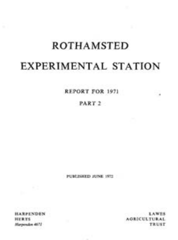
Rothamsted Experimental Station Report for 1971 Part 2



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Experiments on Herbage Crops at Saxmundham, 1967–71

R. J. B. WILLIAMS and G. W. COOKE

Saxmundham soil (described by Hodge (p. 143)) is one of the kinds described by the Agricultural Advisory Council's (1970) Report as 'potentially susceptible' to damage to its structure (our recent work on the soil is described on pp. 122–142). The Report states that 'periodic grass breaks' are particularly useful in helping to get better yields from such land. Thirty years ago Oldershaw (1941) made a similar recommendation when reporting the first 40 years of work on arable crops at Saxmundham: 'The selection of suitable crops for this type of land is very important. It is evidently specially suitable for herbage plants. Red clover has given as heavy crops on this soil as it would on really good land, and when suitably treated with phosphates, wild white clover covers the ground like a carpet. Tares and lucerne have also proved very productive. Temporary leys have given heavier crops of hay, and of better quality, than are often obtained from rich old meadow land. The growth of such crops for hay, for silage or for seed, combined with a system of temporary leys followed by a few years of arable cropping, seems to be a system of husbandry suited to land of this type. Under such a system the farmer would have a rather limited area under the plough in any particular year, and would be able to concentrate his energies upon it, with the idea of growing really good crops instead of the miserable ones which are so common on this kind of land.'

In addition to improving soil physically, leys are a practicable alternative to cereals, affording a 'break' to control soil-borne pests and diseases and the weeds that increase where cereals are grown often. Using leys profitably is not as easy as growing them in an area that is now mainly in arable farming and dominated by cereals. Few stock are kept so the leys may have to be harvested, dried and used as concentrated protein-rich fodder in intensive animal units in areas where there are more cattle. Developments in the drying and processing of herbage crops will influence the extension of ley-farming in arable areas. For ley-farming to be profitable, the leys must yield well and we found little recent information on yields of grasses and legumes that can be grown in East Suffolk, on the manuring leys need, and on the nutrients they remove from soil. The experiments we describe were planned to measure yields that can be produced by grasses and by legumes, and the fertilisers needed to produce good yields and to maintain nutrient reserves in the soils. This information is an essential background for extending the areas of leys grown on these Chalky Boulder Clay soils.

Early experiments

Some experiments on herbage crops made during the first 30 years at Saxmundham were reported by Oldershaw (1934). A 'classical' experiment was started in 1902 in Fiske's Field, on 'semi-derelict' grassland that had never been properly seeded. The experiment lasted until 1933. Yields in three periods are summarised in Table 1. Fertilisers (including nitrogen) were applied, somewhat irregularly, in only six or seven years from 1901 to 1926. Phosphate greatly increased yield, but up to 1926, there were only small gains from potassium; nitrogen, as used in the experiment (about 17 kg N/ha) and given only in five of the years 1908–26, was of little value. From 1927 to 1933, phosphate was applied only twice but nitrogen each spring; the response to potassium became larger, the small

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annual dose of N (on Plot 7) gave over 0·3 t/ha more hay than came from the PK-treated plot (No. 5) where legumes provided nitrogen.

TABLE 1

Yields of hay from Fiske's Field, Saxmundham 1902–33

(Oldershaw 1934)

		Yields of hay (t/ha)		
Plot	Fertiliser treatment*	1902–07	1908–26	1927–33
1a	P (as basic slag)	4·02	2·90	2·49
1b	P (as basic slag) + K	4·02	3·05	3·13
4	No fertiliser	1·27	1·36	1·52
6	P (as superphosphate)	4·26	2·52	2·74
5	P (as superphosphate) + K	4·12	2·85	3·24
7	P (as superphosphate) + N	4·38	2·91	3·57

* The basic slag dressing supplied 99 kg/ha of P to Plot 1a, 1b; the superphosphate supplied 49 kg/ha of P; kainit supplied 47 kg K/ha; the ammonium sulphate dressing on plot 7 gave 17 kg N/ha.

This 'classical' experiment is an example of much early grassland work in England. Phosphates were essential for encouraging legumes; yield of hay was doubled but the gain was only from about 1·3 to 2·9 t/ha. Later, potassium fertilisers were found essential to maintain growth of the legumes providing nitrogen for the swards. Enough fertiliser nitrogen was never tested, and hay yields never exceeded 4·4 t/ha. Oldershaw also described how in 1903 some of the original herbage was ploughed in, the land treated with phosphate, and then sown with several kinds of grasses and legumes (but not wild white clover which was then little used). These 'improved' mixtures, treated with basic slag, yielded (averaging 23 years) 2·5–3 t/ha of hay, no improvement on the herbage they replaced.

In tests on other parts of the field begun in 1903 large yields were obtained from deep rooting plants (chicory, burnet, kidney vetch and lucerne). From 1926 various grasses and clovers (including wild white clover), and lucerne were grown on old arable land. Some species were sown alone, some in mixtures that included ryegrass and white clover; phosphate and 26 kg N/ha were applied annually. Each year the first crop was mown for hay and the aftermath grazed. These sowings gave much larger yields; mixtures with red clover yielded 5·5–6·2 t/ha, and those with lucerne 6·5 t/ha. A mixture of perennial ryegrass with late-flowering red clover plus wild white clover, gave 13·5 t/ha of hay at two cuts in its first year; later this mixture gave less, and the seven-year average was 6·0 t/ha.

Thirty years research at Saxmundham showed that yields could be five times those of the unmanured swards on which the work began. A few experiments done since Oldershaw's 1934 paper were described by Oldershaw (1934–38) and Trist (1950–64). Most important were those showing that lucerne could yield well at Saxmundham. The large amounts of N fertiliser essential for grass to yield well were never tested. We found no accounts of experiments measuring responses to P and K fertilisers of herbage legumes grown at Saxmundham or elsewhere on calcareous sandy clay soils.

Scope of the 1967–71 experiments

In 1967 we began experiments to test N on grasses grown alone, to measure responses to P and K fertilisers by lucerne and red clover, and to measure the yields of grass–white clover swards cut at grazing stage. Fiske's Field was sold in 1951, so we could not continue the old work on permanent grass; all our experiments used small plots sited on old arable land. We now report yields, and the chemical compositions of the crops needed to construct nutrient balances for ley-farming systems on similar soils.

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TABLE 2

Yields (in t/ha of dry matter) of timothy–meadow fescue ley grown at Saxmundham, 1967–69

Treatment	Total N applied in year (kg/ha)		Cut 1		Cut 2		Cut 3		Cut 4	Cut 5	Total
1967	As 'Nitro-Chalk'		28 June	18 July	15 Aug.	26 Sept.	26 Sept.				
1	0		—	2·52	—	0·50	—		—	—	3·0
2	125	2 dressings applied 21 March and 18 July	—	4·08	—	2·11	—		—	—	6·2
3	251	2 dressings applied 21 March and 18 July	—	4·29	—	2·89	—		—	—	7·2
4	377	2 dressings applied 21 March and 18 July	—	4·42	—	3·34	—		—	—	7·8
5	502	2 dressings applied 21 March and 18 July	—	4·84	—	3·63	—		—	—	8·5
6	188	3 dressings on 21 March, 28 June, 15 August	2·42	—	2·02	—	1·66		—	—	6·1
7	377	3 dressings on 21 March, 28 June, 15 August	3·09	—	2·59	—	2·06		—	—	7·7
8	251	2 dressings on 21 March and 28 June	2·96	—	2·65	—	0·84		—	—	6·4
9	502	2 dressings on 21 March and 28 June	3·69	—	2·55	—	1·88		—	—	8·1
		S.E.	±0·130	±0·217	±0·163	±0·119	±0·089		—	—	±0·24
1968	As 'Nitro-Chalk'		1 May	28 May	28 May	16 Aug.	12 July	23 Oct.	16 Aug.	23 Oct.	
1	0		—	1·12	—	0·45	—	0·11	—	—	1·7
2	125	2 dressings on 29 February and 28 May	—	5·21	—	2·99	—	0·33	—	—	8·5
3	251	2 dressings on 29 February and 28 May	—	8·55	—	5·37	—	0·58	—	—	14·5
4	377	2 dressings on 29 February and 28 May	—	9·25	—	5·40	—	1·32	—	—	16·0
5	502	2 dressings on 29 February and 28 May	—	9·40	—	5·60	—	2·06	—	—	17·1
6	251	4 dressings on 29 February, 1 May, 28 May and 12 July	2·02	—	2·37	—	2·57	—	1·91	0·46	9·3
7	502	4 dressings on 29 February, 1 May, 28 May and 12 July	3·83	—	2·57	—	4·04	—	2·46	1·37	14·3
8	251	2 dressings on 29 February and 28 May	2·37	—	2·85	—	1·84	—	0·56	0·12	7·8
9	502	2 dressings on 29 February and 28 May	4·63	—	1·81	—	3·63	—	1·64	0·84	12·6
		S.E.	±0·153	±0·369	±0·132	±0·236	±0·108	±0·125	±0·069	±0·065	±0·37
1969	As anhydrous ammonia	As 'Nitro-Chalk'	29 May		22 July		11 Sept.		28 Oct.		
1	0	0 (Applied on 11 March)	1·26		0·30		0·26		0·53	—	2·3
2	314	0 (Applied on 11 March)	5·90		3·83		1·19		0·97	—	11·9
3	628	0 (Applied on 11 March)	5·95		4·46		2·38		0·93	—	13·7
4	0	314 (Applied on 11 March)	5·76		1·36		0·55		0·60	—	8·3
5	0	628 (Applied on 11 March)	6·58		4·32		1·61		0·88	—	13·4
6	314 + 'N-Serve'	0 (Applied on 11 March)	5·55		4·43		1·73		0·78	—	12·5
7	628 + 'N-Serve'	0 (Applied on 11 March)	5·55		4·71		2·75		0·94	—	13·9
8	0	157 11 March									
8	0	79 29 May	4·84		3·28		2·69		0·77	—	11·6
	0	78 22 July									
	0	320 11 March									
9	0	157 29 May	5·97		4·88		3·28		0·82	—	15·0
	0	157 22 July									
	314	0 11 March									
10	0	157 29 May	6·02		4·74		3·33		0·87	—	15·0
	0	157 22 July									
		S.E.	±0·329		±0·243		±0·105		±0·088	—	±0·41

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The nitrogen manuring of a timothy–meadow fescue ley

A mixture of S215 meadow fescue and S352 timothy was sown in March 1967 on land where barley and occasional crops of sugar beet had grown for many years. Annual basal dressings of 125 kg P_2O_5/ha and 250 kg K_2O/ha were applied. Individual plots were 1·2 m wide and 6 m long; the central 0·9 m was cut by motor scythe after discarding the ends of the plots. There were ten randomised plots in a block, and the experiment had four blocks.

Tests of times and amounts of N and frequency of cutting. The nitrogen test in 1967 and 1968 was from none to 500 kg N/ha, all applied as 'Nitro-Chalk'. On some plots these amounts were divided into two, half applied before each of two cuts. On other plots a quarter of the total dressing was intended to be applied for each of four cuts. In 1967 the grass grew slowly at first and only three cuts were taken, so only three of the four intended nitrogen dressings were given. On two other plots nitrogen was applied only for the first two cuts, and later cuts were taken to measure nitrogen recovered from the soil; these plots also were cut only three times during 1967. The same scheme was used in 1968 and the grass was cut as planned, a final cut (the fifth on half of the plots) was taken in October to measure residues. Table 2 shows times of fertilising and cutting, and yields.

Test of anhydrous ammonia. The treatments were changed in 1969. Total amounts of none, 314 and 628 kg N/ha were applied during the year. On some plots these totals, applied as 'Nitro-Chalk' (21% N), were split, half was applied in March, one-quarter after the first cut in May and one-quarter after the second cut in July. Anhydrous ammonia was injected into other plots by a hand machine, which avoided loss of the gas to the air. Single dressings of ammonia injected during March were compared with equivalent N as single dressings of 'Nitro-Chalk' broadcast on the surface at the same time (and with the split dressings of the main nitrogen test). Other plots tested both materials; 314 kg N/ha injected as ammonia during March was followed by 157 kg N/ha applied as 'Nitro-Chalk' in May and again in July. Two plots in each block tested anhydrous ammonia treated with a nitrification inhibitor ('N-Serve'—described by Gasser (1970)). Table 2 gives yields obtained in 1969.

Response to nitrogen. Total yields harvested in each year are plotted in Fig. 1 against total N applied; the grass responded up to the largest amounts given and the 'curves' were two-part linear relationships (resembling those discussed by Boyd (1970)). Points of inflexion, separating larger from smaller responses per kg of N, were at 157 kg N/ha in 1967, 250 kg N in 1968 and 314 kg N in 1969.

Because the newly-sown grass grew slowly, total yields in 1967 were about half as large as in 1968 and 1969. Best yields in 1967 were with 500 kg N/ha split into two dressings, but 250 kg N gave yields that were only 1·25 t/ha less.

Yield without N fertiliser in 1968 was only half that of 1967. Largest yield (17·1 t/ha of dry grass) was from 500 kg N/ha split into two dressings for grass that was cut three times; 375 kg N/ha split similarly gave only 1·1 t/ha less dry matter. Splitting a total of 500 kg N/ha into four equal dressings for grass that was cut five times gave 2·5 t/ha less dry matter than the same nitrogen given on two occasions for grass that was cut three times. Cutting grass more frequently improves its quality (larger % protein and more digestible), but these gains have to be offset in practice against the smaller total yield harvested and the cost of cutting five times instead of three.

In 1969 'Nitro-Chalk' supplying 314 kg N/ha in March followed by 157 kg N each in

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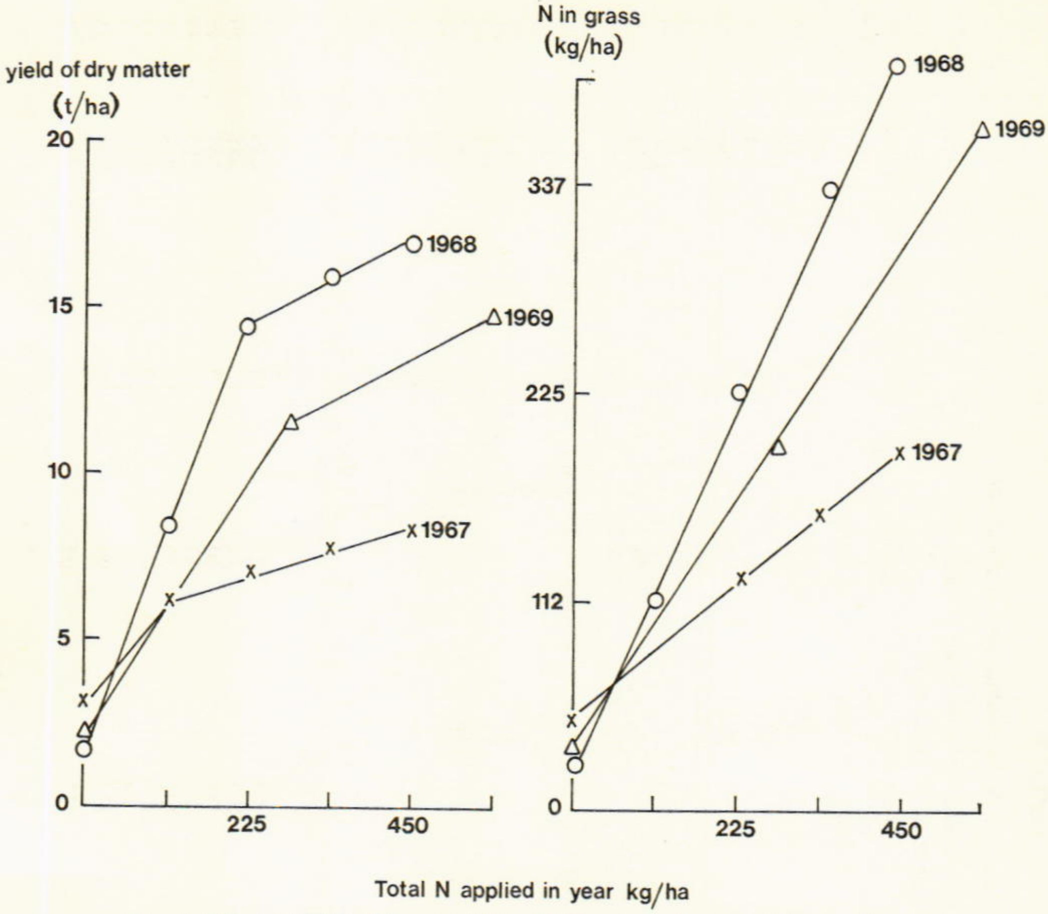

FIG. 1. Effects of N fertiliser on yield and N content of grass at Saxmundham.

May and July gave the largest yield (14·9 t/ha of dry matter). Applying all the N as 'Nitro-Chalk' in March gave 13·4 t/ha of dry matter.

Gains from unit nitrogen. When planning to use nitrogen, farmers need to know the probable response per unit of N. This experiment showed how responses varied above and below the points of inflexion in Fig. 1:

	Response, kg of dry grass/kg of N applied	
	Small dressing	Large dressing
1967 (seeding year)	25	5
1968	51	10
1969	29	11

The smaller dressings tested (125 kg N/ha in 1967, 250 kg N in 1968 and 314 kg N in 1969) should always be very profitable. Larger dressings were probably not profitable in 1967. Good quality dried grass is worth about 3·3p per kg, so the response to 1 kg of N (costing about 10p, neglecting the current subsidy) in 1968 and 1969 was worth about 33p. There was a good margin between value of grass and cost of N fertiliser up to the largest amounts given in 1968 and 1969 to allow for cost of handling and drying the extra crop.

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TABLE 3

Nitrogen in grass grown at Saxmundham in 1967–69

(Details of treatments and dates are given in Table 2)

Uptakes are in kg/ha of N

Treatment	Total N applied in year (kg/ha)		Cut 1		Cut 2		Cut 3		Cut 4	Cut 5	Total	% Recovery
1967	As 'Nitro-Chalk'		28 June	18 July	15 Aug.	26 Sept.	26 Sept.					
1	0		—	39	—	7	—		—	—	47	—
2	125	In two dressings	—	64	—	33	—		—	—	97	39
3	251	In two dressings	—	72	—	54	—		—	—	126	32
4	377	In two dressings	—	80	—	83	—		—	—	163	31
5	502	In two dressings	—	100	—	97	—		—	—	198	30
6	188	In three dressings	43	—	48	—	38		—	—	130	44
7	377	In three dressings	65	—	69	—	64		—	—	198	40
8	251	In two dressings	57	—	70	—	17		—	—	144	38
9	502	In two dressings	87	—	93	—	58		—	—	238	38
		S.E.	±5·0	±5·2	±5·2	±5·0	±3·2		—	—	—	—
1968	As 'Nitro-Chalk'		1 May	28 May	28 May	16 Aug.	12 July	23 Oct.	16 Aug.	23 Oct.		
1	0		—	14	—	7	—	2	—	—	23	—
2	125	In two dressings	—	62	—	44	—	6	—	—	112	70
3	251	In two dressings	—	123	—	93	—	11	—	—	228	81
4	377	In two dressings	—	166	—	138	—	32	—	—	336	83
5	502	In two dressings	—	194	—	161	—	52	—	—	408	77
6	251	In four dressings	44	—	55	—	48	—	48	9	204	72
7	502	In four dressings	106	—	90	—	105	—	92	30	423	80
8	251	In two dressings	70	—	95	—	31	—	10	3	209	74
9	502	In two dressings	163	—	82	—	104	—	51	20	419	79
		S.E.	±5·8	±9·2	±4·1	±4·8	±3·9	±3·9	±2·2	±1·7	—	—
1969	Form of N		29 May		22 July		11 Sept.		28 Oct.			
1	None	0	16		5		5		8	—	34	—
2	Ammonia	314	147		70		22		16	—	255	70
3	Ammonia	628	160		122		51		17	—	351	50
4	'Nitro-Chalk'	314	125		23		10		9	—	167	42
5	'Nitro-Chalk'	628	178		88		33		17	—	317	45
6	Ammonia + 'N-Serve'	314	144		101		30		13	—	288	81
7	Ammonia + 'N-Serve'	628	145		136		66		19	—	367	53
8	'Nitro-Chalk'	314	78		56		52		13	—	200	54
9	'Nitro-Chalk'	628	135		116		98		18	—	368	53
10	Ammonia (½) + 'Nitro-Chalk' (½)	628	151		130		102		22	—	404	59
		S.E.	±9·3		±7·1		±3·5		±1·6	—	±13·6	—

Efficiency of nitrogen. The N recovered by grass was directly proportional to the amount applied as fertiliser up to the largest dressings (Fig. 1); percentages of fertiliser-N recovered differed between years (Table 3).

In 1967 short periods of heavy rain in both April and May leached much N from the soil before the grass, sown in March, was sufficiently established to take it up. The most applied N recovered in 1967 was from total dressings split into three, with two-thirds of the N applied after the period of severe leaching. Twice as much N was recovered in 1968 as in 1967. Spring rain was well distributed in 1968 and little nitrate was leached, even from arable land (Williams, 1969). Dressings that were split into two, and applied on 29 February and 28 May gave almost the same total yields and N uptakes as the same total quantities of N split into four and applied on 29 February, 1 May, 28 May and 12 July.

In 1969 less of the applied N was recovered than in 1968 (Table 3), but recoveries from individual treatments differed greatly. Only 41% of 314 kg N/ha was recovered from a single dose of 'Nitro-Chalk' in March, but 71% from the same amount of N applied at the same time as anhydrous ammonia. 'N-Serve' added to the ammonia further diminished leaching losses so that 81% of the applied N was recovered. The double amount of N (628 kg/ha) was less efficient, and only 50% was recovered from either ammonia or 'Nitro-Chalk' applied in March; dividing the double dressing, giving half as ammonia in March and the other half as two dressings of 'Nitro-Chalk' in May and July, raised the recovery to 60%.

Anhydrous ammonia. In the single-year test, ammonia was at least as efficient as 'Nitro-Chalk'. Both fertilisers applied in March gave similar yields at the first cutting in May; four cuts gave less total grass from 314 kg N/ha as 'Nitro-Chalk' than as ammonia, but similar yields from the two fertilisers applied at 628 kg N/ha. Divided dressings of 'Nitro-Chalk' gave a total yield similar to that from ammonia when the small dressing was applied, but the large rate of 'Nitro-Chalk' divided gave significantly more grass than the large rate of ammonia. Applying half the N as ammonia in March and the rest as 'Nitro-Chalk' in May and July gave the same yield as divided dressings of 'Nitro-Chalk'. Adding a nitrification inhibitor to anhydrous ammonia gave slightly less grass at the first cut and slightly more at later cuts, but the small gain in total yield from using 'N-Serve' was not significant.

Bullen (1968) discussed possible advantages from applying much (or all) of the N-fertiliser early in the year for grass grown in drier parts of Eastern England. Large early dressings are most efficient when there is little leaching during spring and when summer drought prevents late top-dressings washing down to the roots; labour and tractor costs are saved by not giving repeated top-dressings.

Experiments with red clover and lucerne

Identical experiments with Dorset Marl red clover and Europe lucerne were sown on 22 March 1967. The fertilisers (applied on 8 March) tested 63 (P_1) against 251 kg P_2O_5/ha (P_4) and 251 kg K_2O/ha (K_1) against none (K_0). The four factorial treatments (P_1K_0, P_1K_1, P_4K_0, P_4K_1) were arranged in a randomised block, and each experiment had four blocks. P and K fertiliser dressings were repeated in 1968 for clover and in 1968 and 1969 for lucerne. Individual plots were 6·1 m long by 1·2 m wide and the central 0·9 m of each plot was harvested by motor scythe. The experiments were cut twice in 1967 and three times in 1968. The clover died at the end of summer 1968 and wheat was sown on the plots next spring. The lucerne was cut three times in 1969 and ploughed in during September. Table 4 gives yields from the two experiments.

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TABLE 4

Yields of dry matter (tonnes/hectare) of lucerne and red clover grown at Saxmundham, 1967–69

	Red clover			Lucerne		
P_2O_5 applied (kg/ha)	Without K	With 251 kg K_2O/ha	S.E. ±	Without K	With 251 kg K_2O/ha	S.E. ±
		1967 First cut				
63	2·70	3·01	0·118	3·16	3·43	0·110
251	3·06	3·34		3·54	3·83	
		1967 Second cut				
63	3·02	3·36	0·159	2·71	2·92	0·084
251	3·33	3·79		2·79	3·05	
		1967 Total of two cuts				
63	5·72	6·38	0·171	5·87	6·36	0·158
251	6·39	7·13		6·33	6·88	
		1968 First cut				
63	4·00	4·15	0·112	5·42	6·02	0·129
251	3·85	3·97		5·84	6·19	
		1968 Second cut				
63	3·48	3·72	0·107	4·10	4·61	0·086
251	3·33	3·60		4·33	4·74	
		1968 Third cut				
63	1·66	1·58	0·074	2·60	3·05	0·070
251	1·58	1·57		2·81	3·30	
		1968 Total of three cuts				
63	9·14	9·44	0·196	12·1	13·7	0·19
251	8·75	9·14		13·0	14·2	
		1969 First cut				
63	—	—	—	5·70	6·17	0·174
251	—	—		6·40	6·40	
		1969 Second cut				
63	—	—	—	2·05	3·94	0·102
251	—	—		2·71	4·35	
		1969 Third cut				
63	—	—	—	1·77	2·85	0·102
251	—	—		2·05	2·97	
		1969 Total of three cuts				
63	—	—	—	9·5	13·0	0·250
251	—	—		11·2	13·7	
	1967–69 Totals of five cuts of clover, eight cuts of lucerne					
63	14·9	15·8	—	27·5	33·0	—
251	15·1	16·3	—	30·5	34·8	—

Clover. First-year clover responded to the large dressing of phosphate and to potassium; each treatment increased yield by about 0·6 t/ha and the increase from both was 1·25 t/ha. In the second year potassium increased yields by only 0·4 t/ha (totalling all three cuts in the year) and extra phosphate not at all.

Lucerne. The first-year crop resembled the clover, for yields were increased by 0·4–0·5 t/ha by trebling the phosphate, and potassium gave an extra 0·5–0·6 t/ha. Responses by second-year lucerne were, proportionately, about the same as in 1967; trebling the phosphate and giving potassium as well, increased yield by about 2 t/ha.

At the second and third cuts taken in 1969, total yields were increased by 1·2 t/ha by trebling the phosphate and by 3·0 t/ha by giving potassium; the total gain from both

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nutrients was 4·3 t/ha—an increase of nearly 50%. The lucerne was remarkable in yielding more than 12·5 t/ha in the third year, and in persisting as a close healthy crop *on plots receiving K fertiliser* until it was ploughed in during September.

The experiments show lucerne is a better herbage crop at Saxmundham than the species of red clover grown, as it yielded well for three years; red clover persisted only two years. But to achieve good yields and to persist for three years, lucerne needs generous manuring, more than the basal dressing of 63 kg P_2O_5/ha, and at least 250 kg K_2O/ha. Although Saxmundham soil has the reputation for releasing much K, it does not provide enough for lucerne to persist and yield the maximum.

Nitrogen in the crops. Table 5 shows total amounts of N fixed annually by clover and lucerne. In 1967 the clover contained more N than the lucerne; in 1968 the lucerne yielded 50% more than the clover and contained proportionately more N. Table 5 shows the remarkable amounts of N removed in the harvested lucerne during three years—981 kg N/ha from the best plots.

TABLE 5

Amounts of nitrogen (kg/ha) in total annual yields of lucerne and red clover at Saxmundham, 1967–69

	Red clover			Lucerne		
P_2O_5 applied (kg/ha)	Without K	With 251 kg K_2O/ha	S.E. ±	Without K	With 251 kg K_2O/ha	S.E. ±
		1967 (totals of two cuts)				
63	192	196	8·6	166	176	4·6
251	220	234		174	185	
		1968 (totals of three cuts)				
63	305	300	8·0	407	450	6·0
251	296	292		440	463	
		1969 (totals of three cuts)				
63	—	—	—	207	316	11·1
251	—	—		250	333	
		1967–69 (totals of all cuts)				
63	497	497	—	781	942	—
251	515	526		864	981	

Clover–grass leys cut at grazing stage

Most good pastures used for grazing and given little or no N fertiliser rely on shallow-rooted legumes, such as wild white clover, to fix N, some of which reaches the grasses in the sward. In 1968 we could find no published account of yields and N contents of such swards relevant to East Suffolk; we started measurements on two areas of wild white clover with several grasses, sown in 1967 and well established, with clover dominant, by spring 1969. The swards were cut at grazing stage throughout 1969. The same areas were used in 1970 for a simple factorial test using 125 kg P_2O_5/ha (P) and 250 kg K_2O/ha (K). The four plots (none, P, K, PK) were in randomised blocks and there were three replicates in the whole experiment. Individual plots were 11 m long and 1·2 m wide, a central strip was harvested by a rotary motor mower, fitted with a collecting box, at (roughly) monthly intervals. (Nutrients were not returned during the season as they would in excreta dropped on grazed grass.) Summer 1970 was very dry and yield was much less than in 1969. In 1971 P and K dressings were repeated and the plots of one block received 38 kg N/ha in March and again after each cutting except the last.

Table 6 shows the yields and N in the herbage of the nine cuts in 1969. The cold and

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wet spring slowed growth until mid-May. The first three weeks of June were dry, which explains the small yield at the cutting on 3 July. Except for these checks, 1969 was a good year for legumes grown with pasture grasses; altogether 8·4 t/ha of dry matter containing 247 kg N/ha were harvested.

TABLE 6

Yields and nitrogen contents of clover–grass leys harvested at Saxmundham in 1969–71

	No. of days of growth	Rain in period (mm)	Mean yield dry matter* (t/ha)		N in crop (kg/ha)	
1969						
23 April to 15 May	22	52	1·17		27·5	
to 28 May	13	33	0·80		18·6	
to 17 June	20	27	1·38		32·1	
to 3 July	16	22	0·35		11·9	
to 29 July	26	99	1·78		49·4	
to 19 August	21	22	0·97		40·7	
to 12 September	24	52	0·88		34·4	
to 24 September	12	1	0·78		23·4	
to 28 October	36	8	0·29		9·2	
Total	190	316	8·40		247·2	
1970						
1 April to 6 May	36	56	0·22		7·2	
to 21 May	15	11	0·93		30·5	
to 25 June	35	11	0·40		9·9	
to 28 July	33	32	0·73		19·3	
to 30 August	33	20	nil		nil	
Total	152	130	2·28		66·9	
			Without N	With N	Without N	With N
1971						
1 April to 16 April	16	0	0·35	0·96	9·7	21·9
to 30 April	14	15	0·54	0·65	13·8	22·1
to 19 May	19	10	0·48	0·68	11·4	23·8
to 10 June	22	42	0·39	1·22	9·3	37·0
to 30 June	20	54	0·52	0·86	14·0	26·8
to 5 August	36	100	0·38	0·78	12·0	24·6
to 1 September	27	37	0·60	0·88	23·5	33·6
to 20 October	50	64†	0·43	0·87	14·3	29·2
Total	204	322	3·69	6·90	107·8	219·0

* Mean yields of two blocks; in 1970 and 1971 also averaged over test of P and K fertiliser.
† Rainfall to 16 October.

Yields of each cut in 1970 and 1971 are given in Table 6 (averaging over the test of P and K fertilisers). Little rain fell at Saxmundham in summer 1970, only four cuts were made and less than 2·5 t/ha of dry matter was harvested. Table 7 shows the effects of P and K fertilisers on total annual yields. Total yields were unaffected by K fertiliser but were slightly increased by phosphate; only about a quarter as much N was harvested as in 1969.

The early summer of 1971 was also dry but by the end of June, yield of herbage had equalled the total amount harvested in 1970 (Table 6). The small dressing of nitrogen increased yields at every cutting, and by the end of June had given an extra 2 t/ha dry matter—nearly doubling yields. There were good rains in July and August but total yields did not equal those of 1969; giving N fertiliser nearly doubled yield for the whole year. There were small increases from P and K fertilisers used without N fertiliser. When N was applied the gains from both nutrients were larger. Applying both P and K (with N) raised yield by about 1·2 t/ha.

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TABLE 7

The effects of P and K fertilisers on yields and contents of N, P and K from clover–grass leys harvested at Saxmundham in 1970 and 1971

Treatment	Total yields in year (t/ha)		Total amounts of N in crops (kg/ha)	
	1970 (totals of four cuts)			
O	2·21		68	
P	2·35		80	
K	2·21		70	
PK	2·41		80	
	1971 (totals of eight cuts)			
	Without N	With N	Without N	With N
O	3·28	6·30	96	204
P	3·78	6·88	114	229
K	3·96	6·97	116	230
PK	3·77	7·47	105	214

	Total amounts of P and K in crops			
	Phosphorus (kg/ha)		Potassium (kg/ha)	
	1970 (totals of four cuts)			
O	6·3		43	
P	8·2		46	
K	6·3		45	
PK	8·2		54	
	1971 (totals of eight cuts)			
	Without N	With N	Without N	With N
O	11·9	21·7	75	169
P	16·3	26·0	84	219
K	15·4	35·4	100	252
PK	16·4	32·4	95	184

Changes in soluble nutrients in the soils of the experiments

Table 8 shows analyses for soluble-P and -K in the soil (0–15 cm deep) made before the experiments began, and Tables 9 and 10 analyses of the soils from individual plots when the experiments ended. The changes caused by the treatments help to decide how ley farming systems should be fertilised.

TABLE 8

Analyses of soil samples taken when the experiments began

	Soluble-P		Soluble-K	
	In $CaCl_2$ μM/l	In $NaHCO_3$ ppm	In $CaCl_2$ solution ppm	Exchangeable ppm
Experiment				
N tests on grass (Grove Plot)	0·97	21·2	3·9	140
PK tests on Clover	0·71	13·6	4·0	135
PK tests on Lucerne	0·55	14·4	3·7	140
Clover–grass leys cut at grazing stage				
North block	0·32	10·4	26	128
South block	0·48	20·0	51	121

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TABLE 9

Analyses of soils taken in September 1969 from the site of the experiment testing N fertilisers on meadow fescue–timothy ley

Treatment	Total N %	Total[a] C %	P soluble in NaHCO₃[b] ppm	P soluble in CaCl₂[c] μM/1	K soluble in NH₄OAc.[d] ppm	K soluble in CaCl₂[c] ppm	Mg NH₄OAc.[d] ppm
1	0·138	1·01	47·5	4·5	12·0	309	60
2	0·152	1·13	34·2	1·7	5·2	141	58
3	0·150	1·08	30·6	2·2	3·8	125	60
4	0·149	1·11	35·0	1·8	3·2	117	51
5	0·148	1·02	30·4	1·5	3·7	129	55
6	0·151	1·14	29·5	1·7	3·4	117	51
7	0·140	1·04	28·6	1·4	2·6	109	52
8	0·148	1·15	41·8	3·1	7·7	176	57
9	0·155	1·12	32·0	1·8	3·3	117	55
10	0·146	1·09	31·9	2·3	3·5	121	54

[a] Walkley-Black values, uncorrected.
[b] 0·5*M* $NaHCO_3$ solution (Olsen's method).
[c] Equilibration with 0·01*M* $CaCl_2$ solution.
[d] Exchangeable K and Mg measured by leaching with *N* $NH_4OAc.$ solution.

Experiment on nitrogen manuring of timothy–meadow fescue ley

Nitrogen and carbon. N fertiliser increased the nitrogen and carbon of soils by about 10%.

Phosphorus. Both the 'pool' of useful phosphate (measured by sodium bicarbonate extraction) and the 'intensity' (measured by equilibrating with calcium chloride solution) were larger at the end than at the beginning of the experiment, and much larger on plots not given N, which gave small yields. Annual dressings of 125 kg P_2O_5/ha more than sufficed to maintain soluble soil P.

Potassium. Plots not given N fertiliser contained most soluble potassium and plots given the largest dressings of N contained least. The whole site received 250 kg K_2O/ha annually, which maintained the initial amounts of soluble-K where the smallest amounts of N were given (Treatment 2), but not where more N was given.

Magnesium. Exchangeable Mg in soil was only slightly more without N fertiliser than with the largest dressing. Magnesium fertiliser was not given, but all plots had more exchangeable Mg than the 50 ppm below which Reith (1967) considered responses are possible.

At the end of the experiment all plots had more soluble-P than Hooper (1970) considers necessary for arable crops. By contrast, where much N was given, exchangeable K was small enough to make it probable that arable crops following the grass would respond to K fertiliser.

Lucerne and clover experiments. Analyses of soils taken after the last cut of lucerne in 1969 are in Table 10, together with analyses for the clover site sampled at the same time.

Total nitrogen and carbon were changed little by the phosphorus and potassium fertilisers.

Phosphorus. Plots given 250 kg P_2O_5/ha were rich in soluble-P. The small annual dressing (63 kg P_2O_5/ha) maintained soluble-P near to the original amounts for three years, but these were too small for lucerne and clover which responded to extra

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TABLE 10

Analyses of soils sampled in September 1969 from sites of lucerne and clover experiments at Saxmundham

	Treatment				
	P_1K_0	P_1K_1	P_4K_0	P_4K_1	Mean
Lucerne site					
% total N	0·149	0·150	0·149	0·149	0·149
% organic carbon*	1·13	1·08	1·06	1·08	1·09
P soluble in 0·5*M* $NaHCO_3$ solution (ppm)	18·6	15·6	45·4	45·6	31·3
P in equilibrium in 0·01*M* $CaCl_2$ solution (μM/litre)	0·6	0·6	4·5	4·5	2·5
K soluble in 0·01*M* $CaCl_2$ solution (ppm)	2·2	4·7	2·1	3·6	3·1
K exchangeable (ppm)	98	129	90	117	109
Clover site					
% total N	0·147	0·158	0·152	0·155	0·153
% organic carbon*	1·18	1·11	1·09	1·09	1·12
P soluble in 0·5*M* $NaHCO_3$ solution (ppm)	17·0	17·5	41·1	40·8	29·1
P in equilibrium in 0·01*M* $CaCl_2$ solution (μM/litre)	0·7	0·8	3·4	3·4	2·1
K soluble in 0·01*M* $CaCl_2$ solution (ppm)	3·2	5·5	3·3	6·1	4·5
K exchangeable (ppm)	109	141	109	152	129

* Walkley-Black values uncorrected.

phosphate. Seemingly these legumes respond to phosphate on Saxmundham soil containing 19 ppm or less of bicarbonate-soluble P.

Potassium. Without K fertiliser, soluble soil K diminished greatly during the three years. The lucerne gave large responses to K fertiliser at the later cuttings, so exchangeable K in untreated plots (90–100 ppm at the end of the experiment) was not enough for it. Plots given 250 kg K_2O/ha each year plus the large dressing of P, contained little more exchangeable K than plots not given K; possibly the crops would have responded to more than the 250 kg K_2O/ha tested. The K dressing almost maintained soluble-K in plots given the small phosphate dressing, which yielded less. The clover yielded less than the lucerne, and wheat was grown on the site in the third year; less potassium was removed than by lucerne and 250 kg K_2O/ha maintained the soluble soil K.

Chemical compositions of the crops

Our discussion mainly concerns nitrogen and magnesium (important in animal nutrition) and amounts of P and K removed (needed to construct nutrient balance sheets for the sites).

Experiment on meadow fescue–timothy ley. The composition of the herbage differed between years; the results given are averages of N-treated plots cut frequently:

	Percentage in dry matter			
	N	P	K	Mg
1967	2·51	0·28	3·31	0·18
1968	2·70	0·32	3·26	0·17
1969	2·20	0·29	2·42	0·18

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Because the grass grew slowly in 1967, and the treatments were changed in 1969 to test anhydrous ammonia, only the concentrations of nutrients in the large crops harvested in 1968 are discussed. The results in Table 11 are for different N dressings given to plots dressed with N twice and cut three times (2, 3, 4 and 5) and for those dressed four times and cut five times (6 and 7).

TABLE 11

Percentages of nutrients in dry matter of harvests of timothy–meadow fescue ley in 1968

	Dressed with N twice and cut three times						Dressed with N four times and cut five times	
Treatment No.	1	2	3	4	5		6	7
Total N applied (kg/ha/year)	0	125	250	375	500		250	500
			(Percentages in dry matter)					
Cut			Nitrogen			Cut		
1	1·25	1·20	1·45	1·79	2·08	1	2·17	2·78
2	1·52	1·56	1·74	2·56	2·89	2	2·32	3·50
3	1·99	1·78	1·95	2·35	2·50	3	1·86	2·60
						4	2·53	3·72
						5	2·00	2·24
			Phosphorus					
1	0·23	0·19	0·22	0·23	0·23	1	0·27	0·30
2	0·29	0·30	0·35	0·29	0·31	2	0·34	0·37
3	0·33	0·31	0·31	0·35	0·36	3	0·28	0·29
						4	0·35	0·26
						5	0·32	0·34
			Potassium					
1	2·15	2·69	2·90	3·06	3·08	1	2·87	3·42
2	2·85	2·97	3·45	2·94	3·21	2	3·61	4·20
3	2·28	2·03	2·32	2·76	2·94	3	3·13	3·28
						4	3·51	2·82
						5	2·27	2·57
			Magnesium					
1	0·08	0·08	0·09	0·11	0·13	1	0·09	0·11
2	0·12	0·12	0·14	0·20	0·22	2	0·12	0·18
3	0·14	0·14	0·15	0·18	0·20	3	0·13	0·19
						4	0·18	0·28
						5	0·15	0·19

Nitrogen concentrations were smaller in less frequently-cut plots than in the younger grass of 'five-cut plots', all concentrations were increased at every cutting by the fertiliser dressings. Raymond and Spedding (1965) suggest that 14–15% of total crude protein in the whole ration is adequate for productive dairy cows and other stock that is growing rapidly. Assuming the conventional factor of 6·25 to convert % N to % crude protein, grass dry matter should contain from 2·2 to 2·4% N. Tables 2 and 11 show that on treatments 2, 3, 4 and 5 only the largest dressing of N (250 kg N/ha on 29 February) gave grass that approached this protein content at the first harvest (on 28 May) of infrequently-cut plots. These plots were dressed again with N on 28 May; with either 188 or 250 kg N/ha, the dry grass harvested on 16 August and 23 October had adequate protein. The 'five-cut' plots received 63 or 125 kg N/ha for each cut except the last. The larger dressing gave grass rich in protein at all cuttings; the smaller dressing gave grass with 12·5% crude protein or less at the third and fifth cutting.

Largest yields were given by the 'three-cut' plots but only with the most N was the grass rich in protein. Infrequently-cut grass was also less easy to manage and, in practice, the smaller yields from grass cut four or more times in the year may be preferable because it is reliably rich in protein.

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Phosphorus concentrations were little affected by N fertiliser.

Potassium concentrations were increased by increasing the N fertiliser and were largest in the younger grass of the more frequently-cut plots.

Magnesium concentrations were very small in the first cut; they increased later and with increasing amounts of N fertiliser. To prevent hypomagnesaemia in stock fed solely on grass, it is usually considered that dry matter of herbage should contain at least 0·2% Mg. Most of the samples, especially of herbage cut frequently, had less than this and stock using such grass would need a magnesium supplement.

Uptake of nutrients by grass. Table 12 shows the amounts of P, K and Mg removed by the grass. The amounts of N recovered each year (in Table 3) have already been discussed.

TABLE 12

Annual uptakes of nutrients, and total uptakes in three years (1967–69) by timothy–meadow fescue ley grown at Saxmundham

	Treatments								
	1	2	3	4	5	6	7	8	9
	(kilogrammes/hectare of P, K and Mg)								
Phosphorus									
1967	5·0	11·5	14·5	18·4	18·7	11·3	15·1	10·8	13·7
1968	4·1	19·8	40·0	41·9	46·4	28·9	43·7	25·7	41·4
1969	6·2	33·6	38·5	25·1	38·5	36·8	40·6	32·4	44·3
Total	15·3	64·9	93·0	85·4	103·6	77·0	99·4	68·9	99·4
Potassium									
1967	77	168	198	239	265	120	165	114	152
1968	39	232	446	479	528	301	476	274	463
1969	50	331	377	251	359	352	372	325	447
Total	166	731	1021	970	1152	774	1013	714	1062
Magnesium									
1967	5·5	9·1	12·0	15·2	17·6	9·9	13·9	10·8	15·9
1968	1·6	7·9	16·1	23·0	28·0	12·0	25·9	10·6	23·2
1969	2·5	17·0	24·7	11·2	25·2	18·7	23·5	16·1	27·1
Total	9·6	34·0	52·8	49·4	70·8	40·6	63·3	47·5	66·2

Phosphorus. None of the crops removed as much P in any year as the annual basal dressing of 55 kg P/ha. Even with the treatment (No. 5) producing most P in the grass, the fertiliser supplied about 60 kg P/ha more than was removed during three years. The residues that accumulated increased soluble P in the soils (Table 9).

Potassium supplied annually (208 kg K/ha) was less than the grass removed when given any N fertiliser in 1968 and 1969; in 1967 two treatments gave grass containing more K than was applied. The annual dressing may seem generous but grass grown by several treatments in 1968 removed more than twice as much. Growing grass for three years on this site depleted soil potassium reserves by 400–500 kg K/ha wherever much N fertiliser was used, and exchangeable soil K was diminished (Table 9).

Magnesium. Most was removed (about 70 kg Mg/ha during the three years) by grass given much N and cut infrequently. The rain supplied 4·1 kg/ha of Mg annually; the extra 20 kg Mg/ha needed each year could be replaced by release from clay minerals and by weathering of the chalk in the soil.

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Lucerne and clover experiments. Table 13 gives the average *concentrations of nutrients* in lucerne and clover each year grown with and without K fertiliser. (The test of large *versus* small phosphorus dressings had little effect on the compositions of the crops.) K fertiliser diminished the concentrations of all elements except K in both species

TABLE 13

Composition of lucerne and clover crops, averaging all cuts in each year, and the two rates of phosphorus tested

	Lucerne		Clover	
	Without K	With 210 kg K/ha	Without K	With 210 kg K/ha
	(per cent in dry matter)			
Nitrogen				
1967	2·85	2·78	3·38	3·18
1968	3·42	3·31	3·65	3·60
1969	2·62	2·61	—	—
Phosphorus				
1967	0·20	0·19	0·22	0·21
1968	0·31	0·29	0·32	0·31
1969	0·30	0·28	—	—
Potassium				
1967	1·58	1·89	1·88	2·28
1968	1·70	2·07	1·98	2·79
1969	1·54	2·17	—	—
Magnesium				
1967	0·23	0·20	0·33	0·29
1968	0·22	0·19	0·36	0·31
1969	0·20	0·17	—	—

Nitrogen. Both lucerne and clover contained much more protein than the minimum needed for livestock. *Phosphorus* concentrations in both crops resembled those in grass (Table 11), but *potassium* concentrations were considerably less. The two legumes, and especially clover, contained much more magnesium than the grass. Lucerne given K fertiliser had a little less than 0·2% Mg in dry matter. Clover had larger concentrations of all four nutrients than lucerne treated similarly.

Total uptakes of nutrients by two years of clover and three of lucerne are in Table 14. The lucerne removed much less potassium during three years than did grass containing about as much nitrogen (Tables 12 and 14) (lucerne contained only about half as much K per unit of N as grass). Equal yields of grass and lucerne removed about the same amount of phosphorus; lucerne removed more magnesium than grass where the two crops yielded similarly.

In the two years it lasted, clover removed less phosphorus than lucerne did but more potassium; it removed much more magnesium.

The large crops of lucerne grown in 1968 removed more P than the small fertiliser dressing (P_1, 27 kg P/ha) supplied but much less than the large dressing (110 kg P/ha). Lucerne removed more than the 208 kg K/ha supplied as fertiliser in 1968 and 1969; allowing for the large amount of K recovered from soil alone (about 500 kg K/ha in three years), about a third of the dressing of fertiliser-K was removed in 1968 and more than half in 1969.

None of the clover crops removed more P than was applied by the small (27 kg P/ha) dressings, and soluble-P increased in soils given the large dressing (Table 10). Clover given K fertiliser removed more K than the dressing supplied in 1968 but not in 1967.

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TABLE 14

Total amounts (kg/ha) of phosphorus, potassium and magnesium removed in three years by lucerne and in two years by clover

	Treatment				
	P_1K_0	P_4K_0	P_1K_1	P_4K_1	Mean
Lucerne, total amounts in 1967, 1968 and 1969					
Phosphorus	72·9	86·9	83·2	94·9	84·5
Potassium	475·4	502·5	692·8	707·0	594·4
Magnesium	56·5	62·6	59·1	61·7	60·0
Clover, total amounts in 1967 and 1968					
Phosphorus	35·3	41·1	37·0	41·2	38·7
Potassium	256	269	389	403	329
Magnesium	50·5	50·6	46·5	47·4	48·9

Effect of weather on yield of herbage crops

Growth of herbage given enough nutrients depends on soil moisture plus rainfall, solar radiation and temperature. Monthly totals of rainfall from 1964 to 1969 at Saxmundham were published last year (Williams & Cooke, 1971), rainfall in 1970 was given in Part 1 of the *Rothamsted Report for 1970* (p. 359) and in 1971 in Part 1 for this year. Contrasts between the seasons at Saxmundham are shown in Figs. 2a, 2b, 2c and 2d.

The amount of water available to crops depends on rainfall *minus* amount evaporated. The difference is expressed in Fig. 2a as 'accumulated deficit' calculated from $0{\cdot}75 \times E_0 - R$; R is rainfall, E_0 the evaporation from an open water surface (measured at Saxmundham), the factor 0·75 suits the conversion of evaporation from a close grass sward (Ministry of Agriculture and Fisheries, 1954). Fig. 2a shows that 1967 and 1970 were very dry and soil moisture deficits became large. In 1968 and 1969 rainfall roughly balanced evaporation; 1969 was very wet. The early months of 1971 were dry, but summer rainfall and cold weather in June prevented the deficit becoming as large as in 1970.

Soil temperatures 10 cm deep are shown in Fig. 2c by plotting monthly averages. Soil temperatures increased rapidly during the early springs of 1967 and 1968, but much more slowly during 1969 and 1970; 1971 was intermediate. Summer temperatures were hottest in 1967 and 1969, coldest in 1968. 1971 was peculiar; after rising as usual during March/April, there was a long period from early May until late June when soil temperatures stayed constant; afterwards they rose sharply (Fig. 2c).

Growing degree days (GDD) plotted in Fig. 2b summarise air temperatures that affect growth of 'tops' of plants. They show accumulated daily temperature above or below 42°F (below which crops grow slowly or not at all). GDD can be derived from Tables (Meteorological Office, 1965) or calculated from $\Sigma(\bar{T} - Tb)$ ($\bar{T}$ is the average daily means of maximum and minimum temperatures; Tb is the base temperature selected). 1967 was warmer than average throughout; 1968 had the coldest summer.

Solar radiation, plotted in Fig. 2d, determines temperature and evaporation. 1967 provided most radiation; after a good start in spring, 1968 had least of the four years. In 1971, radiation in spring and early summer was much less than in other years.

Clover–grass leys. Yield and rainfall in 1969 (Table 6) were not related when measured over short periods, but Fig. 3a shows a close relationship between *accumulated rainfall*

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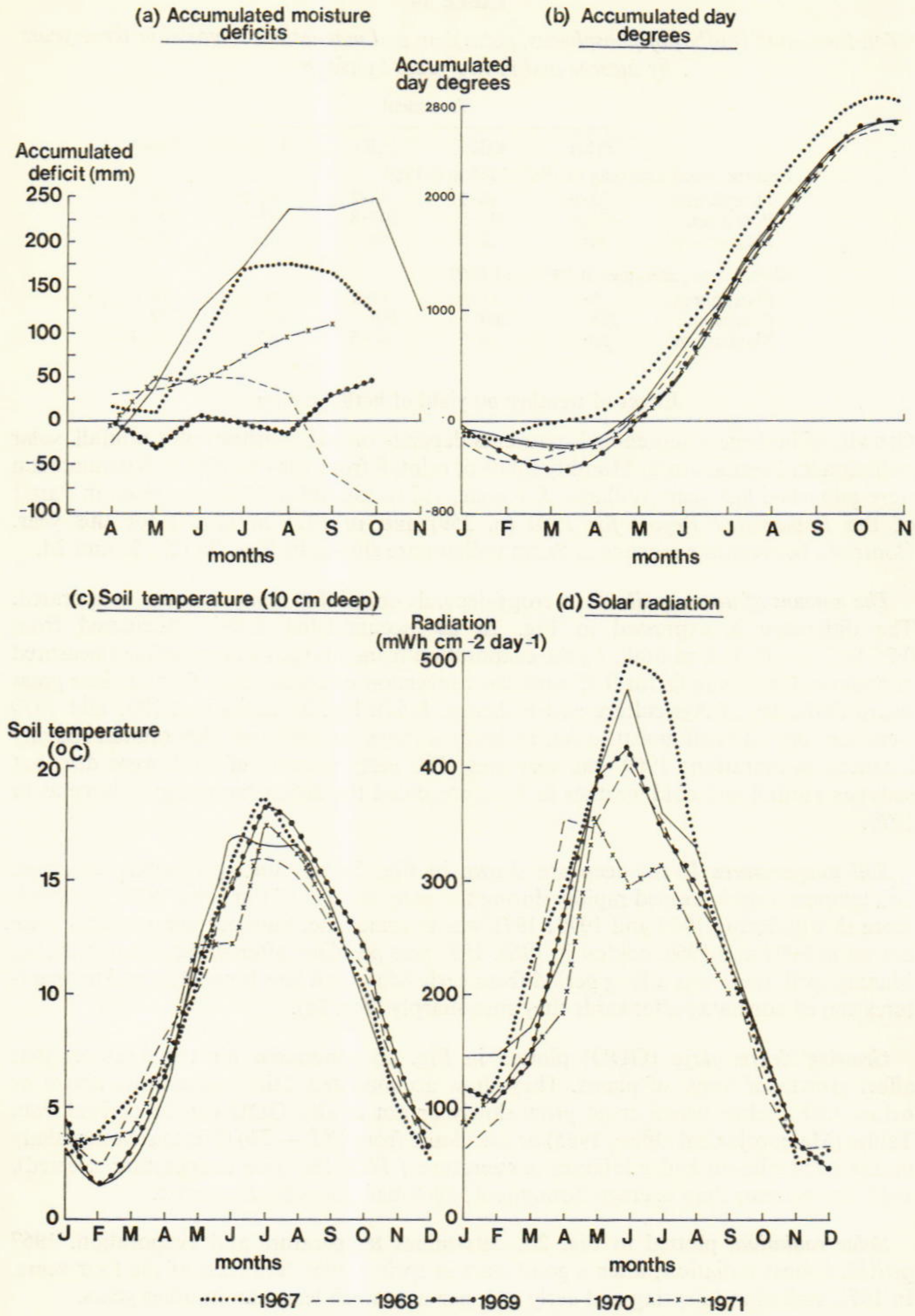

FIG. 2. Weather at Saxmundham (1967–71).

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and *accumulated yield*; the slopes of the lines show that more herbage was produced per mm of rain that fell during spring and early summer than later. Up to 17 June, yield increased at the rate of 30 kg/ha of dry matter per mm of rain, but by 10 August this had decreased to 25 kg/ha per mm. The rate for the whole season was 27 kg/ha per mm which is less than in the experiment testing nitrogen on leys. The figures resemble those Penman (1962) found at Woburn (response to water depended on the nitrogen applied):

Kg/ha of dry grass per mm of rain	Dressing of N kg N/ha per cut
18·8	19
23·2	38
27·2	75

The summer of 1970 was very dry (Fig. 2a); yield and rainfall were again closely associated, with both much less than in 1969 (Fig. 3a). Total yield (2·28 t/ha) was produced by 130 mm of rain, plus soil moisture present in spring, equivalent to 17 kg dry matter/mm of rain (ignoring soil water). The spring of 1971 was as dry as 1970 and the ley not given nitrogen yielded no more than in 1970 until June. Up to the end of June 2·27 t/ha had been produced by 121 mm of rain (plus soil moisture), equivalent to 18·8 kg/mm of rain. With N fertiliser, the same rainfall produced 4·37 t/ha, or 36·1 kg/ha per mm of rain. July 1971 was wet and there was more rain in August; total rain from 30 June to 1 September was 136 mm. The yield produced in this period without N was equivalent to 7·2 kg/ha per mm of rain, and with N 12·2 kg/ha per mm of rain, less than half as much as in 1969 without N. The close relationship between yield and rainfall in 1969 and 1970 (Fig. 3a) was not shown in 1971. Fig. 3b shows that early drought checked the crop but that yield without N did not increase proportionately to the large rainfall in June and July. With N, yield was better related to rainfall. Fig. 3b suggests that when clover–grass leys are severely checked early by drought, as happened in 1970 and 1971, their growth does not recover with later rain unless N fertiliser is given.

Lucerne and clover. Both crops were sown in spring 1967, the dry summer slowed early growth and the first cut was on 13 July. From then until the second cut on 7 September 104 mm of rain fell; best yields were 3·79 t/ha of clover and 3·05 t/ha of lucerne, corresponding to 36 kg/ha and 29 kg/ha respectively per mm of rain.

In spring 1968 March and April rainfall was less than average and the soil became warm (Fig. 2c). Early growth depended more on temperature than on rainfall because the subsoil was saturated at the end of winter. May was drier than average but June, July and August were wetter (Fig. 2a). The first six months of 1969 were very wet; as the drains at Saxmundham ran on every day until 20 June, there was more water than herbage crops needed; rainfall exceeding evaporation from an open water surface until June, but not afterwards (Fig. 2a). Yields and rain in the two years were:

	Yield‡ (t/ha) of dry matter		Rain	Yield/mm of rain (kg/ha of dry matter)	
	Clover	Lucerne	(mm)	Clover	Lucerne
1968					
Cut 1 (28 May)	4·02	6·15	69*	58	89
Cut 2 (25 July)	3·64	4·77	107	34	44
Cut 3 (10 September)	1·50	3·26	112	13	29
1969					
Cut 1 (17 June)	—	6·40	187†	—	34
Cut 2 (29 July)	—	4·39	120	—	36
Cut 3 (12 September)	—	3·01	73	—	41

* From 1 April.
† From 12 March.
‡ Best yields from PK-treated plots are used.

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The first cut of lucerne in 1968 must have been produced partly by soil moisture and partly by rain. Assuming yield per unit of water was the same for the first and second cut (as happened in 1969), 70 mm of soil water were used. A similar calculation for clover suggests the first cut used 40 mm of soil water.

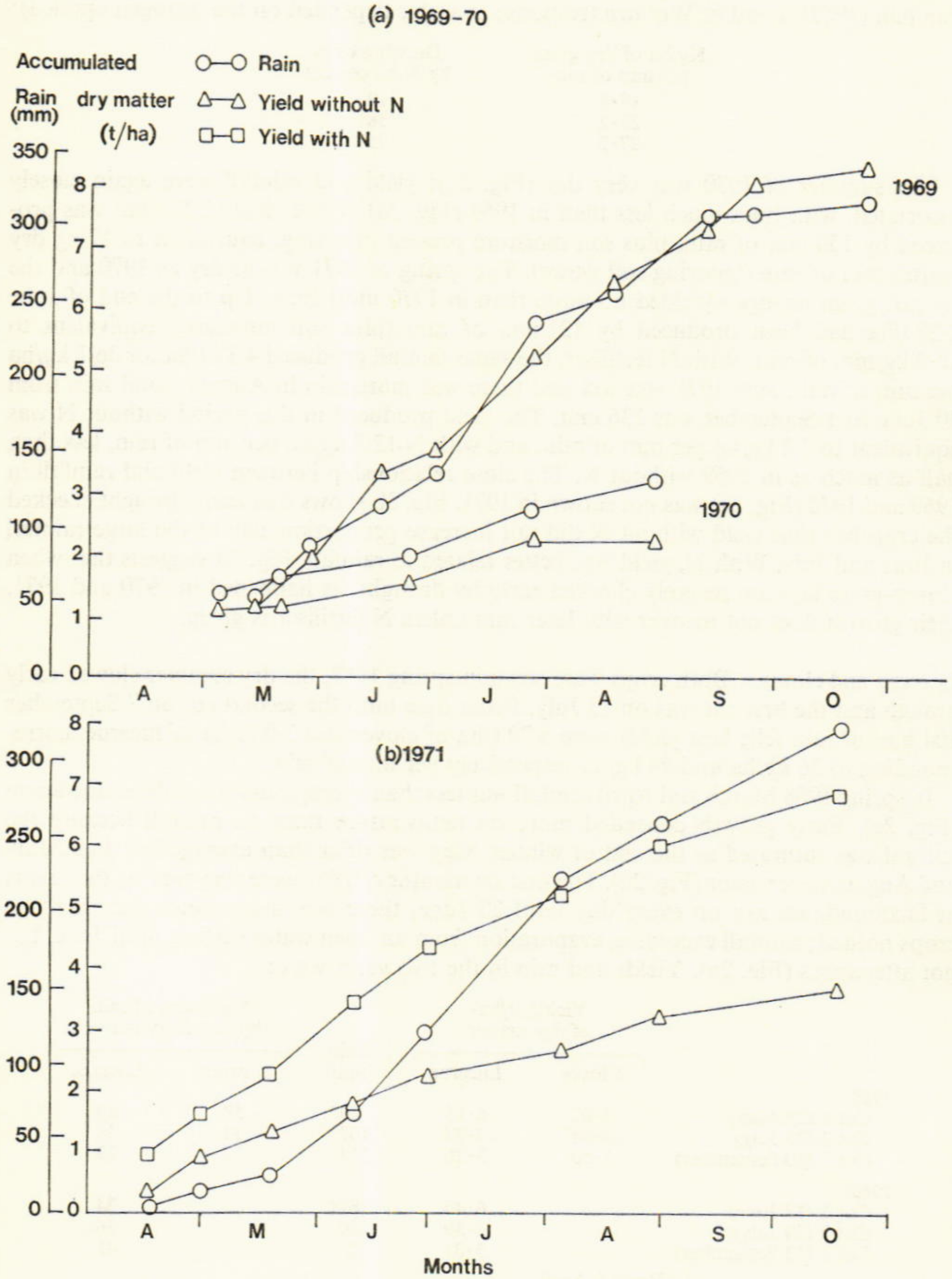

FIG. 3. Yields of clover–grass leys at Saxmundham cut at grazing stage (1969–71).

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Experiment on grass ley. The grass established slowly in spring 1967 and the first cut is ignored here. Yields shown below suggest that grass uses water more efficiently in the first than in the second half of the year:

	Rain in period (mm)	Yield‡ (t/ha)	Yield/mm of rain (kg/ha)
1967			
Cut 2 (15 August)	93	2·59	28
Cut 3 (26 September)	68	2·06	31
1968			
Cut 1 (1 May)	55*	3·83	70
Cut 2 (28 May)	41	2·57	62
Cut 3 (12 July)	92	4·04	44
Cut 4 (16 August)	95	2·46	26
1969			
Cut 1 (29 May)	183†	5·97	33
Cut 2 (22 July)	116	4·88	42
Cut 3 (11 September)	118	3·28	28

* From 1 April.
† March + April + May.
‡ With 125 kg N/ha per cut in 1967 and 1969. In 1969, the first cut had 314 kg N/ha and the second and third 157 kg N/ha.

Yields produced per mm of rain were similar for all harvests taken after midsummer in 1967, 1968 and 1969; this follows the seasonal change in solar radiation and soil temperature. In years with average rainfall, grass given at least 125 kg N/ha per cut should produce about 50–60 kg/ha of dry matter/mm of rain in April/May, 40–45 kg/mm in June/July and 25–30 kg/mm in August/September.

Penman's (1962) results already quoted show how calculations of this kind for grass are complicated by the amount of nitrogen used. Rainfall *after* giving nitrogen affects the value of the fertiliser to the crops—dressings may be leached by much rain or be inactive during a dry spell; residual effects of large dressings benefit later cuts. Table 3 shows that nitrogen was nearly twice as efficient in 1968 (when there was little leaching) as in 1969 when rain was excessive.

Lucerne and grass in Rotation I experiment. Rotation I experiment at Saxmundham grew arable crops from 1899 to 1969. In 1970 it was modified, half of each plot being sown with a mixture of timothy and meadow fescue and the other half with lucerne. Both crops established very slowly in the 1970 dry summer, the lucerne was cut once but grass not at all. A. E. Johnston obtained these yields:

	With NPK fertilisers* (t/ha of dry matter)	
	Grass	Lucerne
1970	0·0	2·0
1971		
Cut 1	4·0	5·2
Cut 2	3·5	4·8
Cut 3	4·4	3·0
Total	11·9	13·1

* Including 100 kg N/ha for each cut of grass.

These results confirm ours with small plots. Lucerne can yield at least 12·5 t/ha (5 tons/acre) of dry matter in a dry summer, more than the grass ley cut three times and given

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100 kg N/ha for each cut. Lucerne again made good use of rainfall in 1971. From 1 April to 7 September (when the third cut was taken) 258 mm of rain fell, the total yield corresponds to 51 kg dry matter/ha per mm of rain. Assuming the first and second cuts needed the same water to produce 1 kg of dry matter, the first crop extracted 82 mm of water from the soil (similar to the amount extracted in 1968 (p. 114)). The grass on RI experiment was severely checked by May and June drought and the third cut was not taken until 6 October, four months after the second cut. From 1 April to 6 October 297 mm of rain fell, corresponding to 40 kg/ha of dry matter per mm of rain.

Yields of cereals grown after herbage crops

We have so little land at Saxmundham that we could not test the value of herbage crops as preparations for following cereals. Observations made when the sites were ploughed, and yields of following crops are recorded in this section.

Lucerne and clover sites. The red clover died in 1968. In spring 1969, dressings of P and K fertilisers as given in previous years for clover were repeated, the area was treated with paraquat, worked 3 cm deep by rotary cultivator, and Kolibri spring wheat was sown by a Smythe drill with Suffolk-type coulters. Despite a top-dressing of 94 kg N/ha, the wheat did not grow well. Best yields were 1·96 t/ha of grain and 4·02 t/ha of straw. None of the small effects of P and K fertilisers was significant.

The whole site (stubble of spring wheat and of lucerne) was ploughed in September 1969. The plough furrows crumbled as they were formed while adjacent land that had carried winter wheat, ploughed up in massive clods. Soil structure was greatly improved (as described below, p. 134), especially by lucerne; the site could have been sown immediately without further cultivations, but it had to be cultivated and managed with the adjacent Intensive Wheat experiment where seedbeds could not be prepared from the cloddy ploughed land until rain fell in October. Cappelle Desprez wheat, sown on 5 November, grew well, and was given spring top-dressings of 75 kg N/ha on the lucerne site, 150 kg N/ha on the clover site. The summer-long drought (only 107 mm of rain fell in April to July) ripened the crop prematurely and yields were:

	After lucerne (t/ha)	After clover and wheat (t/ha)
Grain (at 85% dry matter)	5·10	4·58
Straw (dry matter)	3·26	3·00

The largest yield on the adjacent Intensive Wheat experiment was 3·87 t/ha of grain, from plots where wheat followed wheat in 1969, beans in 1968 and a ley in 1967.

The area was ploughed in September 1970 and sown on 15 October with 212 kg/ha of Cappelle wheat in rows 15 cm apart. Basal dressings of 250 kg/ha each of P_2O_5 and K_2O were given before ploughing and a compound fertiliser broadcast before sowing, supplied 63 kg N, 31 kg P_2O_5 and 31 kg K_2O per ha. In April 1971 the site was split into plots given 0, 50, 100 and 150 kg N/ha. The crop grew well and the yields were the largest we have obtained at Saxmundham:

N applied (kg/ha)	Tonnes/hectare (at 85% dry matter)	
	Grain	Straw
0	4·61	6·86
50	6·33	9·37
100	6·44	9·38
150	6·65	9·21

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Yields nearly as large were obtained in 1968. Fig. 2a shows that these two years had very similar rainfall and evaporation, a drier than average spring was followed by a wet summer so that there was only a small moisture deficit in June and July when the wheat flowered and ripened. Fig. 2a shows water relationships in the wet year (1969) and the two dry years (1967 and 1970) were very different. The best yield of grain from an individual treatment in 1971 was 6·95 t/ha (55 cwt/acre). In the adjacent Intensive Wheat experiment yield with the same seed rate, spacing and N fertiliser was 6·66 t/ha of grain (53 cwt/acre).

Barley after grass. Although when ploughed during November 1969 the soil on Grove Plot seemed not to have been improved by grass, next spring the area was cultivated more easily and dried sooner than adjacent land that carried cereals in 1969. The area received a basal dressing of 125 kg/ha each of P_2O_5 and K_2O and was sown with Julia barley on 23 April 1970. Grasses leave root residues poor in N, so eight amounts ranging up to 250 kg N/ha were tested on individual plots 12 m long and 1·5 m wide. The crop was satisfactory for such a dry summer. Table 15 shows that, although the response curve was somewhat irregular, barley grown after ploughing grass needs much nitrogen. Grain and straw given most N fertiliser contained three times as much N as the unfertilised crop. There was no indication that the grass had improved the site for Julia barley, which yielded more on the nearby Rotation II experiment which has grown arable crops for 70 years.

TABLE 15

Responses to nitrogen by barley grown after a grass ley at Saxmundham in 1970

N applied (kg/ha)	Yield t/ha (85% dry matter)		Amounts of N in the crop (kg/ha)	
	Grain	Straw	Grain	Straw
0	1·87	1·95	19·1	25·7
50	2·92	2·74	33·9	43·7
100	3·24	3·25	43·9	56·1
125	3·59	3·77	50·5	66·5
150	3·86	3·79	48·3	65·8
175	3·51	4·04	49·9	65·9
200	3·89	4·41	52·5	71·8
250	4·21	4·81	58·9	80·9
S.E.	±0·131	±0·192	±2·47	±3·54

In 1971 Midas barley was sown on the area on 31 March. Eight amounts of N were tested as dressings broadcast at sowing, and all plots had basal dressings of 125 kg/ha each of P_2O_5 and K_2O. The experiment was duplicated on adjacent land that had carried sugar beet and barley in the last two years. Yields were small because of an exceptionally severe attack of brown rust and did not exceed 2·7 t/ha after grass; the barley grown after a sequence of arable crops in the duplicate experiment gave 3·2 t/ha. Yields were largest with 50 kg N/ha. Midas and Sultan barley both gave similar poor yields in an adjacent experiment where both were attacked by brown rust, but the old arable land of Rotation II experiment yielded twice as much from Julia barley which had much less rust. The results do not suggest that growing grass for three years improves Saxmundham soil in ways that increase the barley yields.

Choice of herbage crops for sandy-clay soils of East Suffolk

Both the grass ley and the clover and lucerne yielded only half as much during the year they were sown as during later years. To compensate for smaller yields during the first

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year, leys must be chosen and managed to persist as long as possible; the longer they grow well, the more effect they may have on soil conditions. Dorset Marl red clover yielded about as much as lucerne in the first year but only two-thirds as much in the second, and did not persist into the third; so lucerne was the better crop. Both crops needed more than 60 kg P_2O_5/ha annually and much potassium. The yields from clover–grass leys were small and depended greatly on rainfall; such leys cannot be recommended for cutting unless they are treated with N fertiliser. The practical choice is between leys given much nitrogen, and lucerne.

Total yield. Grass yielded more dry matter than lucerne in each of the three years, but only when given much N. Taking the maximum yield of lucerne in 1968 and 1969, about 14 t/ha, as a target, Fig. 1 suggests that to achieve this, the timothy–meadow fescue ley would have needed about 250 kg N/ha in 1968 and about 440 kg N/ha in 1969, costing about £25 and £40 per ha respectively (ignoring current subsidies).

Quality. Fig. 1 shows that, over the range of nitrogen dressings tested, yield of crude protein was directly proportional to the N used on the grass ley. Yield of protein may be more important than yield of dry herbage. Tables 3 and 5 show that lucerne contained nearly as much N in 1967 and 1969 and just as much in 1968 as did grass given 500 kg N/ha (costing £50 per ha). When dairy cows, or rapidly-growing animals are feeding mostly on herbage, this should contain about 2·3% N: this was achieved or exceeded in most cuts of the lucerne, but only in the grass ley given much N and cut frequently (total yields of dry grass were decreased by frequent cutting). Another advantage of lucerne is that it contained more magnesium and less potassium than grass given nitrogen, so would be a safer feed where stock may suffer from hypomagnesaemia.

Management. Lucerne was managed more easily than the grass ley. Weeds died under the dense crops grown with P and K fertilisers; the lucerne was much easier to harvest than the large crops of lush grass cut only two or three times a year. Grass leys need at least 250 kg N/ha annually, given in several dressings, and must be cut at least four times in an average year. Cutting less often gave larger yields, but caused patches of the grass to die and might shorten the useful life of a ley. If early growth is needed, either to feed to stock or to lengthen the season for a drying plant, some grass treated with N must be grown. For instance in 1968 125 kg N/ha given to the grass ley at the end of February had produced 3·8 t/ha of dry grass by 1 May, whereas lucerne was not ready to be cut until June.

Manuring. The £50/ha for N fertiliser needed to produce 12·5 t/ha of dry grass is a basic cost of production. The large amounts of potassium leys removed must also be replaced. During three years grass, given enough N to produce about 38 t/ha of dry matter, removed about 600 kg K_2O/ha more than was given; this drain on soil reserves diminished exchangeable K to amounts we consider too small for crops of potatoes, sugar beet and cereals. When beginning a ley–arable rotation on such land, we suggest supplying as much K fertiliser as the crops remove—about 440 kg K_2O/ha annually and costing about £18/ha. Potassium manuring was essential for lucerne at Saxmundham, although it removed less K than grass (in three years the total yield of 35 t/ha of dry lucerne removed about 800 kg K_2O/ha). If the K removed is replaced, 300 kg K_2O/ha annually should be enough—costing about £5/ha less than the K needed for grass.

We do not know whether *grass responds* to P and K fertilisers at Saxmundham; the 125 kg P_2O_5/ha given each year was too much and soluble soil P increased. The lucerne

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and clover were grown on a site with less soluble P than the grass site and these crops responded to more P than the annual basal dressing of 63 kg P_2O_5/ha.

Clover–grass leys. The yields of these leys, cut at a 'grazing' stage, depended mainly on rainfall. The cutting system used does not value the grass for grazing satisfactorily because during grazing much N, P and K would have been returned to the soil in excreta and yields would probably have been larger. The wet spring and summer of 1969 favoured the clover–grass sward. Although the total yield of dry matter from the fescue–timothy ley given 313 kg N/ha was 3 t/ha more than from the clover–grass ley, the clover ley contained 45 kg/ha more N, obtained without the cost of fertiliser. The grass ley given N yielded 6 t/ha by the end of May, when the clover–grass ley had produced only 2 t/ha. Lucerne yielded 6·4 t/ha dry matter when first cut on 17 June—twice as much as the clover–grass ley had then given.

The poor yields in 1970 and early in 1971 show that in dry years farmers cannot rely on grazing from clover–grass swards not given N fertiliser; giving only 38 kg N/ha for each cut of the ley doubled yield in 1971 (Fig. 3b). From comparisons of the productivity of grazed grass/white clover swards on heavy and light soils in Devon and Suffolk, Brockman and Wolton (1970) also concluded that without fertiliser-N little early growth could be expected from clover–grass swards. 'Clover may be at its best in well-drained soils in high-rainfall areas and on heavier soils in low-rainfall areas, though even under these conditions its performance is not predictable from year to year.'

Summary

1. Except in the year of sowing, a ley of timothy and meadow fescue yielded 12·5 t/ha of dry matter when given 500–600 kg N/ha in several dressings and cut four or five times in the year. Response 'curves' were linear in two parts, with smaller increases from unit N above a point of inflexion. Responses, in kg of dry grass/kg of N supplied, were:

	Amount of N used	
	Small	Large
1967	25	5
1968	51	10
1969	29	11

Recoveries of the N fertiliser differed between years, and depended on the amount and form applied, and when it was applied; largest values in 1967 were 44% and in 1968, 83%. In 1969, 81% of the N was recovered from anhydrous ammonia treated with 'N-Serve', but only 54% from an equal amount applied as 'Nitro-Chalk'.

2. Anhydrous ammonia injected during March produced 13·8 t/ha of dry grass, and equivalent 'Nitro-Chalk' broadcast during March 13·2 t/ha. Splitting the total dressing, with half as 'Nitro-Chalk' or ammonia given in March and quarters as 'Nitro-Chalk' in May and in July, increased yield to 15 t/ha.

3. Lucerne and red clover sown in 1967 yielded as much as the grass ley given 313 kg N/ha. Clover yielded less than lucerne in the second year and did not persist. Lucerne given K fertiliser persisted for three years and yield of dry herbage exceeded 13 t/ha in 1968 and 1969. Both crops responded to more than 63 kg P_2O_5/ha and to 250 kg K_2O/ha. Lucerne responded most during the third year, when the gain from K fertiliser exceeded 2·5 t/ha.

4. In the first year, clover contained more N than lucerne, but less later. Harvested lucerne contained 456 kg N/ha in 1968 and in three years as much as 981 kg N/ha.

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5. A white clover–grass ley cut repeatedly at 'grazing' stage yielded 8·3 t/ha of dry matter containing 250 kg N/ha in 1969, a wet year. 1970 was very dry; yield was less than 2·5 t/ha, and contained only 60 kg N/ha. Early summer of 1971 was also dry but the clover–grass ley yielded 2·5 t/ha by the end of June and 5 tonnes when given 38 kg N/ha before each cutting. Total yields in 1971 were 3·7 t/ha without N and 6·9 t/ha with N.

6. 125 kg P_2O_5 was more than was needed by the meadow fescue–timothy ley when given most N, and soil P increased. During three years grass removed about 600 kg K_2O/ha more than was supplied (750 kg K_2O/ha), seriously diminishing soluble potassium in soil.

7. 63 kg P_2O_5/ha maintained initial concentrations of soluble soil phosphate but lucerne and clover needed more than this to yield well. Lucerne removed more than the annual dressing of 250 kg K_2O/ha and soluble-K in soil diminished slightly. When yields of herbage crops removed from Saxmundham soil exceed 12 t/ha of dry matter 300 kg K_2O/ha should be given annually for lucerne and 440 kg K_2O/ha for grass.

8. The dry matter of grass given 125 kg N/ha for each of four or five cuts contained 14% or more of crude protein; with less N, and less frequent cutting, protein was less. Dry matter of lucerne always contained at least 16% crude protein; in 1968, clover and lucerne contained more than 20%.

9. The grass ley given most N contained less than the 0·2% Mg in dry matter considered desirable for ruminants on all-grass diets. Clover and lucerne contained less potassium and more magnesium than grass.

10. In the wet year 1969, the clover–grass ley produced 27 kg/ha of dry matter/mm of rain; in the dry 1970, only 17 kg/ha. During early summer, yield in 1971 was as in 1970, and was doubled by a little N fertiliser. Total yield in 1971 was at the rate of 21 kg/ha per mm. Lucerne produced 30–45 kg/ha of dry matter per mm of rain. Grass given most N produced about 50–60 kg/ha of dry matter/mm of rain during spring and early summer, 40–45 kg/ha per mm at mid-season and only 25–30 kg/ha per mm during late summer.

11. The structure of soil ploughed after growing lucerne and red clover appeared much better than the structure of adjacent land which had grown wheat. The grass ley when ploughed gave a seedbed for barley that dried sooner and worked more easily than a ploughed barley stubble. Wheat that followed lucerne and clover yielded more than wheat following wheat. Yields of two barley crops that followed the grass seemed not to have been improved by the ley.

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