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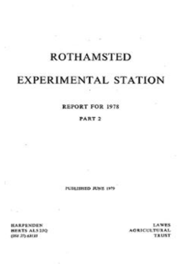

Results from an Experiment on All-grass and Grass-clover Leys at Saxmundham, 1969-76, and Changes in Soil pH, Nitrogen, Phosphorus and Potassium due to Cropping and Manuring

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Results from an Experiment on All-grass and Grass-clover Leys at Saxmundham, 1969–76, and Changes in Soil pH, Nitrogen, Phosphorus and Potassium due to Cropping and Manuring

A. E. JOHNSTON, P. R. POULTON and R. J. B. WILLIAMS

Introduction

A number of experiments with herbage crops have been made at Saxmundham on soils formed in Chalky Boulder Clay (Beccles series). Their aim, as given by Williams and Cooke (1972), was 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'. The treatments in one experiment were modified during the first few years but for much of the period the productivities of all-grass leys given fertiliser N, 'all-grass ley', and grass-clover leys without fertiliser N, 'grass-clover ley', were compared at different levels of P and K. Williams and Cooke (1972) reported yields for the first 3 years (1969–71): these have been summarised here in a complete account of the experiment. We give special attention to changes in soluble P and K and total N in the soil as a result of cropping and manuring.

Methods

In 1967 two small areas of old arable soil were sown with a mixture of wild white clover and several grasses. The swards were well established, with clover dominant, by spring 1969. Throughout 1969 the swards were cut at grazing stage and yields and nutrient contents were measured. In spring 1970 each area was divided into plots, each $11 \times 1{\cdot}2$ m, for a simple test of P (125 kg P_2O_5 ha^{-1}) and K (250 kg K_2O ha^{-1}), applied as triple superphosphate and muriate of potash in late winter for the coming year. There were four plots receiving, none, P, K or PK, in each of three randomised blocks; two blocks (plots 1 to 8) were adjacent on one small area, with a third (plots 9 to 12) about 70 m away.

During 1970–71 the herbage was harvested at grazing stage and removed, using a rotary motor mower fitted with a collecting box. In 1971 plots 5 to 8 each received 38 kg N ha^{-1} for each of the eight grazing cuts harvested that year. From 1972 the grass was cut with a motor scythe at silage stage, raked up, weighed and removed; two or three harvests were taken each year. Nitrogen continued to be tested on plots 5 to 8 but at 125 kg N ha^{-1} for each cut.

In 1972 and 1973 a simple test of irrigation was made on plots 1 to 8, by watering a 3 m length of each plot. A tractor-mounted sprayer was modified to apply 84 litres of water per minute from jets at 10 cm spacing in a 300 cm boom. The tractor speed was adjusted so that 20 passes of the boom over the watered sub-plots applied 2·1 cm of water. Amounts of water applied are given later. In 1974 although no extra water was given the previously watered and unwatered parts of each plot were again harvested separately. The grass was harvested by whole plots in 1975 and 1976 but no fertilisers were applied in the latter year.

Main treatment changes can be summarised as follows:

1967 A mixture of grass and clover seeds sown on two areas of old arable soil. Yields not taken in 1967–68.

1969 Yields of the grass-clover sward measured. Harvests taken frequently to simulate grazing.
1970 Areas divided into plots to test P and K.
1971 N test introduced. Where applied, N dressings eliminated clover and the sward became an all-grass ley.
1972 Grass harvested at silage stage.
1972–73 Test of irrigation.
1974 Residual effects of irrigation measured.
1976 No fertilisers applied but yields taken.
Details of soil samples taken in 1970, 1976 and 1977 are given later.

Yields

Effect of N, P and K. The two blocks of the experiment which received no N were about 70 m apart but yields from identical treatments were very similar. The mean total dry matter yield each year during 1971–76, averaged over all PK treatments, was 4·68 t ha^{-1} from plots 9 to 12 and 4·70 t ha^{-1} from plots 1 to 4. We have averaged therefore yields from these two blocks.

Applications of N in 1971 to plots 5 to 8 killed much of the clover and from 1972 onwards most of the yield on these plots was from grasses. Although the plots were small, 11 m × 1·2 m, the yields each year where N was given were similar to those on much larger plots, 17 m × 5·5 m, in the Rotation I experiment on the same field. In the latter experiment 100 kg N ha^{-1} was applied for each cut to a timothy-meadow fescue ley sown in 1970 on soil that had grown only arable crops since 1899. Yields of grass, t ha^{-1} dry matter, in the two experiments were:

	All-grass ley			Rotation I		
Year	Number of cuts	N applied kg ha^{-1}	Yield t ha^{-1}	Number of cuts	N applied kg ha^{-1}	Yield t ha^{-1}
1971	8	304	6·9	3	300	12·1
1972	2	250	10·1	2	200	10·9
1973	3	375	8·0	3	300	8·8
1974	2	250	9·3	2	200	8·6
1975	2	250	6·4	2	200	7·8

The large difference in yield in 1971 was because of the different frequencies of cutting.

Table 1 shows dry matter yields from 1970, after the start of the PK test. Year to year variation, averaged over PK treatments, was from 2·1 to 6·9 t ha^{-1} without N and from 6·4 to 10·1 t ha^{-1} with fertiliser N. Possible reasons for these large seasonal variations are discussed later.

The grass-clover ley yielded, on average, 4·7 t ha^{-1} dry matter. The largest yield, 6·9 t ha^{-1} in 1972, was much less than the 8·4 t ha^{-1} in 1969 reported by Williams and Cooke (1972). The cause of the large 1969 yield is uncertain, but March–August rainfall and average monthly soil temperature at 10 cm depth between March and September were both larger in 1969 than 1972 (Table 2).

Nitrogen applied at 125 kg ha^{-1} for each cut increased yield of the all-grass ley by about 2 t ha^{-1} in the absence of K fertiliser and by nearly 4 t ha^{-1} where K was applied (Table 1). In 1976 yields on previously N treated soils declined to only 2·4 t ha^{-1} suggesting that there was little residual effect from the previous N dressings.

The effect of P was small, ranging from 0·18 t ha^{-1} on the all-grass ley given N and K to 0·40 t ha^{-1} on the grass-clover ley without K. This small effect was on soils with bicarbonate-soluble P values ranging from 14 to 26 mg kg^{-1} in the 0–15 cm depth at the start of the experiment. These soil P values would place the soils at the top of ADAS P Index 1 and 2 respectively.

TABLE 1

Yields from grass-clover and all-grass leys, Ley experiment, Saxmundham, 1970–76

Dry matter, t ha^{-1}

		Swards without N					Swards with N[a]				
Year	Number of harvests	None	P[b]	K[b]	PK[b]	Mean	None	P[b]	K[b]	PK[b]	Mean
1970	4	2·01	2·07	1·99	2·15	2·06	2·68[c]	2·81[c]	2·75[c]	2·85[c]	2·77
1971	8	3·28	3·78	3·96	3·77	3·70	6·31	6·88	6·95	7·47	6·90
1972[d]	2	6·66	7·00	6·90	7·07	6·91	9·63	8·93	10·90	10·73	10·05
1973[d]	3	4·24	4·42	4·41	4·84	4·48	7·14	7·72	8·76	8·42	8·01
1974[d]	2	4·57	4·85	5·11	5·14	4·92	8·60	9·28	10·60	10·00	9·62
1975	2	2·98	3·72	3·52	4·32	3·64	4·82	6·87	7·19	6·86	6·44
1976	2	4·24	4·11	3·83	4·93	4·28	2·33[c]	2·50[c]	1·96[c]	2·83[c]	2·41
Mean annual yield 1971–75		4·35	4·75	4·78	5·03	4·73	7·30	7·94	8·88	8·70	8·20

(a) 125 kg N ha^{-1} for each cut except 1971 when 38 kg N ha^{-1} given for each cut.
(b) 125 kg P_2O_5 ha^{-1}, 250 kg K_2O ha^{-1} applied annually in late winter, none applied in 1976.
(c) No N applied in 1970 and 1976.
(d) Yields from sub-plots not given water in 1972–73.

K increased the yield of the grass-clover ley by only 0·36 t ha^{-1}, but where N was given yield increased by 1·17 t ha^{-1}. Both in the absence and presence of N the effect of K was larger on soils without fresh P than on those with, suggesting that perhaps P increased root growth and hence K uptake. At the start of the experiment exchangeable K in the soils ranged from 120 to 178 mg K kg^{-1} so that the responses to fresh fertiliser K occurred on soils in ADAS K Index 2.

Effect of rainfall. We can find no simple explanation for the large seasonal variation in yield. Although we now have yields for more years we cannot find any relationship with spring and early summer rainfall as Williams and Cooke (1972) suggested nor with total rainfall during the growing season.

For the whole period of the experiment the years divide into two groups: 1972, 1974, 1975, 1976, with dry summers in which there were two cuts and 1969, 1970, 1971 and 1973 with wetter summers, in which there were three or more cuts. The March–August

TABLE 2

Total rainfall (1 March to 31 August and 1 March to 30 September), mean soil temperature (1 March to 30 September) and total annual yield, 1969–76, Ley experiment, Saxmundham

	Year	Rainfall, mm 1 March–31 August	Rainfall, mm 1 March–30 September	Mean soil temperature °C at 10 cm depth 1 March–30 September	Yield, t ha^{-1} dry matter Grass–clover ley	Yield, t ha^{-1} dry matter All-grass ley
2 cuts each year	1972	220	286	11·1	6·91	10·05
	1974	192	298	11·5	4·92	9·62
	1976	175	303	13·3	4·28	—(a)
	1975	260	367	12·7	3·64	6·44
3 or more cuts each year	1970	179	241	11·9	2·06	—(a)
	1971	296	335	11·8	3·70	6·90
	1973	261	347	12·4	4·48	8·01
	1969	394	396	12·2	8·40	—(a)

(a) N not applied in these years.

rainfall in the first group averaged 211 mm, in the second group 284 mm. Table 2 shows the total yield each year, March to August and March to September cumulative rainfall, and average soil temperature at 10 cm depth during March–September with the years grouped by the number of cuts taken. Yields from grass-clover swards without fertiliser N decreased with increasing March–September rainfall when only two cuts were taken, but increased with increasing rainfall when three or more cuts were harvested. Similarly for grass receiving N, yield decreased with increasing March–September rainfall. For both swards yield did not appear to be related to March–August rainfall. Also, yield and soil temperature do not appear to be directly related. A simple relationship between yield and rainfall may exist when grass is cut frequently and N is not limiting as in the first two years of this experiment (Williams and Cooke, 1972). However, this method of management frequently decreases the efficiency of N use (see next section). When only two or three harvests are taken in an attempt to increase dry matter yield per kg N applied, as in the later years of this experiment, rainfall appears to have a much less obvious effect on yield.

Efficiency of N use on the all-grass ley. When more than one rate of N is tested the relationship between yield and increasing amounts of applied N can be represented graphically. An estimate of the efficiency with which N has been used can then be calculated for any part of the relationship; as kg dry matter produced per additional kg N applied. We are unable to use this test with these results but we have related total dry matter produced during the year per kg N applied to the March–September rainfall and the number of grass harvests:

Rainfall, mm	286	298	367	335	347
Kg dry matter for each kg N applied	40	38	26	23	21
Number of cuts	2	2	2	3	3

The efficiency with which the N was used was less when three cuts rather than two cuts were taken and also appears to have diminished with increasing rainfall. Possibly some N was lost by denitrification with increasing rainfall on this heavy soil; some may have been leached to horizons below the main root system but little was lost in drainage because the field drains did not run during the summer months, except in 1969 and 1971.

The relationship between dry matter production and N uptake by grass-clover leys. For the grass-clover swards it is only possible to calculate kg dry matter per kg N taken up. There is a relationship with the number of harvests but not with the March–September rainfall:

Rainfall, mm	241	286	298	303	335	347	367
Kg dry matter for each kg N taken up	36	45	48	54	34	38	46
Number of cuts	3	2	2	2	3	3	2

When only two cuts were taken there was, on average, 48 kg dry matter produced per kg N taken up, when there were three cuts dry matter production declined to 36 kg ha^{-1} per kg N uptake.

Effect of irrigation. In 1972–73 a test of irrigation was made. Total rainfall during March–June was similar in both years but it was wetter during July–September in 1973 than in 1972. Estimated soil moisture deficits for the experiment were calculated from the observed water loss from an open water surface. In both years when no extra water was given there was a deficit by mid-June, and by mid-September this had reached 120 mm in 1972 and 132 mm in 1973. In 1972, 25·2 cm of irrigation prevented any deficit between the end of May and early September, but in 1973 21·0 cm of irrigation still left a small deficit (maximum 21 mm) during June.

Irrigation increased all yields (Table 3), except in 1972 where the grass-clover ley was

TABLE 3

The effect of irrigation on two leys at Saxmundham, 1972–73

Increase in yield, t ha^{-1} dry matter

	Swards not given N					Swards given N				
	None	P	K	PK	Mean	None	P	K	PK	Mean
1972	−0·24	1·68	1·86	1·45	1·19	2·28	3·62	2·25	2·44	2·65
1973	1·00	1·29	1·16	0·62	1·02	2·95	1·73	1·99	1·60	2·07
Mean	0·38	1·49	1·51	1·04	1·11	2·62	2·68	2·12	2·02	2·36

grown on soils given no PK. On average, extra water increased yields of the grass-clover ley by 20% and of the all-grass ley by 26% which was disappointingly small considering the amounts of water applied. There appeared to be no interaction between watering and additions of P and K fertiliser.

The increase in dry matter (t ha^{-1}) per cm of water applied was:

	1972	1973
Grass-clover ley	0·047	0·048
All-grass ley with N	0·105	0·098

These values tended to be much smaller than many of those given by Penman (1971) for similar leys grown on a sandy loam soil (Cottenham Series) at Woburn. This could have been due to a greater water holding capacity of the Saxmundham soil, but in 1972 and 1973 we also made an experiment testing extra water to winter wheat and observed that the soil given additional water appeared much more compact than non-irrigated soil when ploughed in autumn. Irrigation on the grass leys was not continued after 1973 but yields in 1974 were always less on previously irrigated sub-plots, on average, by 12%. It is not possible to tell from this experiment whether watering adversely affects the structure of this sandy clay loam (Appendix Table 1), but the small response to additional water and the decreases in yield in the year after irrigation ceased suggest the need for more experiments before recommending the use of irrigation on this type of soil.

Chemical composition of the crops

Nitrogen. Raymond and Spedding (1965) suggest that 14–15% of total crude protein (%N × 6·25) in the whole ration is adequate for productive dairy cows and stock that is growing rapidly. In 1972, 1974, 1975 and 1976 the grass-clover leys contained less than this value at the first cut, but for nearly all remaining cuts in all years there was more. Grass from the all-grass leys contained sufficient N except in 1972, 1974 and 1975. These were years when only two cuts were taken, so less total N was applied, and the larger yields in 1972 and 1974 may have led to dilution of the N taken up. In 1976 when no fresh N was applied there was too little residual soil N to give enough protein. The P and K dressings and applying water in 1972 and 1973 had little consistent effect on %N in the herbage.

On swards without applied fertiliser N total N uptake ranged from 100 to 120 kg N ha^{-1} (Table 4). Supplying about 290 kg N ha^{-1} $year^{-1}$ increased N uptake to 180 to 200 kg N ha^{-1}. Extra N uptake with irrigation during 1972–73 was about 22% on the N fertilised swards, about the same as the increase in yield. On the grass-clover swards watering increased the N content of the herbage by about 35%, rather more than the 20% increase in yield.

Phosphorus. Grass-clover swards without P removed 13·0 kg P ha^{-1} each year; where annual dressings of superphosphate (55 kg P ha^{-1}) were applied 17·2 kg P ha^{-1} were removed (Table 4). Grass leys with N yielded almost twice as much as the grass-clover leys but only removed approximately 50% more P; 18·2 kg ha^{-1} where none was applied and 27·3 kg ha^{-1} where P was given. The extra P removed on the watered sub-plots during 1972–73 was about 28% of that on unwatered sub-plots.

The dressing of fertiliser P tested (55 kg P ha^{-1} $year^{-1}$) was generous to ensure that lack of P would not limit growth. The effects of the P balance (amount applied minus amount removed) both with and without applied P on soil P values are discussed later.

Potassium. Where no K was given herbage, from the grass-clover swards removed 92 kg K ha^{-1} whilst the herbage from the all-grass sward took off 125 kg ha^{-1} (Table 4). Where fertiliser K (208 kg ha^{-1}) was applied the amount of K removed increased to 125 and 224 kg ha^{-1} on the grass-clover and all-grass swards respectively. The effect of watering during 1972–73 was to increase K uptake by 25%, about the same percentage as the increase in yield.

Whether or not any K fertiliser dressing is sufficient depends on the amount of K released by the soil. Failure to make an allowance for the release of soil K can lead to

TABLE 4

Average annual uptake of N, P and K, kg element ha^{-1}, by two leys at Saxmundham, 1971–75

	Swards without N				Swards with N[a]			
	None	P[b]	K[b]	PK	None	P	K	PK
N	102	115	113	120	180	183	194	201
P	12·4	16·7	13·6	17·6	16·2	26·0	20·2	28·5
K	91	93	120	130	123	127	220	227

Rates of application (a) 125 kg N ha^{-1} for each cut, except 1971 when 38 kg N ha^{-1} was given for each cut.
(b) 55 kg P ha^{-1}, 208 kg K ha^{-1} each year.

large concentrations of K in the grass (luxury uptake) if much fertiliser K is applied. However, we know too little about the amounts or duration of K release from many soils. In this experiment the all-grass ley removed, on average, 125 kg K ha^{-1} annually. In the Rotation I experiment on the same field an all-grass ley first sown in 1970 removed 180 kg K ha^{-1} annually during 1971–74 from soils receiving no fertiliser K (Mattingly and Johnston, 1976). Both these amounts were larger than the 60 kg K ha^{-1} removed annually by similarly treated grass leys on soil with similar amounts of clay at Rothamsted during the period 1958–70 (Johnston and Penny, 1972). One objective of the Rotation I experiment is to see how long the Chalky Boulder Clay soil at Saxmundham can go on releasing such large amounts of K. The amounts of K applied to and removed by the leys in the experiment described here are related to changes in exchangeable soil K later.

Percentage K in herbage varied from 0·8% to 3·8% K in dry matter. Even with the smallest values the K needs of lactating cows would be met (Kemp, 1971) and the protein content of the herbage would be unaffected. Nowakowski, Johnston and Lazarus (1975) showed that grass with 0·8% K and grown on neutral soils contained the same total protein as grass with 4·4% K, but that with less K there was less asparagine and glutamine.

Most of the herbage contained about 2% K. Percentage K in the grass-clover swards tended to be larger than in the all-grass swards, presumably because there was less dry matter and therefore less dilution of available K. Initial applications of fertiliser K increased %K in dry matter by only 0·2% on both the grass-clover and all-grass swards. Later in the experiment the differences became much larger, 0·6 to 1·0% K, because where no K was applied, K in the herbage declined. Occasionally grass given K and cut frequently had more than 3% K, the concentration above which there is a risk of hypomagnesaemia in grazing stock.

P and K uptakes in relation to current fertiliser recommendations. The amounts of P and K currently recommended for grassland cut for conservation depend on the number of cuts taken and the P and K Index of the soil (MAFF, 1973). This experiment was made on soils at the top of P Index 1 and 2 (page 100) and K Index 2 (page 102).

For P the recommendation is to apply 22 kg P ha^{-1} for the first and 9 kg P ha^{-1} for subsequent cuts. Thus for swards cut twice a year the total P dressing would be 31 kg ha^{-1}. We took two cuts in 1972, 1974 and 1975 in this experiment and the amounts of P (kg ha^{-1}) removed, on average, each year were:

	Grass-clover ley	All-grass ley
Without P fertiliser	12·8	16·0
With 55 kg P ha^{-1} year^{-1}	17·7	25·2

Therefore the recommended dressing would have been greater than the largest amount of P removed and P would have accumulated in the soil.

For K the recommended dressing would be 50 kg K ha^{-1} for the first and 33 kg K ha^{-1} for subsequent cuts, i.e. a total of 83 kg K ha^{-1} for the years in which two cuts were taken. The K (kg ha^{-1}) removed in the herbage, on average, during 1972, 1974 and 1975 was:

	Grass-clover ley	All-grass ley
Without K fertiliser	98	113
With 208 kg K ha^{-1} year^{-1}	134	218

These results suggest that this soil was releasing 100 to 110 kg K ha^{-1} annually in these years and that the recommended dressing of 83 kg K ha^{-1} would have been more than sufficient for the extra off-take from the grass-clover swards to which K was applied but not for the all-grass ley given N.

Relationship between manuring, nutrients removed and soil N, P and K

In the two previous sections discussion on yields and nutrients removed was restricted to the period 1971–75 because of changes in manuring before and after these years. Soil samples however were taken in April 1970 and autumn 1976 and 1977. Hence total uptakes and P and K additions during 1970–76 are used here to relate to changes in soil composition.

Soil bulk density. In 1970 only site samples (0–15 cm) were taken from both areas on which the experiment was made. Until 1964 the soils were ploughed on the ridge and furrow system and the depth was gradually increased to about 20 cm. During winter 1964–65 the plough layer was deepened to about 25 cm, and both soil organic matter and total P were diluted as in soils of other experiments at Saxmundham (Mattingly, Johnston and Chater, 1970).

In autumn 1976 the soil of each plot was sampled to 25 cm using semi-cylinder augers, each core being divided into 5 cm horizons; there were eight cores per plot.

The sampling was repeated in autumn 1977 but to 37 cm and undisturbed sub-soil was observed at about 25 cm on plots 1 to 8, but at about 30 cm, on plots 9 to 12. Where the ploughing was deeper the soil was wetter, and the plough had probably dug in. These cores were divided into 0–15, 15–25, 25–30 and 30–37 cm horizons. Soils from individual plots were not kept, bulked samples representing plots 1 to 4, 5 to 8 and 9 to 12 only were retained, primarily for N analysis.

Also in 1976 and 1977 samples were taken to determine bulk density using a metal

TABLE 5

Total amounts of each nutrient removed[(a)] *and the balance remaining in the soil, under all-grass and grass-clover leys at Saxmundham, 1970–76*

kg element ha^{-1}

Plot and treatment

	Grass–clover ley				All-grass ley with N				Grass–clover ley[(b)]			
	1 K	2 PK	3 —	4 P	5 PK	6 P	7 —	8 K	9 —	10 K	11 PK	12 P
N removed	752	884	745	780	1218	1091	1072	1175	621	643	726	753
applied	—	—	—	—	1431	1431	1431	1431	—	—	—	—
balance	—	—	—	—	+213	+340	+359	+256	—	—	—	—
P removed	86	125	85	112	174	163	109	121	79	80	104	104
applied	0	330	0	330	330	330	0	0	0	0	330	330
balance	−86	+205	−85	+218	+156	+167	−109	−121	−79	−80	+226	+226
K removed	731	939	577	564	1367	828	763	1238	642	679	753	647
applied	1248	1248	0	0	1248	0	0	1248	0	1248	1248	0
balance	+517	+309	−577	−564	−119	−828	−763	+10	−642	+569	+495	−647

(a) Nutrients removed and the balance are averaged over the values for sub-plots with and without water during 1972–73 in proportion to the areas with and without water.
(b) Plots 9, 10, 11, 12 were in a separate block about 70 m to the North of the other blocks.

box 6×6×9 inch deep (15×15×23 cm). Soil weights, M kg ha^{-1}, were:

Plots	Year	Sample Number	Weight of stones >6·25 mm in each depth, cm 0–15	15–23	0–23	Weight of dry fine soil <6·25 mm in each depth, cm 0–15	15–23	0–23	Bulk density of whole soil 0–23 cm kg m^{-3}
1–8	1976	1	—	—	0·13	—	—	3·12	1410
	1977	1	0·085	0·088	0·17	1·99	1·20	3·19	—
		2	0·057	0·035	0·09	2·06	1·20	3·26	—
9–12	1976	1	—	—	0·07	—	—	3·41	1510
	1977	1	0·048	0·025	0·07	2·09	1·39	3·48	—
		2	0·067	0·021	0·09	2·08	1·29	3·37	—

Agreement between the two sets of samples taken in the 2 years is good. There are two reasons for the difference in bulk density between soil from plots 1 to 8 and 9 to 12. Firstly, plots 1 to 8 were on soil that received 25 t ha^{-1} FYM every fourth year from 1899 to 1952. Secondly much more subsoil was incorporated into the plough layer of plots 9 to 12 by the deeper ploughing.

The weight of small stones between 6·25 mm and 2 mm was less than 1% of the total weight of <6·25 mm soil and soil weights have not been corrected for this small amount. To calculate the amounts of N, P and K in the soil the following weights, M kg ha^{-1}, of fine soil have been used:

Plots	0–15 cm	15–25 cm*
1–8	2·03	1·60
9–12	2·08	1·79

*15–23 cm depth weight increased proportionately.

The mechanical analysis of the soil is given in Appendix Table 1.

Nutrient balance. Soils treated with N, P and K during 1970–76 received 1431 kg N, 330 kg P and 1248 kg K ha^{-1}. Table 5 shows the total amount of each nutrient removed and the balance remaining in each soil.

Soil pH. Table 6 shows soil pH for the two sites in 1970 and in various horizons in 1976. Most change in pH occurred in the top 5 cm, and the decline was larger under the grass-clover sward than where N was applied as 'Nitro-Chalk 21' to the all-grass ley. The decline in soil pH on plots 9 to 12 was smaller than on plots 1 to 4 presumably because the former soils contained more free calcium carbonate in 1970

TABLE 6

pH (in water) of surface soils, Ley experiment, Saxmundham, 1976

Site samples taken in 1970; plots 1–8, pH 7·4; plots 9–12, pH 7·7

	Plot and treatments											
	Grass–clover ley				All-grass ley with N				Grass–clover ley			
	1	2	3	4	5	6	7	8	9	10	11	12
Depth, cm	K	PK	—	P	PK	P	—	K	—	K	PK	P
0–5	6·2	6·2	6·6	6·7	6·8	6·9	6·6	6·8	7·5	7·5	7·2	7·3
5–10	6·9	6·7	7·1	7·1	7·5	7·2	6·9	7·1	7·9	7·9	7·8	7·7
10–15	7·3	6·8	7·4	7·4	7·6	7·5	7·3	7·3	7·8	7·9	7·8	7·9
15–20	7·7	7·5	7·4	7·5	7·6	7·6	7·3	7·4	7·9	7·9	8·0	8·0
20–25	7·7	7·6	7·6	7·7	7·7	7·6	7·5	7·6	8·0	7·9	8·0	8·0

TABLE 7

%N in air-dry soil, Ley experiment, Saxmundham, 1976

Site samples taken in 1970; plots 1–8, 0·165% N; plots 9–12, 0·149% N

Plot and treatment

	Grass–clover ley					All-grass ley with N					Grass–clover ley				
	1	2	3	4	Mean	5	6	7	8	Mean	9	10	11	12	Mean
Depth, cm	K	PK	—	P		PK	P	—	K		—	K	PK	P	
0–5	0·269	0·264	0·273	0·302	0·277	0·236	0·269	0·303	0·256	0·266	0·234	0·229	0·236	0·221	0·230
5–10	0·190	0·191	0·186	0·189	0·189	0·168	0·177	0·182	0·178	0·176	0·164	0·167	0·167	0·160	0·165
10–15	0·146	0·165	0·167	0·162	0·160	0·154	0·166	0·155	0·164	0·160	0·140	0·146	0·147	0·146	0·145
15–20	0·153	0·163	0·172	0·162	0·162	0·147	0·155	0·166	0·157	0·156	0·137	0·139	0·139	0·148	0·141
20–25	0·139	0·151	0·155	0·149	0·148	0·133	0·147	0·153	0·152	0·146	0·131	0·134	0·133	0·137	0·134

Nitrogen. In 1970, 3 years after these experiments were started, plots 1 to 8 contained more N (0·165%) than 9 to 12 (0·149%) because the former were on what was, until 1952, treatment 10 of the Rotation II experiment, receiving 25 t ha^{-1} FYM every fourth year from 1899. Plots 9 to 12 were also ploughed more deeply in 1965, diluting the top-soil with more subsoil, and so decreasing %N.

By 1976 there were large differences in %N with depth (Table 7), but N in the top 5 cm was only about 0·01% N larger under grass-clover swards than under all-grass leys (plots 1 to 8). In 1977 the difference in %N between plots 1 to 8 and 9 to 12 was the same as in 1970 suggesting that N had accumulated at about the same rate in both soils. P and K manuring had little effect on the N content of the soil.

The site samples taken in 1970 cannot be used to measure all changes in soil N due to growing grass because the plots were sown in 1967 and some N would have accumulated by 1970. However we sampled in 1977 soils adjacent to plots 1 to 8 which were still in arable cultivation and had been since 1899, and which also received the same FYM dressings until 1952. Percentage N in the different horizons are in Table 8; the results suggest that the top 25 cm of this arable soil is homogeneous and the N content (0·151%) agrees with the value (0·153% N) given by Mattingly, Johnston and Chater (1970) for this soil in 1966–68. It is therefore not unreasonable to use 0·150% N as the likely value for plots 1 to 8 in 1967. On this assumption there was little change in %N in the 15 to 25 cm horizon by 1977 (Table 8). This could be explained by the observation that 90% of the total grass roots present in the top 30 cm of soil at Saxmundham were found in the top 10 cm (Williams and Johnston, 1977).

TABLE 8

%N in air-dry soil under leys and continuous arable, Saxmundham, 1977

	Grass–clover leys				All-grass leys with N		Continuous arable cultivation since 1899
	Plots 1–4		Plots 9–12		Plots 5–8		
Depth, cm	A[(b)]	B[(b)]	A	B	A	B	A
0–15	0·220	0·207	0·192	0·178	0·204	0·205	0·151
15–25	0·158	0·154	0·139	0·135	0·151	0·158	0·151
25–30	0·121	—	0·127	—	0·107	—	0·116
30–38	0·070	—	0·090	—	0·072	—	0·062

(a) Samples A taken with semi-cylinder augers.
(b) Samples B taken with 6×6×9 in metal box.

We have therefore calculated the increase in soil N (kg ha^{-1}) from the extra N in the 0–15 cm horizon compared with the 15 to 25 cm depth. Using the soil weights given previously the increases in soil N, kg ha^{-1}, in the 11 years (1967–77) were:

Under grass–clover leys	plots 1–4	1260
	9–12	1100
Under all-grass leys given N fertiliser	plots 5–8	1080
	mean	1150

These increases can be related to cropping and manuring. For the grass-clover leys N offtake during 1970–76 was 690 kg ha^{-1} (Table 5). If offtake during the whole 11 years was proportional to this then 1080 kg N ha^{-1} was removed; this almost equals the accumulation of soil N. On the all-grass leys there was a known positive N balance of only 290 kg ha^{-1} during 1971–75 whilst fertiliser N was applied. Even if all this N remained in the soil, 790 kg has still to be accounted for. Some of this, perhaps 390 kg, could have accumulated between 1967 and 1970 when the sward was a mixture of grass and clover before fertiliser N was applied. This still leaves about 400 kg N ha^{-1} unaccounted for and this may have built up in the soil even whilst N fertiliser was being applied.

Richardson (1938) gave a relationship between increase in soil N and time for Rothamsted soils sown to grass and Johnston (unpublished data) confirmed the shape of the curve with some more recent results. From the curve it is possible to calculate that old arable soils at Rothamsted, with about 0·12% N, would accumulate about 1650 kg N ha^{-1} in the top 23 cm during the first 10 years. This value is larger than that which we give here for Saxmundham soil, about 1150 kg in the top 15 cm during 11 years.

Recently there is much interest in N balance studies. The results given here show that there can be large changes in total soil N over relatively short periods. This lends emphasis to a comment by Jenkinson (private communication) that N balance studies over short periods will only be successful if they are made under farming systems and on soils which have reached equilibrium in the build-up or decline of soil organic matter.

Phosphorus. P soluble in 0·5 M–$NaHCO_3$ in 1970 and 1976 is in Table 9. The 1970 site samples (taken to 15 cm) probably give reasonable estimates for the soluble P and K present in the previously well mixed plough layer 0–25 cm depth. In 1970 there was almost twice as much soluble P in plots 9 to 12 than 1 to 8, and these site differences persisted on soils with and without P manuring during the course of the experiment. On plots 1 to 8, which had the lowest soluble P initially, $NaHCO_3$–P declined to values ranging from 3 to 6 mg P kg^{-1}, much the same as on arable soils which had received no P since 1899 (Mattingly, Johnston and Chater, 1970).

TABLE 9

Bicarbonate-soluble P, mg P kg^{-1}, in air-dry soils, Ley experiment, Saxmundham 1976

Site samples taken in 1970; plots 1–8, 14 mg P kg^{-1}; plots 9–12, 26 mg P kg^{-1}

	Plot and treatment											
	Grass–clover ley				Grass ley with N				Grass–clover ley			
	1	2	3	4	5	6	7	8	9	10	11	12
Depth, cm	K	PK	—	P	PK	P	—	K	—	K	PK	P
0–5	10	62	8	59	47	54	9	10	20	18	79	72
5–10	6	43	5	31	20	17	5	3	15	14	32	33
10–15	4	26	4	15	10	12	3	3	19	15	22	25
15–20	7	14	6	11	9	8	3	3	17	17	20	21
20–25	4	7	5	7	5	5	3	3	15	17	19	21

Changes in soluble P (Table 9) are related to the P balance (Table 5) in Table 10. Where no P was applied soluble P decreased under both swards. The decreases ranged from 28 to 36 kg P ha^{-1} when the P removed in the crops ranged from 80 to 115 kg ha^{-1}. On average the decrease in soluble P accounted for only about 35% of the P uptake by the crops so that much P came from initially non-bicarbonate-soluble sources. Where P was given the dressings were larger than the removals and the amount of P remaining in the soil ranged from 161 to 226 kg ha^{-1}. Increases in bicarbonate soluble P however ranged only from 16 to 45 kg ha^{-1}; this increase accounting for only 10 to 21% of the residues. These results for the changes in soluble P in soil due to manuring and cropping agree with results for arable soils growing barley at Rothamsted (Johnston and Poulton, 1977).

TABLE 10

Changes in bicarbonate-soluble P, kg ha⁻¹, and the P balance, kg ha⁻¹, net gains or losses of P, due to cropping and manuring, Ley experiment, Saxmundham 1970–76

	Bicarbonate soluble P(a), kg ha^{-1}								
	0–15 cm			15–25 cm			Net change in 0–25 cm depth	P balance(b) kg ha^{-1}	Change in soluble P as a percentage of the P balance
	1970	1976	Change	1970	1976	Change			
Grass-clover leys									
Without P									
Plots 1–4	28	12	−16	22	10	−12	−28	−86	32
Plots 9–12	54	35	−19	47	30	−17	−36	−80	45
With P									
Plots 1–4	28	79	+51	22	16	−6	+45	+212	21
Plots 9–12	54	92	+38	47	36	−11	+27	+226	12
All-grass leys									
Without P	28	12	−16	22	5	−17	−33	−115	29
With P	28	55	+27	22	11	−11	+16	+161	10

(a) Soil weights, M kg ha^{-1} 0–15 cm: plots 1–8, 2·03; plots 9–12, 2·08
15–25 cm: plots 1–8, 1·60; plots 9–12, 1·79

(b) From Table 5.

It is much more difficult to relate the P balance to changes in total soil P over short periods because of variation due to sampling and analysis. In 1977 total P at various depths in plots 1 to 8 and the adjacent arable soil of Treatment 8, Rotation II was:

	Depth, cm			
	0–15	15–25	25–30	30–38
	Total P, mg kg^{-1}			
Under grass	570	480	388	394
Under arable	582	540	456	404

The data suggest that since 1965 there might have been occasional ploughing to depths a little greater than 25 cm on the arable site and that under grass there has been considerable enrichment of the top 15 cm of soil compared with the 15–25 cm depth.

Potassium. K exchangeable to 1 N–ammonium acetate in 1970 and 1976 is in Table 11. This shows that soils without K manuring on plots 1 to 8 contained very similar amounts

TABLE 11

Exchangeable K, mg K kg^{-1}, in air-dry soils, Ley experiment, Saxmundham 1976

Site samples taken in 1970; plots 1–8, 120 mg K kg^{-1}; plots 9–12, 178 mg K kg^{-1}

	Plot and treatment											
	Grass–clover ley				Grass ley with N				Grass–clover ley			
	1 K	2 PK	3 —	4 P	5 PK	6 P	7 —	8 K	9 —	10 K	11 PK	12 P
Depth, cm												
0–5	343	232	109	109	227	102	132	250	198	460	388	131
5–10	226	190	87	87	132	87	84	152	160	376	304	113
10–15	164	151	96	92	108	84	85	111	164	299	245	117
15–20	130	124	91	94	102	86	89	108	170	232	204	123
20–25	109	108	92	94	98	88	87	97	184	186	170	127

of exchangeable K in 1976 but there were large differences between the similarly unmanured soils on plots 9 to 12. This difference cannot be explained by the removal of different amounts of K from the two soils (Table 5) which were on opposite sides of the block. In autumn 1977 we sampled the soil at the end of each plot and along the two outer sides and found that soil outside plot 9 contained 267 mg kg^{-1} exchangeable K whilst that near plot 12 contained 197 mg kg^{-1}. Soil heterogeneity of this magnitude over such a small distance, 3 to 4 m, is unusual and it makes interpretation of the 1976 soil K values for these four plots impossible.

Exchangeable K declined in soils which received no K to amounts less than those in soils also without K but growing arable crops only since 1899 (Williams and Cooke, 1971). Presumably the soil could not maintain the same exchangeable K under both cropping systems because more K was removed in the herbage crops.

Changes in exchangeable K (Table 11) are related to the K balance (Table 5), in Table 12. Where no K was applied decreases in exchangeable K were 90 and 100 kg ha^{-1} under grass-clover and all-grass swards respectively. These decreases only accounted for 15% of the K removed in the herbage so much K came from initially non-exchangeable sources. Where K was applied to the grass-clover swards the K removed was between 58 and 75% of the K applied. Exchangeable K in the soil was increased but only about 50% of the residue remained exchangeable.

On the all-grass swards the herbage removed all of, or more than, the applied K but

TABLE 12

Changes in exchangeable K, kg ha^{-1}, and the K balance, kg ha^{-1}, net gains or losses of K, due to cropping and manuring, Ley experiment, Saxmundham 1970–76

	Exchangeable K[a], kg ha^{-1}								
	0–15 cm			15–25 cm			Net change in 0–25 cm depth	K balance[b] kg ha^{-1}	Change in exchangeable K as a percentage of the K balance
	1970	1976	Change	1970	1976	Change			
Grass-clover leys[c]									
Without K	244	197	−47	192	149	−43	−90	−570	16
With K	244	443	+199	192	189	−3	+196	+413	47
All-grass leys									
Without K	244	195	−49	192	141	−51	−100	−796	13
With K	244	331	+87	192	162	−30	+57	−55	—

(a) Soil weights, M kg ha^{-1} 0–15 cm: plots 1–8, 2·03
15–20 cm: plots 1–8, 1·60

(b) From Table 5.

(c) Results for plots 9–12 had to be omitted, see text.

the exchangeable K in the soil nevertheless increased. This could be explained if the crop given K was also able to utilise some of the soil K taken up by the crop to which no fertiliser K was applied. The crop without K removed 796 kg K ha^{-1}, the fertiliser K applied was 1248 kg ha^{-1} therefore 2044 kg K ha^{-1} may have been available to the grass given K. This grass removed 1302 kg K ha^{-1} and the K balance could have been as large as 742 kg but the measured increase in exchangeable K was equal only to 57 kg, i.e. about 8% of the suggested balance. This difference suggests that all the K available to an unmanured crop may not have been available to one given K or that the K, although released from the soil minerals, was either fixed in non-exchangeable forms or leached below 25 cm, the depth to which the samples were taken. These results however support the ADAS recommendation that less K should be applied than is removed in the crop where much K is likely to be released from the soil. There is nevertheless considerable uncertainty as to the number of years during which soils may continue to release such large quantities of K and this is being studied on other experiments.

Exchangeable calcium and magnesium. Table 13 shows that both exchangeable Ca and Mg declined very little between 1970 and 1976, and P and K treatments had little or no

TABLE 13

Exchangeable Ca and Mg, mg kg^{-1}, in surface soils, 0–25 cm, Ley experiment, Saxmundham 1976

Site samples taken in 1970. plots 1–8: 4090 mg Ca kg^{-1}, 77 mg Mg kg^{-1}
plots 9–12: 4770 mg Ca kg^{-1}, 65 mg Mg kg^{-1}

	Plot and treatment											
	Grass–clover ley				Grass ley with N				Grass–clover ley			
	1 K	2 PK	3 —	4 P	5 PK	6 P	7 —	8 K	9 —	10 K	11 PK	12 P
Exchangeable Ca	3700	3800	3840	4040	3810	4460	3700	3650	4760	4460	4720	4820
Exchangeable Mg	70	69	69	70	68	65	72	74	62	57	62	62

effect on exchangeable Ca and Mg. As would be expected from the pH values (Table 6) exchangeable Ca was least in the top 5 cm of all soils and at each depth was larger on plots 9 to 12 than on 1 to 8 (Table 14). There was more exchangeable Mg in the top

TABLE 14

Distribution of exchangeable Ca and Mg with depth, mean of all treatments, Ley experiment, Saxmundham 1976

	Exchangeable Ca, mg kg^{-1}		Exchangeable Mg, mg kg^{-1}	
Depth, cm	Plots 1–8	Plots 9–12	Plots 1–8	Plots 9–12
0–5	3640	4130	90	70
5–10	3720	4650	67	57
10–15	3900	4630	64	56
15–20	4150	4940	64	58
20–25	3980	5120	66	64

5 cm of soil than at any other depth. Some Mg may have been returned to the soil from crop residues or some may have been released as the chalky particles in the soil dissolved. In K exhausted soils exchangeable Mg was almost as large as exchangeable K.

Summary

1. Yields of grass-clover leys without fertiliser N and all-grass leys receiving 125 kg N ha^{-1} for each cut were compared when grown on Beccles series soil during 1971–76. Tests of P, 125 kg P_2O_5 ha^{-1} $year^{-1}$, and K, 250 kg K_2O ha^{-1} $year^{-1}$, were also included. Changes in soluble P and K and total N in soil as a result of cropping and manuring are discussed.

2. The best dry matter yield of the grass-clover ley was, 5·0 t ha^{-1} $year^{-1}$ and of the all-grass ley 8·9 t ha^{-1} $year^{-1}$, on average. The effect of P was small, ranging from 0·18 t ha^{-1} to 0·40 t ha^{-1}, the soils initially contained 14 to 26 mg kg^{-1} bicarbonate-soluble P. The effect of K was only 0·36 t ha^{-1} on the grass-clover sward, but more, 1·17 t ha^{-1}, on the all-grass ley. Exchangeable K at the start of the experiment was 120 to 180 mg K kg^{-1}.

3. There appeared to be no simple relationship between yield and rainfall but nutrients, especially N, may be leached below rooting depth on this soil in which grass develops only a shallow rooting system.

4. Irrigation, 25·2 cm in 1972, 21·0 cm in 1973 increased yield of the grass-clover ley by 20% and of the all-grass ley by 26%. There was no interaction between watering and additions of PK fertilisers. In 1974 yields from swards irrigated during 1972–73 were 12% less than where no water had been applied. Irrigation had little effect on %N, %P or %K in the herbage.

5. Herbage from grass-clover swards often contained less than 14–15% crude protein at the first cut as did that from all-grass leys cut only twice per year. There was usually more than 14% crude protein in second and subsequent cuts from grass-clover leys and in all cuts from all-grass leys cut three times a year.

6. Amounts of P removed, when none was applied, were 13·0 and 18·2 kg ha^{-1} from grass-clover and all-grass swards respectively. Where 55 kg P ha^{-1} was applied 17·2 and 27·3 kg ha^{-1} were removed by the two swards respectively.

7. Where no K was given 92 and 125 kg ha^{-1} were removed from the grass-clover and all-grass swards respectively and where 208 kg K were given offtakes increased to 125 and 224 kg ha^{-1} by the two swards.

8. Data are given for soil bulk densities.

9. Changes in soil pH were mainly restricted to the top 5 cm of soil, decline was larger under grass-clover swards than all-grass leys.

10. The increase in soil N in the top 15 cm during 11 years was almost the same under grass-clover and all-grass leys and was little affected by PK treatments. Averaged over all treatments, soil N increased by 1150 kg N ha^{-1}.

11. P removed in the crops where none was given ranged from 80 to 115 kg ha^{-1} but the decreases in bicarbonate-soluble P were only 28 to 36 kg ha^{-1}, the decrease in soluble P was only about 35% of the P offtake. Much P came from initially non-bicarbonate soluble sources. Where P was given residues remained in the soil but the increase in bicarbonate-soluble P accounted for only 10–21% of the residues.

12. Only 15% of the K removed in the herbage was accounted for by the 90 to 100 kg ha^{-1} decreases in exchangeable K in the top soil where no K was applied. Much K came from initially non-exchangeable sources. The grass-clover swards removed only 58 to 75% of the applied fertiliser K but only 50% of the residue remained exchangeable. Herbage on the all-grass swards removed more K than was applied but exchangeable K in soil increased nevertheless. The grass took up some soil K and some fertiliser or soil K remained on sites exchangeable to ammonium ions.

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APPENDIX TABLE 1

Mechanical analyses[a] and %$CaCO_3$ of soils in 1977, Leys experiment, Saxmundham

		Mechanical analysis, % oven-dry soil						
Plots	Depth, cm	Coarse sand 2000–200 μm	Fine sand 200–20 μm	Silt 20–2 μm	Clay <2 μm	Loss on solution	Air-dry moisture	% $CaCO_3$ air-dry soil
	0–15	31·40	26·56	10·55	24·30	5·74	2·04	0·38
1–4	15–25	32·96	26·98	10·27	25·12	4·17	1·93	0·33
	25–30	24·84	24·15	12·60	33·45	3·19	2·83	0·38
	30–38	17·42	20·57	14·25	39·35	6·55	3·21	4·48
	0–15	35·19	26·88	9·37	21·75	5·66	1·76	0·33
5–8	15–25	34·79	28·45	9·45	22·35	4·92	1·77	0·33
	25–30	26·11	23·46	11·70	34·40	2·89	2·88	0·26
	30–38	17·53	21·01	13·30	42·70	3·36	3·49	1·42
	0–15	32·08	16·06	9·80	25·10	5·65	2·07	0·62
9–12	15–25	32·08	27·20	10·10	25·20	4·28	2·27	0·87
	25–30	35·87	26·73	9·74	22·40	3·97	2·27	0·95
	30–38	30·44	26·80	11·55	27·05	3·31	2·20	0·77

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