ROTHAMSTED RESEARCH

Details of the Classical and Long-term Experiments Up to 1967

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Ley-arable Rotation - Woburn

Rothamsted Research

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LEY-ARABLE ROTATION EXPERIMENT, WOBURN, STACKYARD FIELD, SERIES D, 1938 ONWARDS

The purpose of this experiment is to test the effects on soil fertility of a three-year grazed ley, three years of lucerne (cut) and an arable rotation which includes a one-year ley, in comparison with a rotation without leys. The effects of these crop sequences are measured by the yields of two successive test-crops, a root crop and a cereal. Each rotation therefore has five courses.

There are five series, one for each phase of the cycle; each course of each rotation is present every year. Each series has eight whole plots (in one randomised block). Four of these carry the same rotation repeatedly ('continuous'). The other four carry the four rotations in succession ('alternating'), two in the order: ley, arable with hay, lucerne, arable with roots; two in the order: ley, arable with roots, lucerne, arable with hay. The four 'alternating' plots in a series are always one in each rotation.

Throughout the whole period each whole plot has been divided into two subplots of 0·0413 acres, one of which receives 15 tons FYM per acre before the first test-crop, applied cumulatively. The FYM has been ploughed in except 1948–55 (see below). Details of the further splitting of plots will be found in the full account below.

The production of the grazed ley is measured in terms of sheep grazing days. Sample cuts are also made when each period of grazing begins and (since 1946) when the sheep are removed.

Major changes 1938–67

(For details see pp. 106–114)

When the experiment started the rotations compared were as follows:

		Treatment crops			Test crops	
Rotation	Year: 1st	2nd	3rd	4th	5th
Ley	Ley, grazed	Ley, grazed	Ley, grazed	Potatoes	Barley
Lucerne	Lucerne, cut	Lucerne, cut	Lucerne, cut	Potatoes	Barley
Arable (hay)	Potatoes	Winter wheat*	One-year hay	Potatoes	Barley
Arable (roots)	Potatoes	Winter wheat	Kale	Potatoes	Barley

* Undersown.

The lucerne and grazed leys were sown in the open in the spring.

With minor changes, those continued until 1955. In 1955 the treatment-crop potatoes in plots in continuous arable (roots) and continuous arable (hay) yielded badly. This was the eighth crop of potatoes grown in a period of 19 years and soil samples indicated serious infestations of potato cyst-nematode (*Heterodera rostochiensis*) with moderate infestations on many other plots.

All the rotations were then changed; sugar beet took the place of

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potatoes as the first test-crop and the treatment-crops of the two arable rotations were altered to minimise the incidence of all soil-borne pathogens likely to affect the test-crops.

The new scheme was as follows:

	Treatment crops			Test crops	
Year:	1st	2nd	3rd	4th	5th
Rotation					
Ley	Ley, grazed	Ley, grazed	Ley, grazed	Sugar beet	Barley
Lucerne	Lucerne, cut	Lucerne, cut	Lucerne, cut	Sugar beet	Barley
Arable (hay)	Potatoes	Winter rye*	One-year hay	Sugar beet	Barley
Arable (roots)	Potatoes	Winter rye	Carrots	Sugar beet	Barley

* Undersown.

At about the same time it became clear that the rates of application of phosphate and potash on half-plots not receiving FYM were inadequate and rates were increased. The total amounts of P and K applied per five-year cycle were still, however, the same for all rotations.

In 1962 the dressings of P and K were again revised; each crop was manured according to its estimated needs and the totals varied between the four rotations. In addition, 'corrective' dressings of potash were applied before the first test-crop from 1962 onwards. The rates were based on soil analysis and varied with cropping history and with the presence or absence of FYM. Half-plots not receiving FYM received additional muriate of potash containing the same amount of K as the FYM. From 1957 lucerne on some plots (in the second and third year) was seen to be damaged by stem eelworm (*Ditylenchus dipsaci*). This damage continued in spite of fumigation of the soil of certain plots, and of the use of fumigated seed and from 1964 sainfoin was introduced in place of lucerne.

Period 1938–48

TABLE 49

Fertilisers and methods of application

	cwt nutrient				
	N	P_2O_5	K_2O	Material	How applied
Potatoes	0·6	0·5	0·72	Sulphate of ammonia, superphosphate and sulphate of potash	In furrows
Wheat	0·2	—	—	Sulphate of ammonia	Top-dressed in spring
Barley	0·2	—	—	Sulphate of ammonia	In the seedbed
Kale	0·6	—	—	Sulphate of ammonia	In the seedbed
One-year hay	0·2	—	—	Sulphate of ammonia	In spring
Ley: first year	0·2	0·5	0·72	Sulphate of ammonia, superphosphate and sulphate of potash	In the seedbed
second and third years	—	—	—	—	
Lucerne: first year	—	0·5	0·72	Sulphate of ammonia, superphosphate and sulphate of potash	In the seedbed
second and third years	—	—	—	—	

After 1943 sulphate of potash was replaced by the muriate.

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All rotations had equal total amounts of phosphate (1·0 cwt P_2O_5) and potash (1·44 cwt K_2O) per acre every five years, but nitrogen was given according to the needs of the crop. Both treatment- and test-crop potatoes received the same fertiliser treatment but test-crop potatoes tested 0 v. 15 tons FYM which was ploughed in until 1947, thereafter it was placed in the furrows before planting.

In 1945 sugar beet replaced kale as the third treatment-crop of the arable (roots) rotation and received the same fertiliser as the kale had previously until 1947. Since then 4 cwt nitrate of soda was applied instead of 3 cwt sulphate of ammonia. The tops of the sugar beet were carted off. The seeds mixture for the one-year hay changed during the period as follows (lb):

	1940–44	1945	1946–47
Italian ryegrass	16	24	24
Broad red clover	10	12	—
Montgomery red clover	—	—	12

In 1948 the undersown seeds hay failed and was replaced by a spring sowing of 22 lb Italian ryegrass and 27 lb Trifolium.

The seeds mixture for the three-year ley changed during the period (Table 50).

TABLE 50

Seeds mixture for the three-year ley

	1938–40	1941–47
Italian ryegrass	—	10
Perennial ryegrass S.23	14	14
Cocksfoot S.143	8	8
Late-flowering red clover S.123	4	4
White clover S.100	—	2
Wild white clover	2	—

Period 1949–55

In 1949 sulphate of ammonia was replaced by 'Nitro-Chalk' 15·5% N for the following crops (with new rates of application): barley 0·23 cwt N; rye 0·45 cwt N; ley second and third years 0·15 cwt N; hay first cut 0·30 cwt N, and second cut 0·15 cwt N as 'Nitro-Chalk'.

From 1950 the basal dressing for the block carrying the first treatment-crops was applied as compound granular fertiliser (0:13:13) to supply 0·6 cwt P_2O_5 and 0·6 cwt K_2O and the block with test-crop potatoes received a basal dressing of granular compound fertiliser (7:7:10½) to supply 0·56 cwt N, 0·56 cwt P_2O_5, 0·84 cwt K_2O. Plots of the test-crop potatoes were split in 1955 into eighths to test sulphate of ammonia and muriate of potash additional to the basal application (0 v. 0·56 cwt N) × (0 v. 0·84 cwt K_2O), these amounts being equal to the N and K applied as the basal dressing. Also in 1956 the second test-crop barley received an equalising dressing of 0·84 cwt K_2O on subplots that had not received

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extra potash for the previous test potatoes. The subplots were not harvested separately in the barley.

From 1951 the first year of the three-year ley received 0·2 cwt N as 'Nitro-Chalk' (15·5% N) in place of sulphate of ammonia. In 1954 and 1955 the one-year hay plots were split after the first cut to test 0·15 v. 0·30 cwt N as 'Nitro-Chalk'. The 'Nitro-Chalk' dressing in the spring to the three-year ley was repeated at the same rates in mid-season.

The seeds mixture for the one-year hay changed during the period as follows (lb):

	1949–50	1951–55	1956
Perennial ryegrass S.24	24	27	19
Late-flowering red clover	12	12	9
Alsike clover	3	3	2

The seeds mixture for the three-year ley during the period remained the same except for a change from S23 to S24 perennial ryegrass for 1955 and 1956 (lb):

Perennial ryegrass S.23	21
Cocksfoot S.143	12
Late-flowering Montgomery red clover	6
White clover S.100	3

Period 1956–61

From 1956 sugar beet replaced potatoes as the first test-crop, and carrots replaced sugar beet as the third course of the arable (roots) rotation. The tops of both crops were carted off. The system of manuring was revised in 1956, but the total phosphate (1·72 cwt P_2O_5) and potash (3·9 cwt K_2O) were still the same for all rotations. Nitrogen was still given according to the needs of the crops to give the following scheme of manuring (Table 51).

Carrots failed in 1957 and turnips were sown instead. The sulphate of ammonia and muriate of potash applied to carrots, one-year hay, and the second- and third-year leys were replaced in 1958 by the compound (16:0:16) to supply 0·6 cwt N and 0·6 cwt K_2O applied in the seedbed for carrots, and in the spring for the one-year hay. For the ley the total dressing was 0·54 cwt N and 0·54 cwt K_2O applied in three equal applications or two according to growing conditions during the season.

Because of stem eelworm (*Ditylenchus dipsaci*) the third-year lucerne ('alternating' only) was ploughed up and fallowed in 1958, at the end of the second year, and in 1959 all plots of the third-year lucerne were similarly treated. From autumn 1960 to autumn 1962 certain areas were treated with various materials in an effort to control the eelworm (Table 52). Fumigated seed was sown from 1959. In spite of these precautions the lucerne continued to yield poorly.

'Nitro-Chalk' 15·5% N was replaced by a 20·5% N grade in 1959 and by a 21% grade in 1960; the rates of application were adjusted accordingly. The (7:7:10½) mixture for potatoes was replaced by (12:12:18). The sugar beet compound (12:12:15) was replaced by a mixture of (13½:13½:13½) and

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TABLE 51

Fertilisers and methods of application 1956–61

Treatment	cwt nutrients N	P_2O_5	K_2O	Material	How applied
Crop					
Potatoes	1·0	1·0	1·5	(7:7:10½)	On the flat
Rye	0·6	—	—	'Nitro-Chalk'	Top dressed
Carrots	0·48	—	0·6	Sulphate of ammonia, muriate of potash	In seedbed
One-year hay	0·48	—	0·6	Sulphate of ammonia, muriate of potash	In spring
	0·22	—	—	'Nitro-Chalk'	For aftermath
Ley: first year	0·6*	1·0	1·0	'Nitro-Chalk' and (0:13:13)	In seedbed and (N only) during the season
second and third years	0·6*	—	0·55	'Nitro-Chalk', muriate of potash	In spring and during the season
Lucerne: first year	—	1·0	1·0	(0:13:13)	In seedbed
second and third years	—	—	0·55	Muriate of potash	Top dressed
First test crop: Sugar beet					
	0·72	0·72	0·9	(12:12:15)	In seedbed
A test on eighth plots of (O v. 0·72 cwt N) × (O v. 0·9 cwt K_2O) as 'Nitro-Chalk' and muriate of potash in seed bed.					
Second test crop: Barley					
	0·6	—	—	'Nitro-Chalk'	In seedbed
An application of 0·9 cwt K_2O as muriate of potash was made after ploughing on those eighth plots which did not receive test potash for the sugar beet.					

*Total. In 1956 in two dressings, thereafter in three dressings.

TABLE 52

Fumigants, etc., applied for control of Ditylenchus dipsaci

Date applied	Crop following application	Areas treated	Material	Rate of application
October 1960	Third-year lucerne	Half plots (not randomised)	Thionazin (5% granules)	8 lb a.i.
November 1960 (before ploughing)	Sugar beet	Half plots (not randomised)*	Metham sodium (undiluted)	109 gallons
March 1961 (before ploughing)	First-year lucerne	All plots	Metham sodium (undiluted)	109 gallons
October 1961 (between first and second ploughings)	First-year lucerne	All plots	'D-D' (injected)	800 lb
October 1962 (between first and second ploughings)	First-year lucerne	All plots	'D-D' (injected)	600 lb

* Plots in lucerne 1958–60, 'alternating' only.

(12:12:18) in 1959. Cereals were combine harvested for the first time in 1959. The hay and carrot crops on the 'alternating' plots were accidentally interchanged in 1960.

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WOBURN LEY-ARABLE

Period 1962–67

In 1962 the standard applications to the treatment-crops were revised to give the following scheme (Tables 53 and 54):

TABLE 53

Fertilisers and methods of application
1962–63

Treatment crops	cwt nutrients N	P_2O_5	K_2O	Material	How applied
Potatoes	1·0	0·9	1·8	'Nitro-Chalk' superphosphate and muriate of potash	On the flat
Rye	—	0·3	0·6	(0:14:28)	In seedbed
	0·6	—	—	'Nitro-Chalk'	In spring
Carrots	0·6	0·6	1·8	'Nitro-Chalk' superphosphate and muriate of potash	In seedbed
One-year hay	0·6	0·6	1·2	'Nitro-Chalk' (0:14:28)	In spring
	0·22	—	0·6	'Nitro-Chalk' and muriate of potash	After first cut
Ley: first year	—	1·5	1·0	Superphosphate and muriate of potash	In seedbed
	0·6	—	—	'Nitro-Chalk'	In three equal dressings
second and third years	0·55 (Total per year)	—	0·55	(16:0:16)	In three equal dressings
Lucerne: first year	—	1·5	1·0	Superphosphate and muriate of potash	In seedbed
second and third years	—	—	1·5	Muriate of potash	In spring
First test crop: sugar beet					
(a) without FYM	—	0·9	3·0*	'Nitro-Chalk', superphosphate and muriate of potash	Plough furrow
(b) with FYM	—	0·3	0·9		Plough furrow

* Ploughed in.

A test on eighth plots of (0·72 v. 1·44 cwt N) x (0 v. 0·9 cwt K_2O) as 'Nitro-Chalk' and muriate of potash, applied in seedbed. Also a test on sixteenth plots of 0 v. 50 lb Mg as sulphate of magnesia applied after ploughing.

Second test crop: barley					
	0·6	0·3	—	'Nitro-Chalk' and superphosphate	In seedbed

Also 0·9 cwt K_2O as muriate of potash applied in spring to subplots that did not receive test K to sugar beet.

The dressings to the one-year hay were revised in 1963 to supply 1·0 cwt N as 'Nitro-Chalk', and 0·6 cwt P_2O_5, 1·2 cwt K_2O as (0:14:28) in spring and 0·6 cwt N, 0·6 cwt K_2O as (16:0:16) after the first cut. The dressing to the three-year ley was altered so that there was an initial dressing in the first year in the seedbed of 0·3 cwt N as 'Nitro-Chalk' followed by early and late summer applications of (16:0:16) each of 0·3 cwt N and 0·3 cwt K_2O. The second and third years of the ley had, in each year, three equal dressings of (16:0:16) each of 0·3 cwt N, and 0·3 cwt K_2O. The

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TABLE 54

Corrective potassium applications in cwt K_2O as muriate of potash

	Year of sugar beet																	
	1962		1963		1964		1965			1966			1967					
	O	D	O	D	O	D	O	D		O	D		O	D				
'Continuous' rotations																		
L	1·3	0·0	3·0	0·0	3·0	0·0	0·0	0·0		2·0	0·0		2·0	1·0				
Lu (S from 1965)	3·6	3·2	6·0	6·0	3·0	3·0	3·0	3·0		5·0	5·0		4·0	3·0				
Ah	3·6	3·2	6·0	6·0	4·0	3·0	4·0	3·0		6·0	6·0		5·0	4·0				
A	3·6	3·2	6·0	6·0	3·0	3·0	3·0	2·0		5·0	5·0		2·0	2·0				
'Alternating' rotations (Last two rotations in chronological order)																		
AhL	2·9	2·3	AL	3·0	3·0	AhL	3·0	3·0	AL	3·0	1·0	AL*	4·0	0·0	AL	3·0	2·0	
ALu	3·6	3·2	AhLu	6·0	6·0	ALu	3·0	2·0	AhLu	3·0	3·0	AhLu*	5·0	4·0	AhS	4·0	4·0	
LAh	3·6	3·2	LuAh	6·0	6·0	LAh	3·0	2·0	LuAh	3·0	3·0	LAh	5·0	5·0	SAh	3·0	3·0	
LuA	3·6	3·2	LA	6·0	6·0	LuA	3·0	2·0	LA	3·0	2·0	LuA	6·0	5·0	LA	2·0	0·0	

* Shows the sequence as it was and not as it should have been.

Symbols

L = grazed ley. Lu = lucerne. S = sainfoin. Ah = arable (hay). A = arable (roots). D = FYM to first test-crop.

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dressing to lucerne was also altered to supply 0·5 cwt N as 'Nitro-Chalk', 1·5 cwt P_2O_5 as superphosphate and 1·0 cwt K_2O as muriate of potash in the first year. In the second and third years the dressing was 0·5 cwt P_2O_5 as superphosphate and 1·5 cwt K_2O as muriate of potash.

By 1962 it was found that little K was available in the soils and corrective K dressings were applied year by year, based on soil analysis. Details are given in Table 54 (page 111).

These dressings were applied at the end of the third treatment year before sugar beet, the first applications being made in autumn 1961. The dressing was split, half being applied in the autumn before ploughing and the other half broadcast on the plough furrow in February. The exceptions were in 1963 when the dressing was split, two-thirds in autumn and one-third in spring, and 1965 when the dressing of 1·0 cwt for the plot after AL with FYM was applied all before ploughing. Half-plots of the test-crop not receiving FYM received a dressing of muriate of potash equivalent to that in the FYM applied before ploughing.

Muriate of potash application equivalent to FYM:

		(cwt K_2O)			
1962	1963	1964	1965	1966	1967
3·0	3·2	3·7	3·3	4·8	1·9

(Until 1966 the manure was made by pigs, from 1967 by bullocks.)

In 1964 further revisions were made in the basal and test fertiliser dressings as follows (Table 55):

TABLE 55

Fertilisers and methods of application
1964

	cwt nutrients				
Treatment crops	N	P_2O_5	K_2O	Material	How applied
Ley: first year	0·4	1·5	1·0	'Nitro-Chalk' superphosphate and muriate of potash	In seedbed
	0·8	—	0·8	(16:0:16)	Two equal dressings: early and late summer
	(Total per year)				
second and third years	1·2	—	1·2	(16:0:16)	Three equal dressings: spring, early and late summer
	(Total per year)				

First test crop, sugar beet

(0·9 v. 2·4 cwt P_2O_5) as superphosphate to plough furrow (to sixteenth plots)
0·9 cwt K_2O (basal) to plough furrow
(0 v. 0·9 cwt K_2O) (to eighth plots) in seedbed, all as muriate of potash.
50 lb Mg (basal) as sulphate of magnesia in seedbed.
(a) Ley and lucerne rotations: 1·05 v. 1·40 cwt N
(b) Arable (hay) and arable (roots) rotations: 1·40 v. 1·75 cwt N as 'Nitro-Chalk' to seedbed (to eighth plots).

From 1964 the lucerne crop was changed to sainfoin because of the failure to control stem eelworm (*Ditylenchus dipsaci*). The basal and test

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fertiliser dressings to the sugar beet test-crop were revised in 1965 to give the following scheme (Table 56):

TABLE 56

Fertilisers and methods of application for sugar beet 1965–67

Basal: 2·0 cwt P_2O_5 as superphosphate, applied half to plough furrow, half in seedbed (1965: 0·9 cwt to plough furrow, 1·1 cwt in seedbed); 0·9 cwt K_2O as muriate of potash to plough furrow; and 50 lb Mg as sulphate of magnesia ($MgSO_4.7H_2O$) applied in seedbed.

Test of (0 v. 0·9 cwt K_2O) applied as muriate of potash in seedbed on sixteenth plots

Test of N applied as 'Nitro-Chalk' in seedbed:

(a) Ley and lucerne rotations: 0·35 v. 0·70 v. 1·05 v. 1·40 cwt N.

(b) Arable (roots) rotation: 0·70 v. 1·05 v. 1·40 v. 1·75 cwt N.

(c) Arable (hay) rotation: 1·05 v. 1·40 v. 1·75 v. 2·10 cwt N.

The third-year lucerne failed and was replaced by sainfoin and received a fertiliser dressing of 0·5 cwt N as 'Nitro-Chalk', 0·5 cwt P_2O_5 as superphosphate and 1·5 cwt K_2O as muriate of potash. The second-year sainfoin failed and was re-sown with a dressing of (0:20:20) to supply 0·5 cwt P_2O_5 and 0·5 cwt K_2O.

In 1966 the third-year sainfoin failed and was resown with a fertiliser application of (0:20:20) to supply 0·5 cwt P_2O_5 and 0·5 cwt K_2O. No spring dressing of N and K was applied. The rye crop in 1967 failed and was replaced by spring wheat which received 0·6 cwt N as 'Nitro-Chalk'. The K test on sugar beet was discontinued and the N test was on quarter plots instead of eighth plots.

Husbandry

During the whole period of the experiment the varieties and crops grown have changed as shown in Table 57, (p. 114.)

Liming. Commencing in 1947 an application of ground chalk was made before every barley crop. The rate of dressing was approximately 15 cwt calcium carbonate. In 1953 the rate was increased to 10 cwt calcium oxide, i.e. about 19 cwt ground chalk. In 1958 the dressing was further increased to the maximum amount of ground chalk delivered by one passage of the manure drill. This was about 23 cwt. In spite of rotational liming before barley, plots carrying the second-year treatment crops of the arable (roots) and arable (hay) rotations in 1957 were found to be slightly acid and 12 cwt chalk was applied to these plots in 1958. The dressing to barley in 1959 and 1960 was 18 cwt chalk. In 1960 chalk was applied also to the carrots and one-year hay at 20 cwt. From 1961 to 1967 the application to barley was 40 cwt chalk (1966: 35 cwt). In 1966 sugar beet also received 35 cwt chalk.

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TABLE 57

Varieties and crops grown

Year	Lucerne	Sugar beet	Barley	Potatoes	Rye	Carrots	Wheat	Kale
1938–44	Provence	—	Plumage Archer	Majestic	—	—	R.S.	T.H.
1945	Grimm	Klein E	,,	,,	—	—	,,	—
1946	Argentine	,,	,,	,,	—	—	,,	—
1947	Provence	,,	,,	,,	—	—	,,	—
1948	,,	,,	,,	,,	—	—	S.H.M.*	—
1949	,,	,,	,,	,,	King II	—	—	—
1950–55	Du Puits	,,	,,	,,	,,	—	—	—
1956	,,	,,	Herta	,,	,,	J.S.I.	—	—
1957	,,	,,	,,	,,	,,	Turnips†	—	—
1958–61	,,	,,	,,	,,	,,	J.S.I.	—	—
1962–63	,,	,,	Proctor	,,	,,	,,	—	—
1964–65	Sainfoin‡	,,	Maris Badger	,,	,,	Autumn King	—	—
1966	,,	,,	,,	Maris Piper	,,	,,	—	—
1967	,,	,,	,,	,,	Spring Wheat§	,,	—	—

R.S. = Red Standard J.S.I. = James's Scarlet Intermediate
S.H.M. = Squarehead's Master T.H. = Thousand Head

* Winter wheat failed and was replaced by spring wheat (Atle).

† The carrots failed and turnips (Imperial Green Globe) were sown instead.

‡ Sainfoin introduced as first-year treatment-crop (Common sainfoin).

§ The rye failed because of bird damage and was replaced by spring wheat (Kloka).

References

For design and cropping see *Rep. Rothamsted exp. Stn for 1938*, 135–137.

For a summary of the first eight years' results see *Rep. Rothamsted exp. Stn for 1948*, 94–97.

For a full discussion of the results to 1956 see Mann, H. H. & Boyd, D. A. (1958). Some results of an experiment to compare ley and arable rotations at Woburn, *J. agric. Sci.* **50**, 297–306.

For a summary to 1967 see: Boyd, D. A. (1968) Experiments with ley and arable farming systems. *Rep. Rothamsted exp. Stn for 1967*, 316–331.

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