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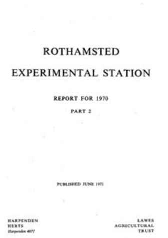
Rothamsted Experimental Station Report for 1970 Part 2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EXPERIMENTAL STATION
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Results of the Rotation I Experiment at Saxmundham, 1964–69

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

Rotation I experiment was started by the East Suffolk County Council in 1899. The four course practised until 1969 was: 1, Wheat; 2, Roots; swedes or turnips in the early years, then usually mangolds until 1964; from 1956 to 1964 mangolds and sugar beet were grown side by side on half-plots: 3, Barley: 4, Legume; usually beans but sometimes clover, peas often between 1940 and 1964. From 1965 to 1969 only beet and beans were grown on the root and legume breaks. Each crop was grown on one block of the experiment each year.

Classical treatments. The manurial treatments, unchanged from 1899–1965 and listed in Table 1, were applied annually to the same plots in each of the four blocks. The treatments had the full factorial arrangement of N, P and K, but were not randomised, and repeated in each block in the order listed in Table 1. Until recently, the manures used were not analysed and the nutrients applied are estimates based on probable average compositions. The figures for FYM are based on analyses of samples used at Saxmundham from 1964 to 1969; average contents were:

22% dry matter, and
3·3% N, 1·2% P and 2·1% K in dry matter.

Sodium nitrate probably had nearly constant %N but %P in superphosphate and %K in muriate of potash must have increased, especially since 1940. Two cwt/acre of superphosphate were applied each year; assuming that this was usual commercial material it will have contained 12–14% P_2O_5 at the beginning of the period and 20% P_2O_5 at the end; the figures in Table 1 assume an average of 16% P_2O_5. Similarly, the muriate of potash also changed, probably from 50% K_2O (or less) from 1900 to 1950 to 60% K_2O by 1960; the K supplied in Table 1 assumes an average analysis of 50% K_2O.

The experiment was described by Oldershaw (1941) and Trist and Boyd (1966), who summarised the yield results from 1899 to 1962. Crops were never systematically sampled and analysed until 1965. Cooke, Mattingly and Williams (1958) calculated a rough balance sheet for the period 1901 to 1956, using average compositions of crops from other experiments, and compared the results with analyses of soils taken from each plot in 1957.

New manuring treatments. In autumn 1965 most of the treatments were modified. The 'new' manuring (described on p. 74) was applied to six-sevenths of each plot, but a square sub-plot with 6 yd sides in the lower section of each block continued to receive the 'classical' manuring listed in Table 1, except that 12 tons/acre FYM was applied to Treatment 1. The sub-plots provided continuity with past results and the crops grown from 1964 to 1969 were analysed to make a balance sheet relevant to the main period of the experiment. They also provide soil for laboratory and pot experiments. In 1970 the cropping was greatly changed, for lucerne was sown on one one-half of each plot and grass on the other; manuring was little altered.

SAXMUNDHAM ROTATION I EXPERIMENT, 1964–69

TABLE 1

Experimental treatments in Rotation I experiment at Saxmundham in the classical period

Treatment number	Symbol	Treatment per acre	Plant nutrients applied annually (approximate estimates) N	P (lb/acre)	K
1	FYM	6 tons farmyard manure	98	35	61
2	BM	4 cwt bone meal	16	43	—
3	N	2 cwt nitrate of soda	35	—	—
4	P	2 cwt superphosphate	—	16	—
5	K	1 cwt muriate of potash	—	—	47
6	O	No manure	—	—	—
7	PK	2 cwt superphosphate + 1 cwt muriate of potash	—	16	47
8	NK	2 cwt nitrate of soda + 1 cwt muriate of potash	35	—	47
9	NP	2 cwt nitrate of soda + 2 cwt superphosphate	35	16	—
10	NPK	2 cwt nitrate of soda + 2 cwt superphosphate + 1 cwt muriate of potash	35	16	47

Cultivations. Two changes in management were made that affect results: 1. The whole field was mole-drained in 1964 and afterwards was ploughed, all one way, with a reversible single-furrow deep plough. The old ploughing depth was 5–6 inches (or shallower where the subsoil was compact). The new plough worked 10–12 inches deep and roughly doubled the depth of cultivated soil. 2. From 1965 cereals have been combine-harvested (the plots have no 'blank' rows) and from 1967 beans also. Yields of straw from the main plots after 1965 are not comparable with earlier yields when crops were cut by binder and threshed. On the small plots which continue the classical treatments, cereals have been harvested by hand and straw yields are comparable with the past.

This paper reports results from the experiment from 1965 to 1969, both for the 'classical' and the 'new' treatments. Yields and crop compositions were used to calculate the nutrients removed; analyses of soil from the main plots and the sub-plots in 1969 were compared with analyses in 1957 and 1966 to show how changed manuring and deeper ploughing since 1965 had altered nutrient reserves.

Varieties. Cappelle Desprez wheat has been grown each year since 1964; sugar beet has been Klein E. Proctor barley was grown from 1964 to 1967, Zephyr was used in 1968 and Sultan in 1969. Spring tick beans were grown in 1966 and 1967, Maris Bead in 1968 and 1969.

Results from the classical treatments, 1964 to 1969

Yields. Average yields from the classical treatments for the whole period of the experiment, given by Trist and Boyd (1966), are compared in Table 2 with yields since 1964.

In 1964–69 unmanured wheat and beans yielded a little more, and barley a little less, than average yields for the first 60 years of the experiment. Yields of unmanured beans were almost identical in 1905–18 (Trist & Boyd, 1966) and in 1967–69. There was no

Table 2

Yields per acre of crops grown in Rotation I experiment at Saxmundham with Classical treatments

Wheat (cwt of grain)

Treatment number	Treatment	1900–61	1964	1965	1966	1967	1968	1969	Average 1964–69
6	None	10·2	13·9	18·2	—	9·1	19·8	3·9	13·0
3	N	13·9	21·3	24·6	—	19·5	31·9	9·9	21·4
4	P	13·8	19·7	15·9	—	15·8	23·7	8·7	16·8
5	K	10·1	9·9	13·9	—	12·9	18·1	5·9	12·1
9	NP	19·0	27·4	24·3	—	29·1	34·2	11·9	25·4
8	NK	15·0	20·8	26·5	—	22·2	27·5	7·4	20·9
7	PK	14·6	18·1	16·9	—	15·3	19·5	6·5	15·3
10	NPK	19·4	25·2	24·8	—	32·4	36·0	16·7	27·0
1	FYM	18·9	25·3	29·4	—	35·1	36·9	10·6	27·5
2	Bone meal	14·3	18·2	20·9	—	15·9	28·8	9·8	18·7

Barley (cwt of grain)

Treatment number	Treatment	1900–61	1964	1965	1966	1967	1968	1969	Average 1964–69
6	None	8·2	2·8	6·4	—	6·3	11·2	6·6	6·7
3	N	10·9	11·7	12·4	—	12·7	18·8	8·5	12·8
4	P	10·0	5·2	5·4	—	11·7	10·9	8·7	8·4
5	K	8·0	2·0	3·7	—	7·7	9·1	6·2	5·7
9	NP	17·0	14·4	23·6	—	15·8	25·9	13·4	18·6
8	NK	12·2	11·1	8·8	—	12·6	18·9	8·8	12·0
7	PK	11·1	3·1	5·9	—	8·1	13·4	9·1	7·9
10	NPK	18·0	16·1	21·2	—	17·5	23·5	10·8	17·8
1	FYM	16·2	21·3	23·2	—	16·6	28·9	19·0	21·8
2	Bone meal	10·7	7·4	9·8	—	14·2	10·9	9·7	10·4

Beans (cwt of grain)

Treatment number	Treatment	1905–61*	1967	1968	1969	Average 1967–69
6	None	10·9	8·0	15·5	16·4	13·3
3	N	11·3	11·5	23·1	12·5	15·7
4	P	17·0	16·4	24·3	15·2	18·6
5	K	11·4	8·2	13·7	10·1	10·7
9	NP	16·9	19·2	23·7	13·7	18·9
8	NK	12·1	12·0	24·8	19·5	18·8
7	PK	20·1	15·6	29·2	16·1	20·3
10	NPK	20·8	19·3	30·4	14·3	21·3
1	FYM	21·7	17·2	31·3	18·9	22·5
2	Bone meal	15·3	21·0	24·6	7·0	17·5

* 33 crops of beans and 18 of peas.

Sugar beet (tons of fresh roots)

Treatment number	Treatment	Average 1956–65	1964	1965	1966	1967	1968	1969	Average 1964–69
6	None	2·3	1·1	1·4	3·5	4·7	5·1	0·6	2·7
3	N	3·0	0·7	2·9	4·4	9·1	5·7	1·5	4·0
4	P	6·2	3·1	7·6	5·0	5·8	7·2	5·4	5·7
5	K	2·8	0·6	2·4	2·1	4·2	6·4	0·8	2·7
9	NP	9·6	5·5	10·2	12·7	9·4	11·9	6·4	9·3
8	NK	2·4	0·9	0·9	3·7	9·6	4·7	0·4	3·4
7	PK	6·0	2·3	6·8	7·3	7·0	8·4	4·5	6·0
10	NPK	10·0	7·1	11·0	11·2	8·5	12·7	4·6	9·2
1	FYM	13·1	9·8	13·9	11·1	12·4	18·5	11·8	12·9
2	Bone meal	7·2	3·2	10·0	5·4	5·8	8·6	5·6	6·4

Notes—1 In 1966 the wheat plots were not established and the barley was so poor it was not harvested.
2. The peas sown in 1964 and the beans in 1966 failed. The legume break was fallowed in 1965.
3. In this and later Tables cereal yields are given as cwt of grain containing 15% of moisture.

suggestion that the small productivity of the soil was further diminished by growing crops for nearly 70 years without manure. Direct comparisons of yields of manured wheat and barley over the whole period cannot be made because different varieties with greater potential yield were grown after 1960. All wheat given N and P fertiliser in 1964–69 yielded more than the long-term averages. Modern barleys yielded no more with most treatments in 1964–69 than the older varieties grown between 1900 and 1919; FYM gave consistently larger yields during the last period (but the dressing was doubled for the last four crops). Mangolds were not grown after 1964; yields of beet in 1964–69 were very similar to those in the previous ten years. Average yields of the three bean crops grown were similar to those obtained between 1905 and 1918.

Trist and Boyd (1966) discussed changes in crop yields and main effects of fertilisers for three sets of 20-year averages between 1900 and 1961. Table 3 gives corresponding results for 1964–69. (The table also contains 'main effects' of the new treatments; these are discussed later.)

TABLE 3

Main effects of fertilisers and their interactions in Rotation I experiment

	Wheat (cwt/acre)					Barley (cwt/acre)				
	1900–19	1920–39	1940–61	1964–69	1966–69	1900–19	1920–39	1940–61	1964–69	1966–69
No. of years	20	20	22	5	4	20	20	22	5	4
	Classical treatments				New treatments†	Classical treatments				New treatments†
N	2·6	4·7	6·6	9·4	(6·4)	4·4	4·8	6·3	8·1	(6·1)
P	2·6	5·1	5·4	4·2	(−0·6)	2·4	3·9	5·8	3·9	(−1·6)
K	0·2	0·8	0·7	0·3	1·7	0·6	0·8	0·7	−0·7	−1·2
NP	0·2	0·3	0·6	0·8	—	1·0	1·6	2·1	1·9	—
NK	0·0	0·4	0·2	0·9	—	0·1	0·4	0·4	0·0	—
PK	−0·2	0·2	0·2	0·4	—	0·4	−0·2	0·4	0·1	—
NPK	−0·2	−0·4	−0·6	0·7	—	−0·2	−0·4	−0·6	−0·1	—

	Beans (cwt/acre)					Mangolds and sugar beet (tons/acre of roots)				
	1905–18	1920–39	1940–61*	1967–69	1966–69	1900–19	1920–39	1940–61	1964–69	1966–69
No. of years	14	15	16	3	9	14	20	22	6	4
	Classical treatments				New treatments	Classical treatments				New treatments
						Mangolds			Sugar beet	
N	0·4	0·1	0·8	2·9	1·3	3·0	3·2	4·2	2·2	(2·9)
P	7·4	8·3	6·1	5·2	(−1·4)	7·2	11·3	11·0	4·3	(−0·5)
K	1·4	2·8	2·1	1·1	3·0	0·2	0·6	1·0	−0·1	−0·4
NP	−0·2	−0·3	0·0	−2·3	0·6	2·0	2·6	2·4	1·2	—
NK	0·3	0·3	0·3	1·6	1·1	0·0	0·2	0·4	0·3	—
PK	1·2	1·7	1·3	0·9	−1·5	0·2	0·1	0·4	0·2	—
NPK	0·1	0·4	−0·1	−1·2	1·2	0·0	−0·2	−0·1	0·0	—

* Beans and peas.

† Main effects of new N and P treatments are in parentheses because they are *differences* between rates of fertilisers, not main effects as normally presented.

Cereals. Responses to nitrogen by wheat and barley have increased steadily through the whole 70 years. Responses to phosphorus have been less since 1964 than in the previous 20 years. Both crops gave small responses to potassium from 1900 to 1961, but the response by wheat in 1964–69 was less than previously and that for barley became negative. The only substantial interaction was for NP.

Beans gave small responses to N throughout the period and larger responses to K; phosphate had the largest effects, as for other crops. There was a consistent positive PK interaction with beans, response to K increasing with P, but it was not larger at the end than at the beginning of the experiment.

Sugar beet yielded smaller weights of roots than mangolds, but responses to N and P were proportionally similar. Mangolds gave small responses to K, which slightly depressed sugar-beet yields. The only large and consistent interaction with beet was of N with P.

There were two important trends: 1. Nitrogen responses tended to increase throughout the period. 2. Potassium responses did not increase. (Trist and Boyd (1966) also commented on the increases in nitrogen responses and suggested that %N in the soil had diminished during the experiment.) The capacity of the soil to supply K has continued undiminished for the 70 years. The small responses to K by wheat, barley and beans, shown from the start of the experiment, diminished for wheat and beans, and became negative for barley in 1964–69. The land has been ploughed twice as deeply since 1965 and the capacity of the soil to supply K may have been increased by cultivating layers that were previously subsoil.

Nutrient balance. Table 4 shows average amounts of nutrients removed by the crops grown between 1964 and 1969. A balance sheet relevant to the 'classical' period calculated from additions (Table 1) and losses in crops (Table 4) is in Table 5.

Until about 1950, FYM for the experiment was made by fattening bullocks housed in winter on the Station, and Oldershaw (1941) suggested it was 'of average quality'. The samples used since 1964 have come from a nearby dairy farm; their analyses were:

	Dry matter %	Per cent in dry matter					
		N	P	K	Ca	Mg	Na
Average	22·1	3·31	1·17	2·07	2·75	0·73	0·36
Range	19·3–28·8	2·45–3·91	0·74–1·75	1·32–2·46	1·88–3·48	0·27–1·63	0·20–0·62

Such manures provided more total nitrogen in a 6 tons/acre dressing than crops removed. The P supplied by 6 tons/acre must have been *much* more than crops removed annually since 1900, but on the basis of these analyses the K supplied has been less than crops grown with FYM contained.

Because losses of N by leaching and denitrification cannot be estimated, and the amounts fixed by legumes and by non-symbiotic organisms are not known, a true balance sheet for nitrogen cannot be calculated. However, Table 5 shows that fertilisers never supplied as much N as crops removed, even where growth was limited by phosphate deficiency. With P, but without N, the four crops have obtained about 200 lb/acre. Table 4 shows that beans fixed, on average, more than 100 lb N/acre/year and wheat has benefited from the residues left by the legumes. Barley receiving only PK fertiliser obtained about 14 lb N/acre from soil or other natural sources, sugar beet about twice as much.

Phosphorus supplied has always been more than crops removed from treated plots. The K supplied exceeded that removed where yields were restricted because neither N nor

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TABLE 4

Amounts of nutrients (in lb/acre) removed each year by crops grown with 'classical' treatments in Rotation I experiment at Saxmundham, 1964–69

	FYM	BM	N	P	K	O	PK	NK	NP	NPK	Mean
Nitrogen											
Wheat	64·9	36·1	42·5	32·4	24·1	25·4	30·7	43·2	50·0	55·3	40·4
Barley	38·4	18·7	22·7	14·2	11·7	12·0	13·7	23·1	29·8	30·2	21·5
Beans	122·3	103·7	82·4	108·1	56·6	73·5	114·3	100·9	112·5	120·7	99·4
Sugar beet	76·2	36·9	28·8	29·8	17·9	22·0	30·7	31·2	49·4	49·8	37·3
Total of four crops	301·8	195·4	176·4	184·5	110·3	132·9	189·4	198·4	241·7	256·0	198·6
Phosphorus											
Wheat	14·0	7·6	6·8	7·3	4·3	4·5	7·0	6·8	10·3	11·3	8·0
Barley	10·0	4·1	4·2	3·4	2·0	2·3	3·3	4·0	7·4	7·5	4·8
Beans	14·3	9·9	5·6	10·8	3·4	4·3	11·2	5·9	12·3	13·1	9·1
Sugar beet	16·5	7·9	3·5	7·0	2·6	3·5	7·2	3·0	11·6	11·3	7·4
Total of four crops	54·8	29·5	20·1	28·5	12·3	14·6	28·7	19·7	41·6	43·2	29·3
Potassium											
Wheat	49·2	22·9	25·2	20·4	17·0	17·4	21·4	27·8	31·0	37·7	25·0
Barley	30·6	12·4	15·2	9·7	8·0	8·0	10·0	18·9	18·6	21·7	15·3
Beans	81·4	25·6	20·2	23·5	25·4	20·2	42·0	42·2	25·9	44·2	35·0
Sugar beet	164·4	70·9	47·7	65·4	42·3	43·5	70·7	47·8	93·0	107·3	75·3
Total of four crops	325·6	131·8	108·3	119·0	92·7	89·1	144·1	136·7	168·5	210·9	150·6
Calcium											
Wheat	13·1	7·9	8·0	7·0	4·6	4·3	6·0	6·9	9·7	10·9	7·8
Barley	9·0	4·5	5·5	3·9	2·6	3·1	4·2	5·6	7·8	8·1	5·4
Beans	26·5	24·8	16·3	21·8	12·5	14·3	28·2	20·6	24·0	29·1	21·8
Sugar beet	41·8	23·3	20·1	22·9	13·9	15·1	22·0	18·5	33·7	34·3	24·6
Total of four crops	90·4	60·5	49·9	55·6	33·6	36·8	60·4	51·6	75·2	82·4	59·6
Magnesium											
Wheat	6·4	3·5	3·5	3·3	1·9	2·1	2·8	3·5	4·7	5·3	3·7
Barley	4·3	1·9	2·2	1·5	1·0	1·1	1·4	2·1	3·5	3·5	2·2
Beans	5·4	4·3	3·6	4·4	2·4	2·9	4·5	3·8	4·7	4·7	4·1
Sugar beet	20·9	10·1	7·0	8·7	4·7	5·5	8·3	5·9	13·8	12·9	9·8
Total of four crops	37·0	19·8	16·3	17·9	10·0	11·6	17·0	15·3	26·7	26·4	19·8
Sodium											
Wheat	0·9	0·6	0·7	0·5	0·4	0·4	0·5	0·7	0·8	0·9	0·6
Barley	1·3	0·6	1·4	0·5	0·3	0·4	0·4	1·1	1·9	1·4	0·9
Beans	6·2	21·0	17·7	18·6	2·9	9·1	12·9	8·1	24·4	16·7	13·7
Sugar beet	26·7	13·2	17·0	9·2	4·5	7·1	7·0	10·5	21·9	19·2	13·6
Total of four crops	35·1	35·4	36·8	28·8	8·1	17·0	20·8	20·4	49·0	38·2	28·8

TABLE 5

Estimates of annual changes caused by classical treatments in nutrients in the soils of Rotation I experiment for 1964–69

Treatment number	Treatment	lb/acre N	P	K
6	None	−33·2	−4	−22
3	N	−9	−5	−27
4	P	−46	+9	−30
5	K	−28	−3	+23
9	NP	−25	+6	−42
8	NK	−15	−5	+13
7	PK	−47	+9	+11
10	NPK	−29	+5	−6
2	Bone meal	−31	+33	−32
1	FYM (at 6 tons/acre)	+23	+21	−20

P was given. NPK fertilisers applied to Treatment 10 supplied a few pounds less K than crops removed.

Without P fertiliser, the crops with N and K removed about 5 lb P/acre/year from the soil, wheat most and sugar beet least. Crops without K fertiliser (but with N and P), removed about 40 lb K/acre/year from the soils, sugar beet several times as much as cereal or beans.

The average annual balance for N, P and K shown in Table 5 is relevant to the period of classical manuring since 1900; average crop yields in 1964–69 were near to the long-period averages and there is no reason to expect crop compositions to have varied greatly. The figures suggest that, in 70 years, crops have removed about 350 lb P/acre where they received N and K fertilisers but no phosphate (roughly equivalent to 175 ppm P in the top soil). About 2800 lb K/acre has been removed by crops receiving N and P but not K, which is equivalent to 0·14% K in the top-soil (assuming that the old ploughed layer, which was about 5 inches deep, weighed 2 million lb/acre).

Results from the modified experiment, 1965–69

New treatments. In 1965 we saw no point in continuing the demonstration on whole plots that unfertilised crops at Saxmundham yield little, that phosphate fertiliser is essential, and that much nitrogen is needed for all crops but legumes. The treatments given to the main part of nine of the ten plots in each block were modified for the crops harvested in 1966. (Sub-plots 6 yds long, out of the total length of 44 yds, retained the classical treatments). Only the bone meal dressings (Treatment 2) remained unchanged. The FYM dressing was doubled to 12 tons/acre and, in all years except 1966, 56 lb N/acre was applied to the main plots. The fertiliser tests are described below. The existing four-course rotation was maintained, spring beans were sown each year and only sugar beet on the root break.

Phosphorus. 39 lb P/acre was applied to all plots not given superphosphate in the past (Treatments 3, 5, 6 and 8); the old rate was increased slightly to 19·5 lb P/acre and was continued on Treatments 4, 7, 9 and 10. The change was intended to discover how quickly yields from very P-deficient soil could equal those from plots given P annually for 65 years and containing nearly enough P residues for maximum yields. The accumulation of fresh P in these poor soils from the new manuring was measured by soil analysis.

Potassium was given only to those plots given it previously but the dressing was increased to 93 lb K/acre. Cereals and beans had responded only slightly to K in the 65 years, and sugar beet not at all. The larger crops grown from 1966 removed more K and the new test was planned to see for how long crops yielding reasonably could obtain adequate potassium from the soil. (There is no other long-term experiment in Britain on soil with a reputation for releasing much K where this information can be obtained.) The dressings and treatment symbols were: P_1 = 19·5 lb P, P_2 = 39 lb P, and K = 93 lb K per acre.

Nitrogen tests were modified as experience accumulated. 'Nitro-Chalk' was used instead of sodium nitrate. Initially 56 (N_1) *v.* 112 (N_2) lb N/acre was given for non-leguminous crops, the smaller dressing to Treatments 4, 5, 6 and 7, where N was not given before. For spring-sown crops, dressings were applied to the seedbed, for winter wheat they were given in March. In each year the test on beans was of none *v.* 56 lb N/

acre (on N_2 treatments). In 1967 large losses of nitrate were measured in drainage water during May, and extra top-dressings of 28 lb N (N_1 treatments) and 56 lb N (on N_2 treatments) were given to barley on 15 June and to sugar beet on 18 July. From 1967, 56 lb N/acre was given to FYM-treated plots for the three non-leguminous crops. In 1968, 112 lb N/acre was given to all the N-treated plots of wheat, barley and beet; on N_2 treatments this was followed by a top-dressing of 56 lb N/acre, given when tissue-tests on the crops suggested they needed more N. The dressings were given to wheat on 15 May, to barley on 29 May, and to sugar beet on 25 July. In 1969 more detailed work was done on tissue testing and provisions were made for testing two top-dressings. 112 lb N/acre was given to all N-treated plots when sowing spring crops and to winter wheat during late March. Top-dressings of 56 lb N/acre were given to wheat on 28 May, to barley on 3 June and to beet on 3 July, all when plant tissue contained little nitrate. A further top-dressing of 56 lb N was applied for sugar beet on Treatments 3 and 10 on 20 August. Table 6 summarises the new nitrogen manuring treatments.

TABLE 6

Nitrogen manuring used in Rotation I experiment, 1966–69

		Beans	Wheat, barley, sugar beet					
Treatment number	Symbol	(all years) cwt N/acre	1966 (All non-legumes)	1967 Wheat	1967 Barley, sugar beet	1968 (All non-legumes)	1969 Wheat, barley	1969 Sugar beet
1	FYM(+N)	0·0	0·0	0·5	0·5	0·5	0·5	0·5
3	N_2	0·5	1·0	1·0	1·5*	1·5*	1·5	2·0†
4	N_1	0·0	0·5	0·5	0·75*	1·0	1·0	1·0
5	N_1	0·0	0·5	0·5	0·75*	1·0	1·0	1·0
6	N_1	0·0	0·5	0·5	0·75*	1·0	1·0	1·0
7	N_1	0·0	0·5	0·5	0·75*	1·0	1·0	1·0
8	N_2	0·5	1·0	1·0	1·5*	1·5*	1·5*	1·5*
9	N_2	0·5	1·0	1·0	1·5*	1·5*	1·5*	1·5*
10	N_2	0·5	1·0	1·0	1·5*	1·5*	1·5*	2·0†

* Includes one top-dressing.
† Includes two top-dressings.

Yields

Results with organic manures. The only continuity with the past has been with the bone meal treatment (No. 2) and for three crops; average yields have been:

	Yields, cwt/acre		
	1900–19	1900–61	1966–69
Wheat	15·4	14·3	15·4
Barley	11·7	10·7	10·3
Beans	17·5*	15·3	14·1

* 1905–18 only.

Average yields of wheat, barley and beans given bone meal have been nearly the same recently as during the first 60 years. Wheat yields in the last four years were the same as the average in the first 20 years of the experiment, but bean and barley yields were less.

Yields with FYM in 1966–69 cannot be compared with older yields because the dressing has been doubled and 56 lb N/acre was given to the main plots in the last three years.

The table below sets out the average yields obtained with FYM and with the full fertiliser dressing.

	1900–61		1964–69 'Classical' treatments		1966–69 New treatments	
	FYM†	NPK†	FYM‡	NPK†	FYM‖	N_2P_1K‖
Wheat (cwt)	18·9	19·4	27·5	27·0	35·2	35·2
Barley (cwt)	16·2	18·0	21·8	17·8	28·9	30·3
Beans (cwt)	21·7	20·8	22·5	21·9	24·7	21·3
Sugar beet (tons)	13·1*	10·0*	12·9	9·2	16·0	15·4

* 1956–65.
† Amounts in Table 1.
‡ 6 tons/acre in 1964 and 1965, 12 tons in later years.
‖ New treatments, including 12 tons of FYM and with 56 lb N/acre on FYM-treated plots from 1967.

During each of the periods, wheat has yielded similarly with FYM and with the NPK dressing. Barley has varied more, yielding a little better with NPK than with FYM except in the continued 'classical' test from 1964–69 which includes four years with double FYM dressings. Beans and sugar beet have yielded consistently more with FYM than with fertilisers during each of the periods.

Results of the fertiliser tests. Table 7 gives yields from the modified experiment. 'Main effects' are summarised in Table 3; only for potassium (with a test of 93 lb K/acre against none) are these normal. The 'main effect' of nitrogen is of double *versus* single dressings in 1966 and 1967, and of seedbed dressings alone *versus* seedbed plus top-dressing in 1968 and 1969. The phosphate test is of a double quantity (P_2 = 39 lb P) to plots not given any before 1965 against half as much (P_1) continued on plots that were dressed annually from 1900 and contained large residues. The complicated interaction effects are not discussed here.

Phosphorus. For all four crops the 'main effect' of P was negative; over the four years, average yields from plots with residues from 65 years of P manuring exceeded those from poor soils given twice as much fresh phosphate. The surprising feature was that giving phosphate to previously starved (P_2) plots quickly increased yields (Table 7). In the first year (1966), Treatment 9 (N_2P_1), which has always received phosphate, yielded more beans, wheat and barley (but a little less beet) than Treatment 3, with superphosphate for the first time. Results in intervening years were variable but wheat, barley and sugar beet yielded better with N_2P_2 than with N_2P_1. Although Saxmundham soil is naturally very deficient in phosphate, the deficiency can be quickly remedied; 39 lb P/acre seems enough for the crops we have grown, both to maintain yields from poor soil and to build up reserves.

Potassium had a much larger effect on wheat in 1966–69 than in any of the preceding periods of the experiment. The effect on beans was also larger than previously, but that on barley and beet was negative; yields of beet were slightly depressed by potassium fertiliser. The results with wheat and beans suggest that potassium reserves in the soil may now be diminishing to the point where K-fertilisers will be generally needed, but this is not supported by the results with barley and beet. The experiment suggests that small K dressings should be used for wheat and legumes on these Chalky Boulder Clay soils, but that other crops need none.

TABLE 7

Yields of crops grown in Saxmundham Rotation I experiment, 1966–69

Crop			FYM	BM	N_2P_2	N_1P_1	N_1P_2K	N_1P_2	N_1P_1K	N_2P_2K	N_2P_1	N_2P_1K	Mean
Field beans	Grain (cwt/acre)	1966	24·3	7·3	9·1	8·4	7·5	8·8	16·8	15·2	14·3	15·1	12·6
		1967	23·2	17·5	18·8	18·6	17·0	18·8	22·8	22·9	16·3	21·7	19·8
		1968	27·6	23·6	24·5	25·4	25·6	25·8	28·4	27·5	22·0	30·5	26·1
		1969	13·8	8·1	13·2	12·0	14·0	13·7	15·2	15·3	14·9	17·8	13·8
		Mean	24·7	14·1	16·4	16·1	16·0	16·8	20·8	20·2	16·9	21·3	18·1
Winter wheat	Grain (cwt/acre)	1966	18·7	9·9	27·1	19·8	16·7	17·8	20·9	28·3	28·9	32·2	22·0
		1967	45·3	14·0	34·3	27·7	25·9	21·0	29·2	38·8	36·8	35·3	30·8
		1968	48·4	27·8	40·0	41·8	42·6	45·9	42·5	47·6	43·5	42·7	42·3
		1969	28·6	10·0	32·1	27·0	28·8	25·3	28·4	35·1	29·6	30·8	27·6
		Mean	35·2	15·4	33·4	29·1	28·5	27·5	30·2	37·4	34·7	35·2	30·7
Spring barley	Grain (cwt/acre)	1966	34·2	11·2	29·8	25·4	19·5	28·1	28·0	32·4	31·6	29·1	26·9
		1967	24·0	11·8	25·0	16·5	16·2	15·0	20·8	26·4	24·8	24·9	20·5
		1968	34·3	11·8	35·1	38·4	35·7	32·2	30·9	29·7	42·6	37·5	32·8
		1969	23·2	6·4	30·4	20·5	17·6	23·3	20·9	28·6	28·5	29·6	22·9
		Mean	28·9	10·3	30·1	25·2	22·2	24·6	25·1	29·3	31·9	30·3	25·8
Sugar beet	Clean roots (tons/acre fresh matter)	1966	13·5	4·7	13·7	9·6	7·3	9·3	10·4	10·1	11·3	10·1	10·0
		1967	19·2	5·2	15·8	10·8	11·9	10·7	11·7	17·3	17·7	16·3	13·7
		1968	19·7	7·9	16·9	15·3	15·4	15·4	16·2	15·8	16·7	16·8	15·6
		1969	11·6	3·8	17·6	13·2	13·1	15·7	18·2	18·4	17·3	18·5	14·7
		Mean	16·0	5·4	16·0	12·2	11·9	12·8	14·1	15·4	15·7	15·4	13·5
Sugar beet	Tops (tons/acre fresh matter)	1966	5·8	2·8	6·9	3·9	3·9	3·8	4·2	6·4	7·4	6·0	5·1
		1967	6·0	2·1	6·1	4·0	3·7	3·9	3·9	6·2	7·6	6·5	5·0
		1968	13·6	3·9	15·7	10·3	9·3	9·6	11·0	14·6	16·2	16·0	12·0
		1969	5·0	2·3	17·5	5·9	7·5	10·5	11·4	17·6	18·1	18·6	11·5
		Mean	7·6	2·8	11·5	6·0	6·1	6·9	7·6	11·2	12·3	11·8	8·4
Sugar beet	% Sugar	1966	16·5	15·9	17·3	17·1	17·1	17·2	17·6	17·4	17·6	17·7	17·2
		1967	17·3	17·0	16·8	17·0	18·4	17·3	17·6	17·3	16·7	17·5	17·3
		1968	16·2	15·8	15·6	16·2	16·6	16·3	16·4	15·7	15·3	15·5	16·0
		1969	19·2	18·4	17·7	19·2	19·7	19·1	19·3	19·0	18·7	18·8	18·9
		Mean	17·3	16·8	16·8	17·4	17·9	17·4	17·7	17·3	17·0	17·4	17·3
Sugar beet	Sugar (cwt/acre)	1966	44·6	15·0	47·5	33·0	25·0	32·1	36·7	35·2	39·8	35·7	34·5
		1967	66·6	17·7	53·0	36·8	43·9	37·1	41·2	59·9	59·3	57·2	47·3
		1968	63·7	25·1	52·8	49·5	51·1	50·0	53·2	49·6	51·1	51·9	49·8
		1969	44·6	13·9	62·3	50·8	51·7	60·0	70·3	69·7	64·7	69·7	55·8
		Mean	54·9	17·9	53·9	42·5	42·9	44·8	50·3	53·6	53·7	53·6	46·8

Nitrogen. The 1966 test was a simple one of two amounts, results were:

N applied lb/acre	Wheat (cwt) Grain	Wheat (cwt) Straw	Barley (cwt) Grain	Barley (cwt) Straw	Sugar beet (tons) Roots	Sugar beet (tons) Tops
56	18·8	12·1	25·2	15·8	9·2	4·0
112	29·1	20·0	30·7	18·8	11·2	6·7

More than 112 lb N/acre might have benefited the wheat, but for barley and beet this amount must have been nearly optimum.

In March 1967, N_1 and N_2 treatments received the same dressings as in 1966. Drainage water contained much nitrate during May and crops became yellow, so top-dressings (shown in Table 6) were given to barley on 15 June and beet on 18 July. Both crops responded quickly. Average yields per acre were:

	N_1	N_2
Seedbed dressing/acre	56 lb N	112 lb N
Wheat (cwt)	26·0	36·3
Barley (cwt)	17·1*	25·3*
Sugar beet: roots (tons)	11·3*	16·8*
Sugar beet: tops (tons)	3·9*	6·6*
Sugar beet: sugar (cwt)	39·7*	57·4*

* With extra top-dressings of 28 and 56 lb N/acre to N_1 and N_2 plots.

The large gains from the double dressing suggested that the crops would have benefited from still more N; from their appearance the top-dressings should have been applied earlier and should also have been given to wheat.

In 1968 following 112 lb N/acre to both N_1 and N_2 treatments extra top-dressings of 56 lb N/acre were applied to N_2 plots for wheat, barley and beet; the top-dressings were given when analyses of nitrate-N in the stems of cereals and in petioles of sugar beet suggested they were needed. Spring of 1968 was drier than 1967, rainfall was better distributed and drainage water removed much less nitrate. (Results of the nitrate tests on the plants have been reported previously (*Rothamsted Report for 1968*, Part 1, 49–51).) Maximum yields of wheat and barley grain, and sugar from beet, were obtained with 112 lb N/acre applied in March; the only gain from the extra top-dressing on N_2 treatments was 5 tons/acre more sugar-beet tops.

In 1969 the drains at Saxmundham ran on every day of the year until 20 June and much nitrate was lost in the drainage water. Measurements were again made on nitrate in cereal stems and beet leaf petioles (*Rothamsted Report for 1969*, Part 1, 51–53). Extra top-dressings of 56 lb N/acre tested on N_2 treatments were applied to each crop when nitrate concentrations became small (29 May for wheat, 3 June for barley and 3 July for beet). A further top-dressing on 20 August was tested on two plots of beet when leaf nitrate had again become small. The first top-dressings were justified on all three crops. They increased yields by 4 cwt/acre of wheat, 9 cwt/acre of barley and 5½ cwt/acre of sugar and also gave extra yields of sugar-beet tops. The additional top-dressing to beet was not justified (little rain fell after it was applied). Results of the top-dressings given in 1968 and 1969 are summarised below:

	Yields/acre					
	Wheat, cwt of grain		Barley, cwt of grain		Sugar beet, cwt of sugar	
	1968	1969	1968	1969	1968	1969
Yield with 112 lb N in March/April	43·2	27·4	34·3	20·6	51·0	58·8
Increase from top-dressing						
First top-dressing	0·2	4·5	1·9	8·7	0·4	5·6
Second top-dressing	—	—	—	—	—	1·3

TABLE 8

Amounts of nutrients (in lb/acre) removed each year by crops grown with 'new' treatments in Rotation I experiment, 1966–69

	FYM	BM	N_2P_2	N_1P_1	N_1P_2K	N_1P_2	N_1P_1K	N_2P_2K	N_2P_1	N_2P_1K	Mean
Nitrogen											
Wheat	68·4	25·1	66·1	50·8	47·7	48·3	51·1	74·6	68·0	70·4	57·1
Barley	53·0	16·2	58·5	40·8	35·3	38·4	41·7	56·9	63·4	58·9	46·3
Beans	116·7	70·9	81·5	83·7	73·0	78·6	105·5	106·0	88·0	103·1	90·7
Sugar beet	100·3	33·0	112·8	68·3	64·8	74·4	77·2	113·2	123·1	113·9	88·1
Total of four crops	338·4	145·2	318·9	243·6	220·8	239·7	275·5	350·7	342·5	346·3	282·2
Phosphorus											
Wheat	13·2	5·2	10·7	9·4	8·8	8·7	10·2	11·5	11·6	12·0	10·1
Barley	12·6	3·6	10·4	9·1	7·2	7·8	8·8	9·5	11·1	10·6	9·0
Beans	14·0	7·3	8·4	8·9	7·0	7·6	11·6	9·5	10·5	12·3	9·7
Sugar beet	19·6	6·9	16·4	14·2	12·8	13·8	16·4	15·3	17·7	18·2	15·1
Total of four crops	59·4	23·0	45·9	41·6	35·8	37·9	47·0	45·8	50·9	53·1	43·9
Potassium											
Wheat	39·2	11·3	25·5	22·7	24·8	20·6	25·0	32·9	24·5	32·2	25·8
Barley	30·2	7·7	23·2	17·8	16·8	18·4	21·3	27·9	23·2	24·6	21·1
Beans	65·4	19·3	20·2	20·7	29·5	23·0	36·3	38·8	19·9	31·6	30·5
Sugar beet	209·0	73·3	160·0	133·3	163·0	142·7	179·6	207·3	162·6	195·1	162·6
Total of four crops	343·8	111·6	228·9	194·5	234·1	204·7	262·2	306·9	230·2	283·5	240·0
Calcium											
Wheat	7·9	2·9	8·1	6·6	5·7	5·8	6·0	7·0	8·3	7·9	6·6
Barley	7·8	2·2	7·7	5·9	4·6	5·0	6·0	7·6	8·8	6·8	6·2
Beans	28·2	11·7	14·5	14·4	14·4	14·4	19·8	20·0	16·1	17·8	17·1
Sugar beet	42·5	22·2	52·9	45·4	47·7	51·0	51·2	56·1	61·8	57·6	49·0
Total of four crops	86·4	39·0	83·2	72·3	72·4	76·2	83·0	90·7	95·0	90·1	78·9
Magnesium											
Wheat	5·3	2·0	4·3	3·5	3·4	3·4	3·9	4·7	4·7	4·6	4·0
Barley	4·8	1·5	4·6	3·9	3·2	3·5	4·0	4·4	5·0	4·6	3·9
Beans	5·1	2·8	3·3	3·3	3·1	3·3	4·0	3·9	3·6	3·8	3·7
Sugar beet	23·5	9·0	25·6	17·2	18·0	20·2	19·2	22·2	26·0	23·0	20·4
Total of four crops	38·7	15·3	37·8	27·9	27·7	30·4	31·1	35·2	39·3	36·0	32·0
Sodium											
Wheat	1·9	0·3	0·9	0·7	0·7	0·6	0·7	1·0	1·0	1·0	0·9
Barley	1·5	0·4	2·3	1·0	0·8	1·0	0·9	1·4	2·5	1·5	1·3
Beans	7·2	8·0	13·3	9·5	3·9	8·8	7·5	8·4	13·5	10·5	9·1
Sugar beet	31·0	12·0	89·8	33·6	23·6	43·1	36·4	67·1	98·0	64·0	49·9
Total of four crops	41·6	20·7	106·3	44·8	29·0	53·5	45·5	77·9	115·0	77·0	61·2

The four years' results emphasise the difficulties of using nitrogen fertiliser, even in an old-established and carefully controlled experiment. In 1966 the two amounts given to the seedbed did not show how much N was needed for maximum yield, or whether applying part of the N as a late top-dressing would have benefited the crop. In 1967 and 1969 much nitrate was leached during short periods of large rainfall in April and May; other experiments on the field showed later top-dressings were much more efficient than seedbed dressings, provided there was enough rain to wash them in. In 1967 the need for extra dressings was realised too late for them to be fully effective. In 1969 the top-dressing for barley was applied at the beginning of June just as three weeks of dry weather started, and the fertiliser remained on the soil surface. By contrast, in a spring with well-distributed rainfall, such as 1968, little nitrate is lost from seedbed dressings and timing of the N-dressing is of little importance.

Nutrients removed. Table 8 gives average amounts of nutrients removed annually by the crops grown with new treatments. P_1 dressings supplied 19½ lb P and P_2 39 lb P/acre/year; the K dressing supplied 93 lb K/acre. The nutrients supplied by 12 tons of FYM were twice those shown in Table 1. Annual changes in N, P and K calculated from Table 8 are in Table 9. No balance has been calculated for nitrogen except for Treatments 1 and 2. The FYM added from 1966–69 supplied more N than the crops removed. On the bone meal-treated plot, yields are limited by N-deficiency and, on average, all crops except beans have recovered little N from natural sources if all the N in bone meal becomes available. Fertilisers given to the other treatments have, on average, supplied about twice as much N as harvested crops recovered.

TABLE 9

Estimates of annual changes in nutrients in soils of Rotation I experiment with modified manuring, 1966–69

Treatment number	Treatment	Annual changes (lb/acre) N*	P	K
1	FYM + N	+152	+55	+35
2	Bone meal	−18	+34	−27
3	N_2P_2	(−80)	+28	−57
4	N_1P_1	(−61)	+9	−49
5	N_1P_2K	(−55)	+30	+34
6	N_1P_2	(−60)	+29½	−51
7	N_1P_1K	(−69)	+7½	+27
8	N_2P_2K	(−88)	+27½	+16
9	N_2P_1	(−86)	+7	−58
10	N_2P_1K	(−86)	+6½	+22

* Data for N are balances for Plots 1 and 2; but for Plots 3–10, they are amounts removed by crops.

Phosphorus. The crops removed only about 50% to 70% of the smaller dressing given to P_1 treatments (depending on the amount of N given). With the double dressing but without P during the classical period, only about a quarter was recovered by the crops (these statements take no account of P recovered from the soil). The crops on plots given phosphate each year from 1900 always contained more P (on average 7 lb P/acre more in the four years) than crops on plots given their first dressing in 1965–66. About 5 lb P/acre/year accumulated as residues from the small dressing during the classical period; the crops now grown leave about 7 lb P/acre from the slightly larger P dressing given since 1965. The double dressing provides nearly 30 lb P/acre/year more than the crops use, and this residue is accumulating in the soil.

Potassium supplied exceeded the total amounts removed by crops during the four years, and from 20 to 40 lb K/acre are accumulating annually (the amount depends on the N dressing applied). Although there was little yield response to K-manuring, crops on K-treated plots contained 57 lb K/acre in the four years more than crops without K-fertiliser. The largest amount of K removed from soil by crops receiving no K fertiliser was about 230 lb/acre in four years. Increasing the nitrogen dressings in the new treatments has increased the maximum K extracted annually from 42 lb/acre during the 'classical' period to 58 lb of K during the last four years. With full NPK manuring from 1900 to 1965, potassium has not accumulated on Treatment 10 (Table 5); the manuring now used on this plot leaves a residue of about 22 lb K/acre annually.

Analyses of the soils

The soils of each plot were sampled in 1957 and the analyses described by Cooke *et al.* (1958). Later samplings were in spring 1966 (after the experiment had been ploughed about 10 inches deep in winter 1965), and in summer 1969. Analyses are in Table 10.

The soils have reserves of calcium carbonate and pH is not altered by treatment.

Organic carbon is most in FYM-treated plots; differences caused by other treatments are small but largest values were in plots given most fertiliser and where crops were largest. The plots were ploughed about 5 inches deep until 1964, and twice as deep since. The subsoil ploughed up diluted the old top-soil so that all percentages of organic matter and nitrogen are less in the 1969 than in the 1957 samples. Total phosphorus in the 1957 samples reflected the balance between P applied by manuring and removed by crops. With the continued classical manuring on the sub-plots, deeper ploughing has obliterated much of these differences between the fertiliser-treated plots. There has been an apparent loss of total P in the ploughed layer of the P-treated plots but not on those without P presumably because the subsoil was as rich in total P as the top-soil of these untreated plots. The only large differences remaining are that both FYM and bone meal have left much more total P in the soil than has superphosphate. The diminution in total P caused by deeper ploughing is smallest on FYM-treated plots, presumably because organic phosphorus from FYM had already been leached into the subsoil (P under FYM-treated plots moves similarly at Woburn and Rothamsted (Warren & Johnston, 1961)).

Comparing the 1969 samples from the large plots given 'new' treatments with those from small sub-plots continuing the old treatments shows there was little effect on total P contents from four years of phosphate manuring (P_2) to previously untreated plots. However, the new dressings considerably increased bicarbonate-soluble P and, already, there are only relatively small differences between P_1 and P_2 treatments. The new manuring has similarly increased P concentrations in equilibrium with 0·01 M calcium chloride solutions.

Exchangeable potassium still reflects the accumulations of K added by FYM, or K-fertilisers, and differences caused by the larger crops produced with N and P treatments and smaller ones without these nutrients. On plots where exchangeable K had accumulated during the classical period, deeper ploughing has diminished the amounts. On plots not given K-fertiliser (Treatments 3, 4, 6 and 9), the exchangeable K changed little between 1957 and 1969, presumably because the newly-incorporated subsoil was as rich in K as the surface soil. Potassium soluble in 0·01 M calcium chloride solution also shows

TABLE 10

Compositions of the soils of Rotation I experiment

(Values are averages for four plots)

	Sampling Date	Sampling Area	1	2	3	4	5	6	7	8	9	10	Mean
Plot			1	2	3	4	5	6	7	8	9	10	Mean
Classical treatment 1900–69			FYM	BM	N	P	K	O	PK	NK	NP	NPK	—
Modified treatment 1966–69			FYM + N	BM	N_2P_2	N_1P_1	N_1P_2K	N_1P_2	N_1P_1K	N_2P_2K	N_2P_1	N_2P_1K	—
$CaCO_3$ %	1969	New	0·74	1·10	1·12	1·12	1·48	1·07	0·80	0·74	0·73	1·16	1·01
pH (in water)	1969	New	8·0	8·2	8·1	8·1	8·1	8·1	8·0	8·0	8·1	8·1	8·1
Organic carbon (Walkley–Black values, uncorrected) %	1957	Classical	1·55	1·01	0·92	0·99	0·95	0·94	1·01	0·95	1·04	1·01	1·04
	1965/66	Classical	1·38	0·77	0·77	0·79	0·74	0·79	0·82	0·80	0·82	0·84	0·85
	1969	Classical	1·32	0·78	0·72	0·75	0·72	0·75	0·75	0·73	0·79	0·83	0·82
	1969	New	1·22	0·77	0·71	0·71	0·67	0·70	0·70	0·72	0·75	0·76	0·77
Total N, %	1957	Classical	0·199	0·149	0·136	0·139	0·137	0·135	0·142	0·139	0·146	0·144	0·147
	1965/66	Classical	0·192	0·127	0·122	0·120	0·121	0·124	0·132	0·130	0·130	0·130	0·132
	1969	Classical	0·193	0·132	0·123	0·133	0·117	0·118	0·128	0·128	0·128	0·135	0·131
	1969	New	0·175	0·127	0·125	0·116	0·121	0·115	0·126	0·127	0·126	0·122	0·128
Total P, %	1957	Classical	0·071	0·088	0·042	0·056	0·041	0·042	0·056	0·041	0·056	0·056	0·055
	1965/66	Classical	0·065	0·065	0·040	0·048	0·036	0·037	0·048	0·036	0·049	0·046	0·047
	1969	Classical	0·068	0·073	0·045	0·049	0·040	0·043	0·048	0·036	0·049	0·050	0·050
	1969	New	0·066	0·068	0·045	0·050	0·043	0·042	0·046	0·040	0·045	0·046	0·049
P soluble in 0·5*M* $NaHCO_3$ ppm	1957	Classical	33	8	3	23	2	2	20	2	21	19	13
	1965/66	Classical	29·9	8·1	6·0	20·5	8·1	5·4	20·8	6·5	19·3	20·1	14·5
	1969	Classical	41·8	7·7	2·9	21·1	2·7	3·0	22·9	3·4	20·6	25·8	15·2
	1969	New	31·4	5·9	11·7	15·6	10·9	9·4	14·5	12·1	15·3	17·6	14·5
P in equilibrium in 0·01*M* $CaCl_2$ solution μM/litre	1957	Classical	6·3	0·2	0·1	1·6	0·1	0·1	1·1	0·1	1·4	1·0	1·2
	1965/66	Classical	4·0	0·6	0·5	1·0	0·5	0·4	1·2	0·5	1·1	1·2	1·1
	1969	Classical	3·5	0·4	0·3	0·7	0·2	0·1	0·7	0·3	0·6	0·8	0·7
	1969	New	2·1	0·4	0·5	0·5	0·4	0·4	0·6	0·5	0·5	0·6	0·6
K exchangeable, ppm	1957	Classical	268	109	124	116	235	137	180	205	110	154	164
	1965/66	Classical	285	114	118	122	192	129	156	181	111	138	154
	1969	Classical	264	125	115	121	182	138	168	179	113	162	157
	1969	New	242	121	126	123	187	141	169	189	115	157	157
K soluble in 0·01*M* $CaCl_2$ solution, ppm	1965/66	Classical	13·4	4·0	3·9	4·1	7·5	4·4	6·0	7·4	3·4	4·8	5·9
	1969	Classical	11·4	3·0	2·9	3·1	5·6	3·6	4·8	5·2	2·7	4·8	4·7
	1969	New	8·0	2·8	2·9	2·9	5·6	3·2	5·0	5·9	2·9	4·2	4·3
Mg exchangeable, ppm	1965/66	Classical	218	117	124	122	117	119	105	124	105	104	125
	1969	Classical	189	107	95	91	103	95	86	97	84	88	103
	1969	New	169	109	102	99	111	112	94	93	78	82	105

clearly how K has accumulated on FYM-treated plots and the differences between plots with and without K fertiliser.

Exchangeable magnesium has been considerably diminished by deeper ploughing. Magnesium fertiliser is not applied, so supplies in the top-soil are maintained by rainfall, by crops residues and by weathering of clay. Amounts in FYM-treated plots are still much larger than in fertilised plots. Exchangeable magnesium has clearly been influenced by yields of crops grown during the classical period; amounts are least where N and P fertilisers gave satisfactory yields.

Soil analyses related to nutrient balances. Figures 1 and 2 relate bicarbonate soluble-P and exchangeable-K with the nutrient balance shown in Table 5. (These calculations replace the earlier balance sheet for P and K by Cooke *et al.* (1958), which was based on assumed crop compositions. The satisfactory agreement between exchangeable K, and K balance of Fig. 2 in our paper, and that in Fig. 1 of the earlier one, justifies attempts to calculate such balance sheets even when local analyses do not exist.) Values for soluble-P in the plots are in two groups, plus the isolated point provided by the FYM-treated plot. The relationship appears to be linear; if losses of P in crops are exactly balanced by fertiliser additions, the soils will contain 10 ppm of sodium bicarbonate-soluble P.

There is a good linear relationship in Fig. 2 between the calculated balance for K (additions *minus* losses) and exchangeable K in the soils. If fertiliser additions exactly balance losses in crops, the soils will contain 160 ppm of exchangeable K. Johnston (1969) found that, when losses and gains were balanced in the Broadbalk experiment at Rothamsted, the soils had a similar amount (about 150 ppm) of exchangeable K.

Batey (1964) analysed samples of soil taken before fertilisers were applied in March 1963. (The results were expressed in ppm of P and K in the soil extract.) Amounts of free

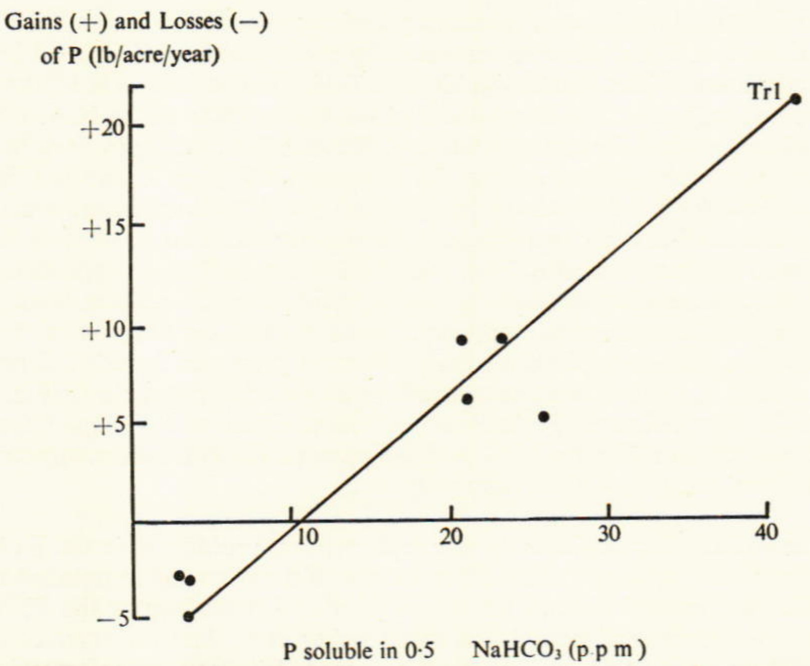

Fig. 1. Relationship between losses and gains of phosphorus and soil P soluble in sodium bicarbonate solution; 1899–1969.

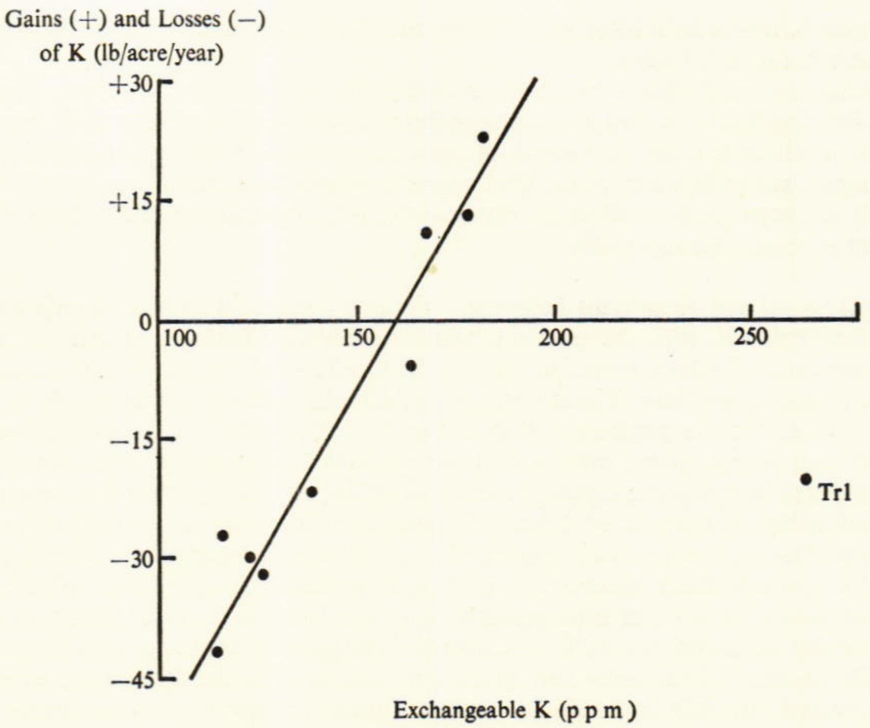

Fig. 2. Relationship between losses and gains of potassium and exchangeable K in the soils; 1899–1969.

calcium carbonate, pH values and percentages of organic matter were similar to values in Table 10. Soluble P and K were measured by the methods used in 1964 in advisory work in England and Wales. Exchangeable K in Table 10, and soluble K by the N.A.A.S. method, were closely related, but soluble P in the soil extracts of the N.A.A.S. method was less well related to bicarbonate soluble P. Because these methods have been widely used, Batey's values are plotted against the balances for P (Fig. 3) and K (Fig. 4). The N.A.A.S. method for P differentiated less clearly than the sodium bicarbonate methods between groups of differently treated plots. Results for the bone meal plots fit satisfactorily in Fig. 3 but are excluded from Fig. 1. Sodium bicarbonate solution does not dissolve bone meal residues whereas the slightly acid N.A.A.S. reagent does. However, in this experiment the bone meal supplied so little N that it is not possible to estimate how valuable the residues are. Relationships between gains and losses of K and Batey's values for soluble K (Fig. 4) were as satisfactory as with exchangeable K (Fig. 2). When losses in crops were balanced by fertiliser additions, Figs. 3 and 4 suggest that the soil extracts would contain 28 ppm of K and 1·5 ppm of P, both values appear to be in Batey's 'medium' category for advisory purposes.

Potassium in FYM. Figures 2 and 4 share a discrepancy; soluble K in the FYM-treated plots is not related to analyses of soils from the rest of the plots and to potassium balance. Either FYM has greatly increased the solubility of soil potassium or the FYM applied during most of the classical period was much richer in K than the samples used from 1964 to 1968 on which this balance sheet is based. We have no information on the composition of FYM used and no evidence except Oldershaw's (1941) statement that

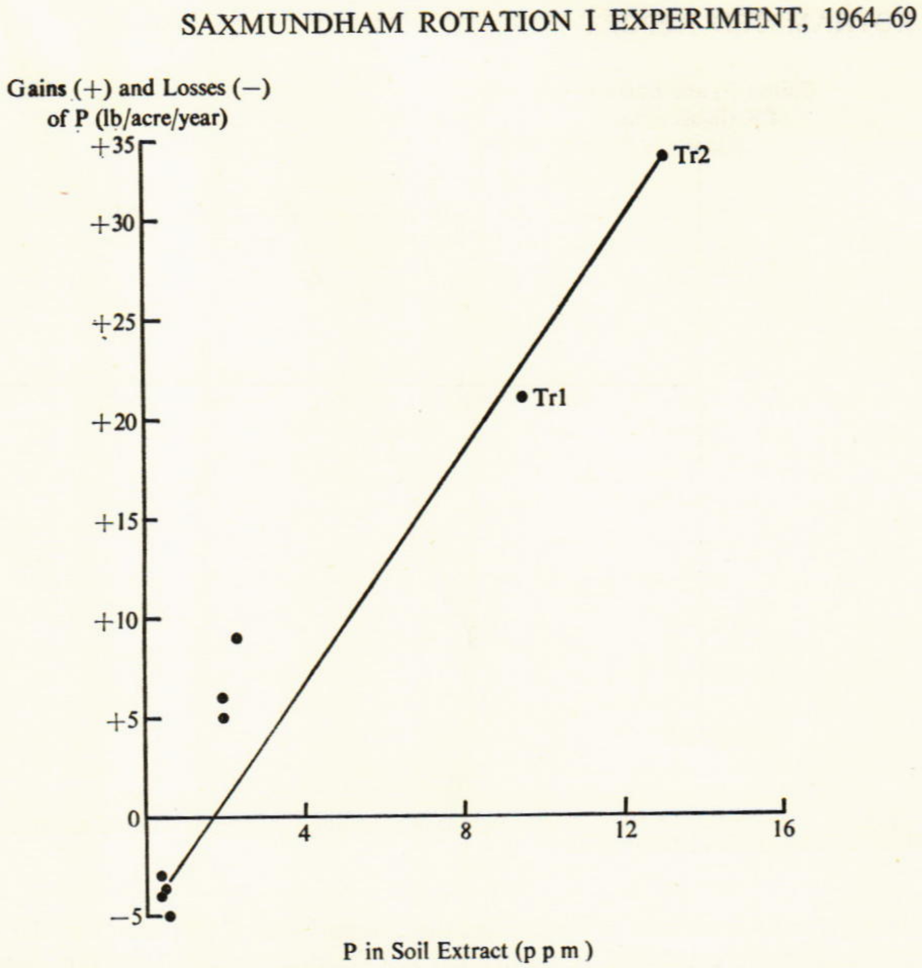

Fig. 3. Relationship between losses and gains of phosphorus and soluble P in soil extracts measured by Batey's (1964) method; 1899–1962.

it was made by fattening bullocks in a covered shed. He said the bullocks did not have a rich cake diet but the FYM made was not removed from the shed until it was applied to the plots. The recent samples used were from dairy stock and were stored in heaps out of doors and their compositions are similar to those of much FYM used in Rothamsted experiments. The earlier Saxmundham manures were completely protected from loss of K by the leaching that occurs during outdoor storage and they may have been much richer in K. Many authors record that some samples of FYM have 4–5% K in dry matter—twice the value assumed here. Extrapolation of the linear relationship in Fig. 2 shows that soluble K would be as found if FYM supplied each year 80–90 lb K/acre more than crops removed (Fig. 4 suggests a similar amount). To supply so much would require FYM with more than 6% K in dry matter (an improbable, but not impossible, value).

Soil differences between blocks. Trist and Boyd (1966) found consistent differences in yield of barley and roots from block to block. Average yields from Block D (Plots 1–10, Fig. 1 of their paper) were about 10% above the mean of the four blocks whereas Block B (Plots 31–40) tended to give smaller yields. Block D also gave the most wheat. These

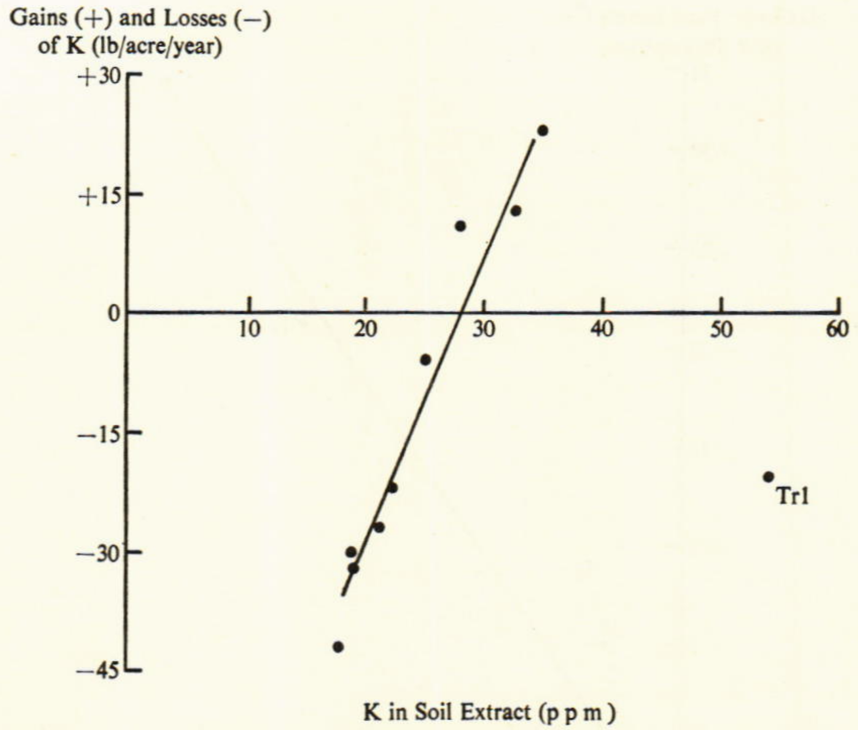

Fig. 4. Relationship between losses and gains of potassium and soluble K in soil extracts measured by Batey's (1964) method; 1899–1962.

fertility trends from east to west affect the comparisons of treatments in the systematic layout; they were ascribed to permanent soil factors, probably depth of the ploughed layer. Table 11 gives average values for blocks of most of the measurements listed in Table 10. There are no large differences that clearly account for better yields from Block D and poorer yields from B. Soils of Block D contain more nitrogen and organic matter and more soluble P than average, but the differences are small. The only striking difference is the much larger content of $CaCO_3$ in Block B—which gave poorer crops. We think this reflects differences in parent material; borings show the subsoils of Block B to be more compact and more gleyed than subsoils of other blocks. The common subsoil in Block B is unaltered typical Boulder Clay, blue-grey, compact and rich in $CaCO_3$.

TABLE 11

Average values of soil properties in blocks of Rotation I experiment (1969)

	Block				
	A	B	C	D	Mean
Nitrogen, %	0·132	0·127	0·123	0·130	0·128
Organic carbon, %	0·78	0·77	0·72	0·81	0·77
Total P, ppm	493	528	464	486	493
$NaHCO_3$-soluble P, ppm	14·7	14·7	13·5	15·2	14·5
Exchangeable K, ppm	154	169	153	151	157
Exchangeable Mg, ppm	105	119	102	95	105
Calcium carbonate, %	0·82	1·87	0·85	0·49	1·01

On other blocks, subsoils are more open and have weathered more deeply; although all blocks are irregular, better subsoils are more common in blocks A and D than in B and C.

Some analyses were made of subsoil 9–18 inches deep. Subsoil of Plot 4 in Block A contained only 1% $CaCO_3$ (the topsoil had 0·8%); subsoils of five plots in Block B had from 3½ to 19% $CaCO_3$ with a mean value of 11% (the topsoil had 1·9%). Subsoils of Block C, above Block B, had little $CaCO_3$ (from 0·04 to 5·1% and a mean value of 1·3%).

Nutrients supplied by rainfall

Nutrients in rain. Rain samples were collected continuously by a polythene gauge 6 ft above the soil at Saxmundham between 1966 and 1970; 41 separate batches were analysed without filtering. The nutrients supplied annually were:

	lb/acre
NH_4–N	8·4
NO_3–N	6·1
P	0·2
Cl	43
SO_4–S	16
K	2·6
Na	24
Ca	12
Mg	3·7

The nitrogen in rain made an appreciable contribution to the needs of crops not given N fertiliser, but P and K supplied was unimportant. The sulphur suffices for a crop rotation of this kind; the large amount of chloride is quickly leached out (balanced by calcium).

Calcium, magnesium and sodium. The other nutrient cations in rain, Na, Ca and Mg have not been discussed previously. Table 4 gives the amounts in crops grown with the classical manuring and Table 8 with the new fertiliser treatments.

Calcium. Much more calcium was removed by beans and sugar beet than by cereals. Annual removals from fully fertilised plots averaged only about 20 lb/acre from 1900–65 and a little more during the recent period. These losses in crops are much less than is leached annually from this calcareous soil—270 lb/acre (Williams, 1971).

Magnesium. Half or more of the magnesium removed in the four-year rotation was taken by the sugar beet crop (Tables 4 and 8), and the total amounts removed were influenced mainly by the effect of fertilisers in increasing yields of beet. During the classical period, about 7 lb Mg/acre/year was removed, only twice as much as rain supplied and half as much as was lost by leaching. FYM-treated crops usually contained more Mg than fertiliser-grown crops. The manure recently used has averaged 0·7% Mg in dry matter; a 6 ton/acre dressing will have supplied 20 lb Mg/acre/year. The soil of FYM-treated plots contains nearly twice as much exchangeable Mg as plots treated with NPK fertiliser; but the fertilised plots with 80 ppm of exchangeable Mg contain much more than the 30 ppm usually thought to indicate a deficient soil.

Sodium. Cereals contained very little sodium, and beans usually from about 5 to 20 lb Na/acre. Sugar beet contained much more; the average for crops grown with 'new' treatments was 50 lb Na/acre/year. Table 9 shows how sodium removed depends on yield but much more on manuring with potassium. Where K was supplied as FYM, or as fertiliser, much less sodium was taken up by beet than where it was not supplied. FYM itself supplied little Na (about 10 lb/acre in a 6 ton dressing). Most Na was removed by crops with the N_2P_1 treatment, when the sugar beet alone contained about 100 lb Na/acre. This is much more than the annual supply of 20 lb Na/acre in the rain. Sodium may not be readily leached and may accumulate in exchangeable forms that can be used by beet; probably the soil also contains a reserve that is slowly released by weathering, because drainage water removes about 30 lb Na/acre/year (Williams, 1971).

Weather and soil conditions at Saxmundham

All previous accounts of the Saxmundham Experiments have stressed the difficulties of working the soil and that good yields depend on good weather. Unseasonable rainfall has had very bad effects on yield. Oldershaw (1941) stated 'In spite of the fact that the district is one of the driest in England, this heavy land is frequently in so wet a state that neither horses nor men can walk on it'. Rainfall has been recorded at Saxmundham for many years but no other weather data until 1965 when we installed instruments to measure temperature, wind, radiation and evaporation with the hope of assessing more precisely the effects of weather on yields.

Oldershaw (1941) and Trist and Boyd (1966) described the drainage of the field and the method of working the plots in 'stetches', with furrows between to remove surface water. A major difficulty with shallow ploughing was that heavy rain was not absorbed quickly enough; the frequent surface run-off washed soil down the field; soil analyses showed that richer soil from some plots must often have washed diagonally across the

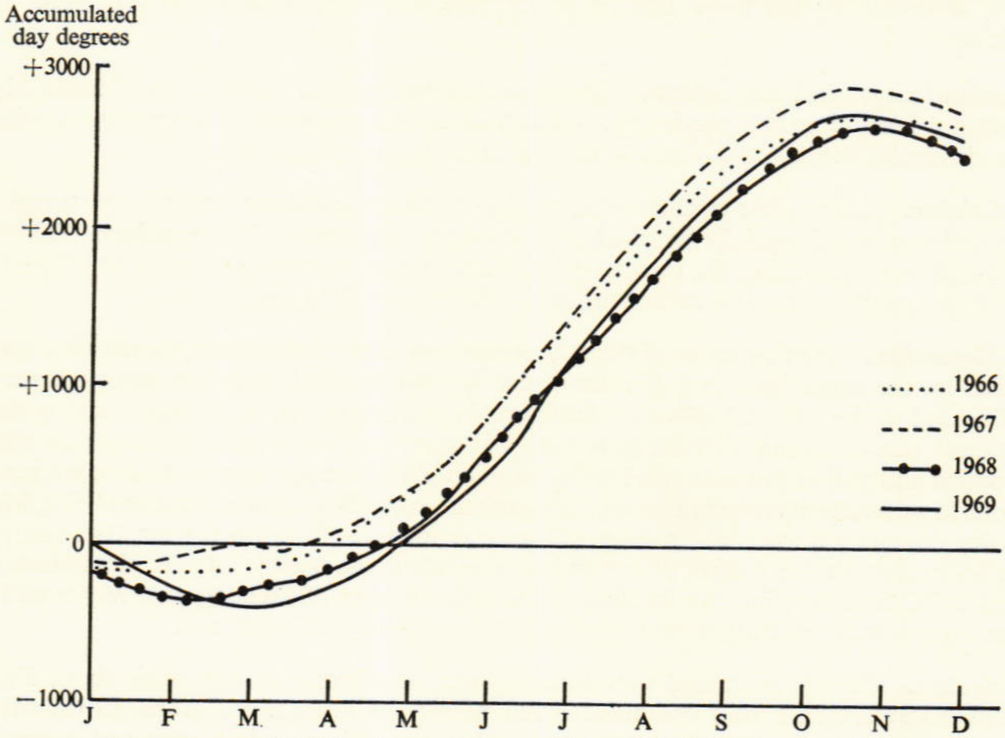

Fig. 5. Accumulated day degrees at Saxmundham for individual years, 1966–69.

field to contaminate the upper parts of other plots. (After these enriched areas had been recognised they were always discarded at harvest.) To get better drainage, the whole field was mole-drained during autumn 1964, and was then ploughed 10–12 inches deep. Ploughing since has been about 10 inches deep. These measures improved drainage and penetration of rain, and water now rarely stands on the surface except in wheel tracks; surface run-off and erosion have stopped. But the deeper ploughing has introduced other problems. It has often been difficult to get a good seedbed for wheat because the deep furrow slices could not be broken up, especially in dry autumns such as 1969. Because the soil does not readily weather (except on the surface) to give good and deep structure (a major difference from Rothamsted soil), spring seedbeds have often been unsatisfactory, with fine material overlying the massive clods formed by ploughing the previous autumn. Sometimes clods seem to remain unchanged for two or more years; ploughing simply turns them over. These cloddy conditions below the surface no doubt aid drainage during wet summers but they must interfere seriously with the supply of water and nutrients during dry weather.

Temperature. Temperatures in individual seasons are conveniently summarised by showing accumulated daily temperatures above or below 42°F (below which there is very little crop growth). 'Growing Degree Days' (=GDD) (sometimes called 'Heat Units') can be read from tables (Meteorological Office, 1965) or calculated from GDD $= \Sigma(\bar{T} - T_b)$ ($\bar{T}$ is average daily means of maximum and minimum temperatures; T_b is the base temperature selected). In the early part of the year GDD are negative and the time when they become positive is a measure of the earliness of the season; the size of negative values indicates the severity of late winter. Figure 5 gives values for 1966 to 1969. The dates when GDD have exceeded zero have ranged at Saxmundham from late March (1967) to the beginning of May (1969). The two earliest and warmest years were 1966 and 1967; 1968 was a late season and much cooler than the other years. In spite of this, all crops yielded more in 1968 than in the other years (Table 7); beans were 8 cwt/acre, wheat 12 cwt/acre, barley 7 cwt/acre and beet 2 tons/acre more than the average. This remarkably consistent result cannot have been caused by favourable temperatures. 1968 was most unusual in that the *average* wheat yield in Rotation I experiment (42 cwt) almost equalled the *best* yield (43 cwt) in the Rothamsted Ley Arable Experiments (*Rothamsted Report for 1968*, Part 1, 250–252); in other years Rothamsted yields have been nearly twice those at Saxmundham.

Rainfall. Tables 12 and 13 summarise annual rainfall at Saxmundham over the last 40 years. 1965, 1966, 1968 and 1969 were all wetter than average. 1964 was very dry (6 inches less rain than average); yields of wheat and barley were close to average, only sugar beet being checked by drought (Table 2). This seems to illustrate dry weather favouring Saxmundham cereals when the soil was shallowly cultivated. 1967 was also drier than average; in the classical tests wheat yielded more and barley less than average, beet about average (Table 2). In the 'new' experiment (Table 7) beans, wheat, and beet yielded near to average for the four years, and barley less. (Barley yields in Rotation II experiment seem to depend much less on weather than those in Rotation I experiment. Mattingly, Johnston and Chater (*Rothamsted Report for 1969*, Part 2, 91–112) report that the *best* yields in Rotation II experiment between 1965 and 1970 varied only between 34·3 and 37·4 cwt/acre.)

In 1969, 43% of the total year's rain fell in May to August (the average is about 33%). Yields of wheat, barley, and beans were all much less than average, but beet yields were

TABLE 12

Annual rainfall at Saxmundham 1930–69 (inches)

Year	Total annual rainfall	Mean monthly rainfall	Percentage of annual rainfall Jan–Apr	May–Aug	Sept–Dec
1930	30·32	2·53	18·8	40·9	40·4
1931	24·65	2·05	35·0	38·8	26·2
1932	23·33	1·94	28·0	40·9	31·1
1933	21·21	1·77	23·8	28·3	47·9
1934	21·29	1·77	29·8	29·9	40·4
1935	27·46	2·29	26·2	27·8	46·0
1936	27·63	2·30	30·7	29·9	39·4
1937	19·02	2·42	43·7	24·9	31·4
1938	19·60	1·63	21·5	28·6	49·9
1939	34·61	2·88	32·0	21·3	46·7
Mean	25·91	2·16	28·9	31·1	39·9
1940	23·02	1·92	35·7	19·7	44·6
1941	23·26	1·94	40·2	37·4	22·4
1942	25·26	2·10	27·0	24·3	48·7
1943	19·45	1·62	30·4	27·1	42·4
1944	22·87	1·91	23·7	23·3	53·0
1945	20·25	1·69	27·7	38·6	33·7
1946	29·65	2·47	21·0	43·5	35·5
1947	19·29	1·61	39·7	29·9	30·4
1948	22·00	1·83	27·4	42·1	30·5
1949	18·11	1·51	23·9	27·9	48·2
Mean	22·32	1·86	29·7	31·4	38·9
1950	22·21	1·85	28·7	31·7	39·6
1951	27·69	2·31	49·0	20·9	30·1
1952	27·14	2·26	23·6	29·3	47·1
1953	17·56	1·46	20·8	45·2	40·0
1954	30·71	2·56	21·3	45·4	33·3
1955	25·54	2·13	23·5	38·6	37·9
1956	26·73	2·23	30·1	29·9	40·0
1957	25·44	2·12	26·4	37·3	36·3
1958	31·17	2·60	24·4	46·7	28·9
1959	18·06	1·50	25·5	25·5	49·0
Mean	25·22	2·10	27·3	35·0	37·6
1960	33·82	2·82	22·4	28·5	49·1
1961	24·59	2·05	27·8	26·5	45·7
1962	20·23	1·69	27·3	32·9	39·8
1963	23·52	1·96	32·7	36·5	30·8
1964	18·94	1·58	36·7	39·1	24·2
1965	27·92	2·33	25·7	35·1	39·2
1966	29·22	2·43	24·4	36·7	38·9
1967	23·84	1·99	26·2	31·1	42·7
1968	27·08	2·26	26·0	34·2	39·8
1969	27·58	2·30	30·5	43·3	26·2
Mean	25·67	2·14	28·0	34·4	37·6
1930–69 range	17·56–34·61	1·46–2·88	18·8–49·0	19·7–46·7	22·4–53·0
1930–69 mean	24·78	2·07	28·5	33·0	38·5

a little larger. Presumably weather affects yields of cereals and root crops differently. (There has been no difficulty in growing nearly 20 tons/acre of sugar beet and potatoes (much more than national averages) in the modified Rotation II experiment.)

Table 14 shows monthly rainfall. The good year, 1968, was drier than average in March, April and May, but then rainfall was close to average until August. The disas-

TABLE 13

Monthly rainfall Saxmundham 1930–69 (inches)

Years		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept.	Oct.	Nov	Dec
1930–39	Range	0·52–5·38	0·32–3·71	0·30–2·85	0·70–3·62	0·34–3·56	0·04–2·76	1·01–4·42	0·40–4·73	1·28–5·86	0·75–8·35	0·95–4·67	0·70–3·81
	Mean	2·30	1·78	1·33	2·18	2·09	1·44	2·56	1·90	2·93	2·73	2·78	1·89
1940–49	Range	0·98–4·10	0·41–2·93	0·31–3·50	0·70–1·78	0·12–2·28	0·41–3·59	0·85–4·31	0·54–4·49	0·24–2·96	0·49–4·30	0·98–5·22	1·15–3·43
	Mean	2·33	1·38	1·62	1·22	1·34	1·66	2·01	2·06	1·75	2·19	2·62	2·11
1950–59	Range	0·42–5·13	0·20–3·76	0·00–3·61	0·10–4·19	0·20–2·90	0·30–3·58	0·84–2·72	1·75–5·63	0·00–3·14	0·72–5·87	0·50–4·71	1·00–3·48
	Mean	2·15	2·04	1·37	1·39	1·63	2·20	1·92	3·16	1·95	2·46	2·79	2·16
1960–69	Range	0·65–3·52	0·64–2·87	0·71–3·19	0·94–3·72	0·44–3·61	0·30–3·65	0·85–4·54	1·20–3·49	0·06–5·44	0·28–7·57	0·91–3·91	0·67–3·39
	Mean	2·02	1·51	1·62	1·90	1·86	1·74	2·56	2·63	2·34	2·55	2·64	2·29
1930–69	Range	0·42–5·38	0·20–3·76	0·00–3·61	0·10–4·19	0·12–3·61	0·04–3·65	0·84–4·54	0·40–5·63	0·00–5·86	0·28–8·35	0·50–5·22	0·67–3·81
	Mean	2·20	1·68	1·49	1·67	1·73	1·76	2·26	2·44	2·24	2·48	2·71	2·11

TABLE 14

Saxmundham rainfall (1964–69)

inches (5 inch gauge)

Month	1964	1965	1966	1967	1968	1969
January	0·65	1·83	2·30	1·62	2·50	1·95
February	0·90	1·00	2·06	1·54	2·37	2·87
March	3·19	1·87	0·71	0·83	1·11	2·18
April	2·22	2·47	2·07	2·26	1·05	1·40
May	1·10	1·57	1·64	2·76	1·66	3·61
June	3·65	2·23	2·56	0·75	2·21	1·53
July	1·45	3·05	3·32	1·08	2·52	3·91
August	1·20	2·96	3·20	2·83	2·87	2·89
September	0·29	5·06	0·51	2·83	5·44	0·06
October	2·08	0·37	4·31	2·85	1·99	0·28
November	0·91	2·12	3·39	2·85	1·60	3·91
December	1·30	3·39	3·15	1·64	1·76	2·99
Total	18·94	27·92	29·22	23·84	27·08	27·58
Mean	1·58	2·33	2·43	1·99	2·26	2·30

trously wet September came too late to affect yields but may have caused the land to be consolidated when ploughed during autumn, so laying the foundation for poor crops of cereals and beans in 1969. In 1969 there was also nearly double the average rain in both May and July; August was also wet. These conditions seem to have injured cereals and benefited beet.

A wet August in 1965 was followed by double the average rain in September; this wet period may have damaged soil structure so that the yields of following beans, wheat and beet in 1966 were much less than average, as happened for cereals and beans in 1968–69. By contrast, 1967 (with near average yields (except for barley)) did not have extreme rainfall in any month; March, June and July were dry and the autumn had near to average rainfall, which seemed a good preparation for satisfactory yields in 1968.

These general comments do not show how temperature and rainfall affect crops yields. Interactions of rainfall and soil structure are undoubtedly important but have not been defined. A moderately dry autumn that permits satisfactory ploughing seems important, as is a spring that permits satisfactory seedbeds to be prepared. We have already commented on the difficulties of using N-fertiliser efficiently at Saxmundham. 1968 was singular, for there was no heavy rainfall during spring to leach early dressings, and later rain was enough for May top-dressings to be used efficiently. Probably intensity and distribution of rain in spring are as important as total amount, and their effect on leaching has been discussed (Williams, 1971).

Seasonal variations in nitrogen in cereals. Nitrogen contents of cereals are important in assessing quality; they have differed considerably during the four years with the new treatments. Average values for crops on all treatments were:

	%N in dry matter			
	Wheat		Barley	
	Grain	Straw	Grain	Straw
1966	1·65	0·42	1·50	0·48
1967	1·62	0·23	1·80	0·49
1968	1·79	0·45	1·58	0·61
1969	1·80	0·46	1·40	0·46

The two crops were affected differently by season. When per cent protein was largest in barley in 1967 it was least in wheat; the converse was true in 1969.

Future work

The experiments at Saxmundham have given excellent opportunities for extending work on P and K to soils with very different characteristics from those at Rothamsted; we have made good progress with valuing phosphate residues in Rotation II experiment and with measuring potassium release in Rotation I. Long-term experiments on the two farms also measure the productivity of the two soils. Some comparisons are in Table 15. By increasing nitrogen fertiliser and testing amounts of N, P and K fertiliser, the crops grown in Rotation I during the last three years were not limited by nutritional deficiencies easily remedied by fertilisers. Except in 1968, cereals and beans grown with our best manuring have yielded much less than crops at Rothamsted; wheat in 1966 and barley in 1967, yielded no more than national averages (Table 15). Cereal yields at Woburn also exceeded those at Saxmundham except in 1968. No crop of wheat or barley at Saxmundham yielded nearly as much as the largest amounts usually harvested at Rotham-

SAXMUNDHAM ROTATION I EXPERIMENT, 1964–69

TABLE 15

Comparisons of yields obtained at Saxmundham, Rothamsted, Woburn and nationally

		National average yields	Best yields			
			Saxmundham		Rothamsted	Woburn
Wheat (cwt of grain)	1966	32·4	32·2		58	43
	1967	30·6	45·3		66	53
	1968	33·3	48·4		40	34
	1969	28·2	35·1		66	44
Barley (cwt of grain)	1966	29·9	34·2		55	51
	1967	29·8	26·4		56	46
	1968	30·1	42·6		39	33
	1969	27·4	30·5		49	41
			R I	R II		
Sugar beet (tons of roots)	1966	14·9	13·5	—	20·8	23·3
	1967	14·6	19·2	19·6	21·1	18·1
	1968	14·9	19·7	—	22·1	19·9
	1969	15·2	18·5	21·2	19·3	16·7
Potatoes (tons of tubers)	1966	10·6	—	20·5	21·4	13·5
	1967	10·2	—	—	22·5	10·6
	1968	10·5	—	—	16·4	13·7
	1969	10·1	—	19·2	17·0	17·2
Beans (spring) (cwt of grain)	1966	—	24·3		31	—
	1967	—	23·2		30	—
	1968	—	30·5		21	—
	1969	—	17·8		25	—
Lucerne (cwt of dry matter)	1968	46 (hay)	113·4 (2nd year)		85·4	—
	1969	—	109 (3rd year)		34·1	—
Temporary grass (cwt of dry matter)	1968	37 (hay)	136 (2nd year)		100·1	104
	1969	37 (hay)	119 (3rd year)		64·2	72

sted during the last ten years; besides being small, cereal yields at Saxmundham also varied widely—as they do at Woburn.

Sugar beet growth in 1966 was checked by a bad seedbed prepared from wet soil, and by waterlogging during summer; yield was less than the national average. In the other three years, beet yielded well, nearly as much as at Rothamsted, and in two years better than at Woburn. Potatoes yielded as well at Saxmundham in 1966 and 1969 as at Rothamsted, and much better than at Woburn. Table 15 shows best yields from the second and third years (1968 and 1969) of lucerne and temporary grass leys and compares them with best yields of corresponding crops on the other farms. Saxmundham yields were much larger, especially in 1969.

These differences between the performance of crops show how difficult it is to develop 'soil productivity ratings' or land use classifications. Cereals are usually rated as easy crops to grow well and roots as difficult; the reverse seems true at Saxmundham. Herbage crops also yielded well in old experiments. Oldershaw (1941) concluded his account of the arable crop experiments by pointing out that Saxmundham land is very similar to an enormous area of boulder clay in various parts of England which was difficult to cultivate; much had gone derelict and become covered with thorn bushes between 1920 and 1940. He said the land was especially suitable for herbage crops. 'Red clover has given as heavy crops as on really good land, . . . tares and lucerne have proved very productive . . . temporary leys have given heavier crops than are often obtained from rich old meadow land'. He recommended temporary leys for hay, silage or seed, followed by a few years of arable cropping.

After 1969 harvest, when both wheat and barley that were well-fertilised and free from root disease yielded badly for reasons we could not identify, we decided to put the experiment under herbage crops. The plots were split across the middle, the upper half was sown with lucerne, the lower half with a mixture of grasses that will receive much N fertiliser. The classical manuring will continue on the sub-plots which were also sown with grass. There are two purposes. We hope that several years of herbage crops will improve soil condition so that, after ploughing, good cereals may be grown. The large yields of herbage crops we hope to obtain will remove much more P and K from the soil than would mediocre cereals; this change will therefore speed work on release of potassium and on the solubility relationships of soil phosphate at Saxmundham.

Summary

1. An experiment using a four-course rotation of legume, wheat, roots and barley was made on calcareous boulder clay in East Suffolk. The crops received factorial combinations of N, P and K annually from 1900 to 1965. 35 lb of N, 16 lb of P and 47 lb of K/acre were tested, and extra plots had 4 cwt/acre of bone meal and 6 tons/acre of FYM. These treatments were maintained on small areas from 1965 until 1969. Beans, wheat, sugar beet and barley were grown on one block each year. Yields in 1964–69 were comparable to averages of those before 1960; the 1964–69 crops were analysed to construct an annual nutrient balance relevant to the whole period of the experiment.

2. From 1966 to 1969 new treatments were superimposed on six-sevenths of the area of the old plots; only the test of bone meal was unchanged. Two amounts of N were given, some as late top-dressings in 1967–69. Where P had not been applied before 1965, 39 lb P/acre was given; the old P dressing continued on other plots. Potassium was increased on treated plots to 93 lb K/acre. The FYM dressing was increased to 12 tons, and these plots were also given 56 lb/acre of N.

3. Responses by wheat and barley to N have steadily increased from 1900 to 1969. Phosphate fertilising has always been essential for all crops but recent responses are smaller than earlier ones. Wheat, barley and beans, but not sugar beet, have always given *small* responses to K-fertiliser; in 1964–69 responses were less than previously. The capacity of the soil to release potassium seems not to be diminishing, despite the larger crops now grown.

4. During a four-year cycle the crops have obtained the following amounts of N, P and K from plots not given these as fertilisers: about 200 lb of N (half was fixed by the beans), about 20 lb of P and 160 lb of K/acre (sugar beet removed most K). Phosphorus and potassium removed during 70 years is equivalent to 175 ppm P and 0·14% K in the top soil.

5. Wheat has yielded similarly during each period with the FYM and with the full fertiliser dressing; beans, barley and sugar beet have yielded more with FYM (+N in the last period) than with NPK fertiliser.

6. In the modified experiment, 39 lb P/acre given where P was not given before 1965 gave nearly as large yields as did plots that had always received about half as much. 93 lb K/acre increased yields of wheat and beans but not of barley or sugar beet.

7. At least 100 lb N/acre applied in late March or early April was needed by wheat, barley and beet. These crops benefited from 56 lb N/acre applied as top-dressings in the

summers of 1967 and 1969, when rain during April/May leached out much nitrate. There was no gain from top-dressing in 1968 with smaller spring rainfall.

8. During the recent period, 12 tons/acre of FYM has supplied more N, P and K than crops removed. About 7 lb P/acre is accumulating annually from the small dressing of P fertiliser and nearly 30 lb P/acre from the large one. K-treated plots receive 20–40 lb K/acre more than crops remove.

9. Soil P soluble in sodium bicarbonate and exchangeable K were linearly-related to the balance of losses (in crops) and gains (from fertiliser). If losses exactly balanced gains, the soils would contain 10 ppm of P soluble in 0·5*M* $NaHCO_3$ and 150 ppm of exchangeable K.

10. With the new treatments, 50–60 lb Ca/acre/year were removed by sugar beet, 20 lb by beans, and 6 lb by cereals. Sugar beet removed 20 lb Mg/acre/year, beans and cereals about 4 lb. Uptake of sodium was increased by giving nitrogen and phosphorus and diminished by giving potassium. Sugar beet removed up to 98 lb Na/acre/year, beans about 10 lb and cereals 1 lb or less.

11. Seasonal differences in yields seem not to be related to differences in air temperatures. Poor yields seem to be associated with: (1) rain during autumn enough to interfere with ploughing and lead to poor soil conditions; (2) rain during spring that leaches much nitrate. Good yields were in years when autumn ploughing and seedbed preparation were done well and when spring and early summer rain was less than usual.

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APPENDIX

Methods of analysis used for crops and soils

Crops

Nitrogen by Kjeldahl digestion using $CuSO_4$ and K_2SO_4 as catalysts and determination by 'Technicon AutoAnalyzer' using Varley's (1966) method modified by adding citrate–tartrate buffer.

Nitrate in fresh plant material by the method of Williams (1969).

Phosphorus by dry ashing with magnesium acetate, solution in dilute HCl, and determination by 'Technicon AutoAnalyzer' using the method of Fogg and Wilkinson (1958).

Potassium by dry ashing and solution in dilute HCl and determination by 'E.E.L.' flame photometer.

Calcium, magnesium and sodium by dry ashing and solution in dilute HCl and determination of Ca and Na by emission spectrophotometry (Salt, 1967), Mg by atomic absorption, with strontium as releasing agent (Elwell & Gidley, 1961), using a 'Unicam' SP.900 flame spectrophotometer.

Soils

Total nitrogen by Kjeldahl digestion with Cu and Se catalysts (Bremner, 1960).

Organic carbon by the method of Walkley (1935).

Total phosphorus by fusion with sodium carbonate (Mattingly, 1970) and determination by 'Technicon AutoAnalyzer' using the method of Murphy and Riley (1962) with a neutralisation step.

Sodium bicarbonate-soluble P by extraction using the method of Olsen *et al.* (1954) and determination by 'Technicon AutoAnalyzer' using the method of Murphy and Riley (1962) with a neutralisation step.

0·01M $CaCl_2$-P. Extraction by the method of Schofield (1955) and determination with a 'Technicon AutoAnalyzer' using the method of Murphy and Riley (1962).

0·01M $CaCl_2$-K. Extraction by the method of Schofield (1955) and determination by 'E.E.L.' flame photometer.

Exchangeable magnesium and potassium extracted by the semi-micro method of Metson (1956); K by emission spectrophotometry; Mg by atomic absorption using a 'Unicam' SP.900 flame spectrophotometer.

Calcium carbonate by the manometric method of Williams (1948).

pH on a 1 : 2·5 soil : water ratio, using a glass electrode.

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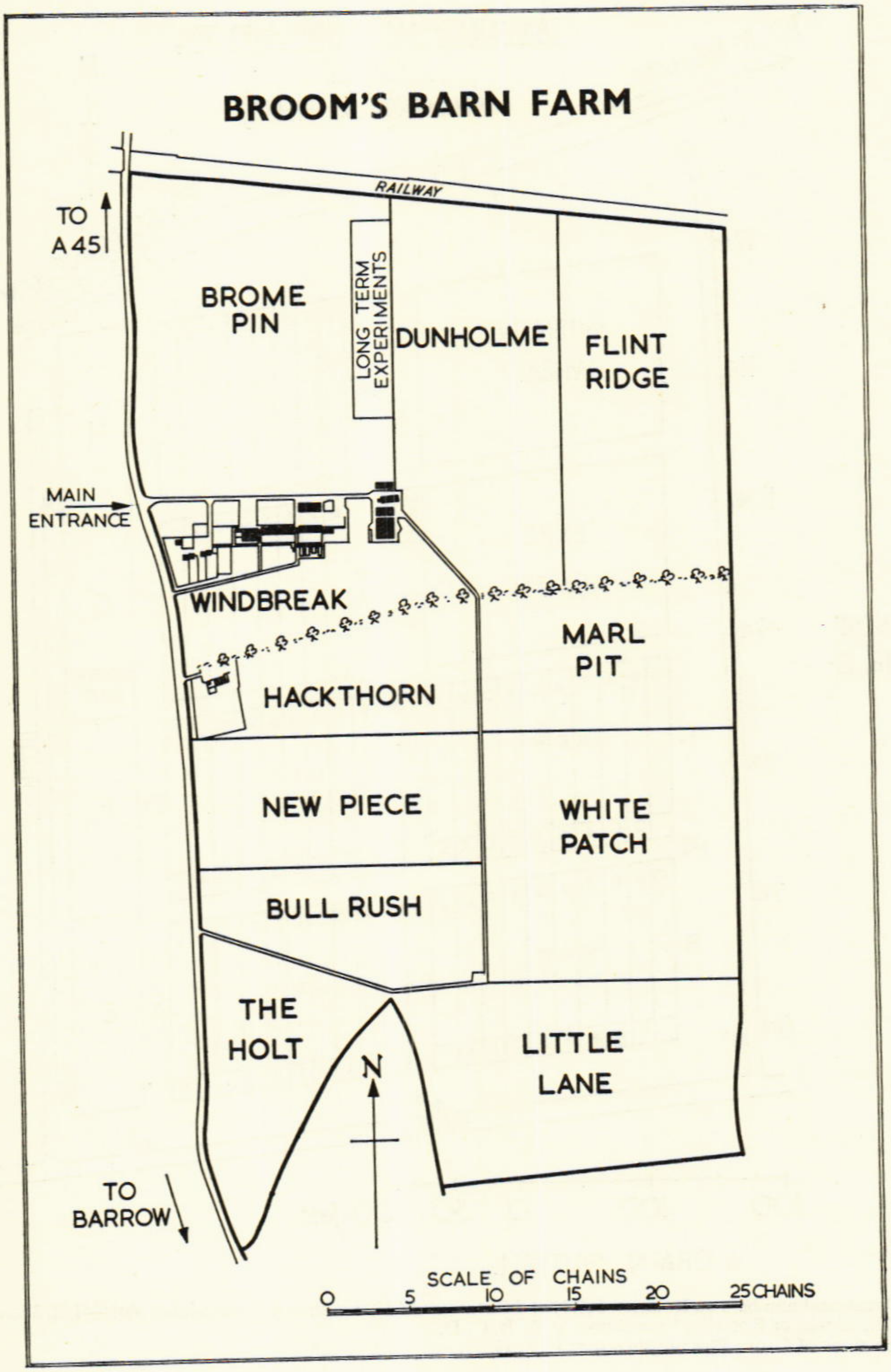
Plan of Saxmundham

A plan of Saxmundham showing the position of the Rotation I experiment is at the end of the volume.


BROOM'S BARN FARM
RAILWAY
TO A45
BROME PIN
LONG TERM EXPERIMENTS
DUNHOLME
FLINT RIDGE
MAIN ENTRANCE
WINDBREAK
MARL PIT
HACKTHORN
NEW PIECE
WHITE PATCH
BULL RUSH
THE HOLT
LITTLE LANE
N
TO BARROW
SCALE OF CHAINS
0
5
10
15
20
25 CHAINS