67(4)	2·21	4·25	4·79	—	3·23(16)	3·75(12)
	R, RU	None	Mean	1·24	2·87	4·14	4·91	—	3·29	3·97
	T, TU, R, RU	T	0	3·15(1)	4·24	5·52	5·30	—	4·55(4)	5·02(3)
			38	2·67	4·02	4·89	5·53	—	4·28	4·81
			75	3·49	3·41	4·33	5·35	—	4·14	4·36
			113	2·11	3·80	4·25	5·11	—	3·82	4·39
			Mean	2·85(4)	3·87	4·75	5·32	—	4·20(16)	
			Mean*	2·76(3)	3·74	4·49	5·33			4·52(9)
		R	0	2·11(1)	2·51	4·23	5·31	—	3·54(4)	4·02(3)
			38	1·27	2·84	3·54	4·62	—	3·07	3·67
			75	1·36	2·57	4·79	5·15	—	3·47	4·17
			113	1·56	3·45	3·82	5·42	—	3·56	4·23
			Mean	1·57(4)	2·84	4·10	5·12	—	3·41(16)	
			Mean*	1·40(3)	2·95	4·05	5·06	—		4·02(9)

* Excluding 0, 151 kg N ha^{-1}

Standard errors	(1)	(2)	(3)	(4)	(6)	(8)	(9)	(16)	(18)	(32)
(a)	0·382	0·270	0·221	0·191	0·156	0·136	0·127	0·096	0·090	0·068
(b)	0·434	0·307	0·251	0·217	0·177	0·153	0·145	0·109	0·102	0·077

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APPENDIX TABLE 7

Mean yields of barley

t ha^{-1}, at 85% dry matter
Lower Half 1966, third successive barley crop

To 1953	1955–62	U/S 1964 and 1965	U/S 1966	N in 1964 and 1965 kg ha^{-1}	N in 1966, kg ha^{-1}: 0	38	75	113	Mean*	Mean†
F	F	None	T, R	38	—	1·91(2)	—	4·47	—	3·19(4)
				75	—	1·56	—	4·23	—	2·90
				113	—	1·98	—	3·64	—	2·81
				151	—	1·73	—	4·05	—	2·89
				Mean	—	1·80(8)	—	4·10	—	2·95(16)
				Mean‡	—	1·82(6)	—	4·11	—	2·97(12)
			T	Mean	—	1·83(4)	—	4·29	—	3·06(8)
			R	Mean	—	1·77	—	3·90	—	2·84
V, M, R, C	T, TU, R, RU	None	T, R	0	—	2·28(2)	—	4·54	—	3·41(4)
				38	—	2·33	—	4·13	—	3·23
				75	—	1·71	—	3·73	—	2·72
				113	—	2·17	—	4·74	—	3·46
				Mean	—	2·12(8)	—	4·29	—	3·20(16)
				Mean‡	—	2·07(6)	—	4·20	—	3·14(12)
			T	Mean	—	2·13(4)	—	4·22	—	3·18(8)
			R	Mean	—	2·11	—	4·35	—	3·23
		None	None	0	1·18(1)	2·97	3·40	5·13	3·17(4)	4·05(2)
				38	1·15	1·56	3·07	3·95	2·43	2·76
				75	1·47	1·86	4·23	5·23	3·20	3·54
				113	0·92	1·58	3·01	4·17	2·42	2·87
				Mean	1·18(4)	1·99	3·43	4·62	2·81(16)	3·31(8)
		T	None	0	3·85(1)	4·77	5·75	5·02	4·85(4)	4·89(2)
				38	3·02	3·65	5·03	4·87	4·14	4·26
				75	2·23	3·71	4·62	5·16	3·93	4·44
				113	2·16	2·81	4·13	4·51	3·40	3·66
				Mean	2·82(4)	3·74	4·88	4·89	4·08(16)	4·31(8)
		R	None	0	1·33(1)	3·12	3·58	3·84	2·97(4)	3·48(2)
				38	1·64	2·57	3·65	4·83	3·17	3·70
				75	1·56	2·35	3·94	4·37	3·05	3·36
				113	1·37	2·43	4·73	4·57	3·28	3·50
				Mean	1·47(4)	2·62	3·98	4·40	3·12(16)	3·51(8)

* Means of four levels of N
† Means of 38, 113 kg N ha^{-1}
‡ Excluding 0, 151 kg N ha^{-1}

Standard errors	(1)	(2)	(4)	(6)	(8)	(12)	(16)
(a)	0·382	0·270	0·191	0·156	0·136	0·110	0·096
(b)	0·434	0·307	0·217	0·177	0·153	0·125	0·109

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APPENDIX TABLE 8

Mean yields of barley

t ha^{-1}, at 85% dry matter
Lower Half 1967, fourth successive barley crop

To 1953	1955–62	U/S 1964 and 1965	U/S 1966	N 1966 kg ha^{-1}	N in 1967, kg ha^{-1}: 38	75	113	151	Mean
F	F	None	T	38	3·61(1)	4·20	5·16	4·67	4·41(4)
				113	3·70	4·51	4·29	4·34	4·21
				Mean*	3·66(2)	4·35	4·72	4·51	4·31(8)
			R	38	2·18(1)	2·91	4·03	4·00	3·29(4)
				113	2·52	2·70	4·28	3·83	3·34
				Mean*	2·36(2)	2·81	4·15	3·92	3·31(8)
			Mean*		3·01(4)	3·58	4·44	4·22	3·81(16)
V, M, R, C	T, TU, R, RU	None	T	38	4·46(1)	4·74	4·44	3·71	4·34(4)
				113	2·92	4·24	3·89	4·12	3·79
				Mean*	3·69(2)	4·49	4·17	3·92	4·07(8)
			R	38	2·76(1)	4·28	3·49	4·22	3·69(4)
				113	3·05	3·15	4·02	5·16	3·84
				Mean*	2·91(2)	3·71	3·75	4·69	3·76(8)
			Mean*		3·30(4)	4·10	3·96	4·30	3·92(16)
		None	None	0	2·92(1)	3·16	2·72	3·66	3·11(4)
				38	1·72	2·41	4·12	3·75	3·00
				75	3·21	2·12	4·03	3·46	3·21
				113	2·16	3·24	3·15	3·28	2·96
				Mean	2·50(4)	2·73	3·50	3·54	3·07(16)
				Mean*	1·93(2)	2·82	3·64	3·51	2·98(8)
		T	None	0	2·03(1)	2·75	4·48	4·93	3·55(4)
				38	2·05	3·19	3·66	3·50	3·10
				75	2·51	4·28	3·56	3·48	3·46
				113	1·82	2·27	3·19	3·36	2·66
				Mean	2·10(4)	3·12	3·72	3·82	3·19(16)
		R	None	0	2·18(1)	3·05	3·94	4·66	3·46(4)
				38	2·35	2·86	4·49	3·79	3·37
				75	1·88	3·75	3·71	3·31	3·16
				113	2·41	3·58	4·29	3·29	3·39
				Mean	2·21(4)	3·31	4·11	3·76	3·35(16)

* 38, 113 kg N ha^{-1} in 1966 only

Standard errors	(1)	(2)	(4)	(8)	(16)
(a)	0·488	0·345	0·243	0·172	0·122
(b)	0·555	0·392	0·277	0·196	0·138

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APPENDIX

The Woburn Experiment on Nitrogen Release from Green Manures, 1967–68

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In an experiment on Great Hill Bottom Field, Woburn, four green manures sown after lifting early potatoes were compared with 'fallow'* as preparation for growing barley or sugar beet. The green manures were ryegrass with fertiliser nitrogen at 75 kg N ha^{-1}, and either cut in the autumn before ploughing in spring or the total growth ploughed in, trefoil, and red clover. They were sampled shortly before ploughing for estimation of total dry matter and nitrogen. Soil was sampled to 90 cm and green-crop samples of barley were taken in June; yields of barley grain and sugar-beet roots and tops were measured at harvest. For details see *Numerical Results of the Field Experiments 1968*, item 68/C/38.

Ryegrass (not cut) provided much more dry matter for ploughing down than any other green manure; cut ryegrass provided about half as much (Table 1). Trefoil and clover

TABLE 1

Dry matter and N in green manures (roots and tops) sampled on 31 January 1968 shortly before ploughing

('Fallow' plots not sampled)

	Green manure			
	Ryegrass	Ryegrass, cut	Trefoil	Clover
Dry matter, t ha^{-1}	7·25	3·64	1·71	1·61
N, kg ha^{-1}	87	46	50	50
N%	1·19	1·27	2·94	3·09

each provided less than half as much dry matter as cut ryegrass. There was about 3% N in trefoil and clover but only 1·2–1·3% in the ryegrass (with little difference due to cutting). Amounts of N per unit area were roughly equal (45–50 kg N ha^{-1}) for the two legumes and the cut ryegrass; the uncut ryegrass provided nearly twice as much.

In June, the increases in dry matter yield and N uptake by barley were similar without added fertiliser N and with the least amount added (50 kg N ha^{-1}). They were also similar with the two larger amounts (100 and 151 kg N ha^{-1}). Using the average values for 0 and 50 kg N ha^{-1} and 100 and 151 kg N ha^{-1}, Tables 2 and 3 show the yields and N uptake by barley grown after 'fallow' and the increases (or decreases) from green manures. These values show decreased growth and N uptake after cut ryegrass; on average of all amounts of N added, barley grew best after red clover. Values for mineral N in the soil at this time (Table 4) show no increase in the total amount in the surface 90 cm after cut ryegrass; there were increases after ryegrass, trefoil and red clover, but the values do not reflect crop performance after the various green manures. Table 5 shows that maximum

* Fallow is used in the same sense as in the main paper (see p. 120).

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yields of barley grain were achieved without added N after trefoil and red clover and with the least amount of fertiliser N after other treatments. However, barley yielded differently with increasing amounts of fertiliser N after the different preliminary treatments.

TABLE 2

Yields of dry matter of barley cut as a green crop

Previous treatment	Fertiliser N applied for crop: Mean of 0 and 50 kg N ha⁻¹	Mean of 100 and 151 kg N ha⁻¹
	Yield, t ha⁻¹	
'Fallow'	4·5	7·1
	Increase (+) or decrease (−) from green manures	
Ryegrass	+1·5	+1·3
Ryegrass, cut	−0·5	−0·8
Trefoil	+1·0	+0·8
Clover	+2·3	+1·1

TABLE 3

Uptake of N by barley cut as a green crop

Previous treatment	Fertiliser N applied for crop: Mean of 0 and 50 kg N ha⁻¹	Mean of 100 and 151 kg N ha⁻¹
	Uptake, kg N ha⁻¹	
'Fallow'	65	142
	Increase (+) or decrease (−) from green manures	
Ryegrass	+25	+5
Ryegrass, cut	−8	−34
Trefoil	+35	+6
Clover	+49	+30

TABLE 4

Mineral N in soil after 'fallow' and green manures

(kg N ha⁻¹, calculated assuming 2242 t dry soil ha⁻¹ (equivalent to 2×10^6 lb acre⁻¹) in each 15 cm layer)

Sampling depth cm	'Fallow'	Green manure: Ryegrass	Ryegrass, cut	Trefoil	Clover
0–15	31	41	30	39	40
15–30	24	37	31	37	35
30–45	15	28	16	25	20
45–60	12	15	10	17	14
60–75	11	10	10	11	10
75–90	11	8	7	10	8
Total 0–90 cm	104	139	104	139	127

TABLE 5

Yields of barley grain after 'fallow' and green manures, with and without fertiliser N

(t ha⁻¹, at 85% dry matter)

Fertiliser N applied for barley kg N ha⁻¹	'Fallow'	Green manure: Ryegrass	Ryegrass, cut	Trefoil	Clover
0	3·2	4·0	3·6	4·1	3·9
50	4·2	4·2	4·2	3·7	3·7
100	3·2	3·3	3·1	3·0	2·3
151	3·2	2·4	3·5	2·9	2·4

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For sugar beet, increasing N supply increased the yield of tops and decreased the percentage sugar in the roots. Table 6 shows that the maximum yield of dry matter of roots was achieved with different amounts of fertiliser N and for all treatments except ryegrass the first increment of fertiliser N increased yield of dry matter of roots. Yields of sugar tended to follow yields of dry matter (Table 7). Most notable was the marked maximum in yields of dry matter and sugar after clover with the least amount of fertiliser N (63 kg N ha^{-1}).

TABLE 6

Yields of dry matter of roots of sugar beet after fallow and green manures, with and without fertiliser N

(t ha^{-1}, at 85% dry matter)

Fertiliser N applied for sugar beet kg N ha^{-1}	'Fallow'	Green manure			
		Ryegrass	Ryegrass, cut	Trefoil	Clover
0	9·8	11·4	9·9	10·5	11·1
63	12·5	11·4	10·8	11·9	12·5
126	12·4	11·0	11·6	11·8	11·4
188	12·5	11·1	10·5	11·5	10·6

TABLE 7

Yields of sugar from sugar beet after fallow and green manures, with and without fertiliser N

(Yield of sugar, t ha^{-1})

Fertiliser N applied for sugar beet kg N ha^{-1}	'Fallow'	Green manure			
		Ryegrass	Ryegrass, cut	Trefoil	Clover
0	7·0	7·9	6·9	7·4	7·8
63	8·7	8·0	7·8	8·3	8·7
126	8·7	7·5	8·1	8·3	8·1
188	8·8	7·7	7·2	8·1	7·4

These results show that the benefits from green manures are not related to the amounts of organic matter or total N provided; they may however be partly explained by their ability to release nitrogen. Legumes and uncut grass release nitrogen readily, residues of cut grass do not.

The soil measurements show the difficulty of trying to quantify the nitrogen release by sampling even to a depth of 90 cm. These results do not indicate whether this was due to sampling error or to the inherent difficulty of trying to assess the contribution of legume nitrogen. There are also indications that the test crops responded differently to increasing amounts of fertiliser N after the various treatments; these interactions require further elucidation.

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