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Results of an experiment at Rothamsted testing farmyard manure and N, P and K fertilizers on five arable crops

I. Yields

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Experiments with very small plots are often used to show advisory officers and farmers the effects of fertilizers on crops, and also to measure the amounts of nutrients taken up. Blood (1957) described a permanent 'reference plot' experiment of this type and showed how the results were used to improve advice on liming and manuring agricultural and horticultural crops. Cooke (1962) suggested that such rotation experiments are useful for assessing the productivity of individual soil types. The experiment described here measured the effects of farmyard manure (FYM) and N, P and K fertilizers on the yield and chemical composition of five arable crops grown in rotation on very small plots. It had the secondary purpose of seeing whether rotation experiments with farm crops could be done accurately in this way. Williams, Stojkowska, Cooke & Widdowson (1960) measured the Cu, Mn, Mo and Zn contents of the five arable crops grown in 1956. This paper reports yields from 1956 to 1960; uptakes of N, P and K by the crops for this period are reported in part II.

NATURE OF THE EXPERIMENT

The experiment was started in March 1956 in Great Field IV, which had been under permanent grass for very many years. The soil is clay-loam (Batcombe series) over Clay-with-Flints. After the experiment was marked out, turf was removed from the five strips needed for the crops. Analyses showed that the soil was very uniform; it was acid (pH 5·5), contained very little P or K soluble in dilute HCl, but total N was large (0·26 %) although the turf had been removed. 30 cwt./acre of hydrated lime was broadcast before, and again after ploughing to bring the final pH (in water) to 6·5. The five ploughed strips were separated by grass paths; each strip grew one of the five arable crops in rotation. The sequence was: winter wheat, kale, barley (under-sown), grass-clover ley, and potatoes. Each strip was divided into twelve plots (each 7 ft. wide and 8 ft. long (0·00128 acre)), with guard plots at each end. Two levels (0 *v.* 1) of N, P and K were tested in the standard 8 plot factorial layout; a double dose of N (N_2) was tested in addition (in the presence of PK). FYM (D) was tested without fertilizer and also with full fertilizer treatments supplying single and double rates of N (DN_1PK and DN_2PK). Treatments and crops were allocated at random to five rows of a particular 12×12 Latin square. From 1957 the same fertilizer and FYM treatments were tested on an adjacent strip of the original permanent grass; it was not limed.

Since soil movement from plot to plot soon limits the value of yields taken from small plots, concrete blocks were used to divide the strips and to contain the soil and plant roots within each plot. The blocks were 7 ft. long, 9 in. deep and 2 in. wide; they were buried so that their tops were just above the soil level. In 1957 and 1958 almost all the clover plants grown without K died, but those within a few inches of the concrete blocks between plots grew well. The concrete contained dilute acid-soluble K which the clover presumably used. Afterwards the blocks were sealed with bitumen paint and this effect stopped.

Rates of manuring

The same P and K rates were used on all crops: 0·5 cwt. P_2O_5/acre (as superphosphate) and 1·0 cwt. K_2O/acre (as sulphate of potash). Rates of N (applied as 'Nitro-Chalk' with 15·5 % N) differed with crop and were (cwt. N/acre):

	Wheat	Kale	Barley	Grass-clover ley	Potatoes	Permanent grass
N_1	0·6	1·0	0·45	0·15	0·6	1·0
N_2	1·2	2·0	0·90	0·30	1·2	2·0

In 1956 and in 1957, FYM (15 tons/acre) was applied to appropriate plots for every crop. On these plots wheat soon lodged and barley was badly lodged, and the clover ley rotted. In 1958, therefore, FYM was omitted for the ley and in 1959 and 1960

for the wheat and barley. From 1959 FYM was applied only for potatoes and kale but the dressing was raised to 20 tons/acre. Permanent grass however received 15 tons/acre of FYM annually.

Experimental method

The strips were ploughed in March 1956, FYM was then spread on appropriate plots and dug in by hand. Other plots were not dug, so that in 1956 FYM plots had an extra digging. In subsequent years, FYM was applied in autumn and the arable strips were hand dug to limit soil movement between plots. P and K were broadcast for winter wheat before sowing but the N was applied in spring (half in March and half in May). For the other arable crops N, P and K were broadcast over the digging and worked in by rotary cultivator before sowing. Permanent grass received three-quarters of the N and all the P and K in spring, the remaining N was given for the second cut. After preparing seedbeds, a small hand-drill was used to sow wheat and barley in rows 7 in. apart and kale in rows 22 in. apart. Grass and clover seeds were broadcast immediately after the barley had been drilled. The plots were then raked and rolled to cover the seed. The potatoes were hand planted. Usually the whole plot area of each crop was harvested, and the produce weighed and sampled for analysis. Grass and kale were cut with a self-propelled motor scythe; wheat and barley were cut with sickles and threshed in a small machine. Potatoes were hand dug. There were two cuts of permanent grass and usually three or four of grass-clover ley each year.

The varieties grown were: wheat, Koga II in 1956, Cappelle in 1957–60; barley, Proctor; kale, Thousand-head; 1 year ley, Giant Hybrid Cow-grass in 1956–58 and a mixture of Broad Red Clover (S. 151) and Italian Ryegrass (S. 22) in 1959–60; potatoes, King Edward.

RESULTS OF THE EXPERIMENT

Effects of fertilizers and FYM

The Appendix Table shows yields from the first 5 years of the arable rotation (1956–60) and the first 4 years of the permanent grass (1957–60). Both FYM and NPK fertilizers greatly increased yields. The heaviest manuring increased wheat yields by half, barley and ley yields were doubled, kale yields were nearly trebled, and potato yields were increased sixfold. Winter wheat yielded most, and potatoes least dry matter when no manures were given. When FYM plus fertilizers were used winter wheat still yielded most dry matter although it responded much less proportionally to extra nutrients than did potatoes which were the most responsive crop. Maximum yields of barley, potatoes, kale and permanent grass had probably not been reached with the heaviest manuring used (DN_2PK). Wheat and ley, however, both yielded less with DN_2PK than with DN_1PK; but some combination of FYM and NPK fertilizer always gave the highest yield of all crops. Boyd (1961) showed that the interactions between the nutrients in FYM and in fertilizers are often large when heavy manuring is given.

Table 1 shows mean responses to N, P and K and the gains from doubling the N (i.e. N_2PK-N_1PK); the effects of each nutrient were measured in the presence of the other two. Responses to individual nutrients differed with crops. The first level of N increased yields of all crops except the 1 year ley. Kale and permanent grass responded well to the second dose of N (N_2-N_1); this dressing increased barley and potato yields but to a smaller extent and the wheat yielded less with N_2 than with N_1. The double dose of N increased yields of kale and potatoes when FYM was also given but yields of all other crops were lower with DN_2PK than with DN_1PK. Kale yields were increased most by P but the other crops also responded to this nutrient. All crops responded well to K, but potatoes, ley and wheat needed K most and yields were very low when no K was given. Barley was the only arable crop which gave regular and similarly-sized responses to N, P and K. Permanent grass responded well to N and K, but not to P.

Comparisons between the responsiveness of arable crops

Table 2 compares the responsiveness of the crops to fertilizers by expressing the response to each nutrient, obtained in the presence of the other two, as a percentage (for N_1 this implies $\left(\frac{N_1PK\text{-}PK}{PK} \times 100\right)$. Yields of wheat, potatoes and the grass-clover ley were increased much more by K than by the other nutrients; the response by potatoes was outstanding. For kale N was the most important nutrient, and P was more important than K; barley used all three nutrients similarly. Permanent grass responded to N and K, but not to P.

Main effects and interactions of fertilizers

Table 3 shows main effects of N, P and K from the 5-year yields of the five arable crops. The formal main effects of N, P and K and the responses shown in Table 1 show similar trends. Kale and barley responded significantly to N, all crops responded significantly to P and all except kale to K. There were large and significant positive interactions from NK on wheat and from PK on potatoes. Other positive, though not significant interactions, which were larger than their standard errors were with NK for kale and potatoes, with PK on wheat and clover and with NPK on wheat, barley and potatoes.

Table 1. *Responses to N, P and K fertilizers (means for 1956–60 for arable crops and for 1957–60 for permanent grass)*

Plots compared	Yields without fertilizer or FYM	Increases in the yield of dry matter (cwt./acre) from N_1 (N_1PK-PK)	N_2-N_1 (N_2PK-N_1PK)	N_2-N_1 (in presence of D) (DN_2PK-DN_1PK)	P (N_1PK-N_1K)	K (N_1PK-N_1P)
Wheat grain	28·6	5·3	−3·5	−0·7	3·1	12·6
Wheat straw	37·0	4·8	1·2	−5·5	8·8	18·6
Barley grain	17·7	6·8	4·1	−1·3	6·6	7·8
Barley straw	15·3	5·2	3·0	9·3	5·7	4·9
Potatoes	14·7	7·7	4·8	7·1	13·0	35·7
Kale	37·8	25·8	11·0	17·5	16·3	9·0
Ley	42·8	−1·9	0·4	−2·4	10·4	29·0
Permanent grass	47·8	8·6	13·4	16·5	−6·6	7·3

NPK interactions were always positive; but the NP interaction was negative for wheat, potatoes and the ley.

Response to farmyard manure

Table 4 shows responses to FYM both without fertilizers and with N_1PK and N_2PK dressings. FYM greatly increased yields of all crops when no fertilizer was given, but the crops responded less when fertilizers were used. Potatoes benefited most from FYM, which quadrupled yields. Wheat, barley and the grass-clover ley also responded well, but kale benefited less, perhaps because the FYM contained too little available N. When N_1PK and N_2PK were also given potatoes still responded most to FYM, no doubt because this crop badly needed the extra K supplied by the FYM; yields of kale and permanent grass were also increased. Wheat, barley and the ley responded much less to FYM when N_1PK or N_2PK were also applied.

Effect of fertilizers on the size of barley grain

Table 5 shows how the grain size of barley grown in 1958 was affected by treatment. Nitrogen depressed and K increased the percentage of large grains, P had little effect. Plots treated with PK and FYM alone gave samples containing the most large grains. The most small grains came from plots having N_1 or N_1P. Yields of first quality grain were much affected by fertilizer treatment; the treatments that gave more than 1 ton/acre were, in increasing order, PK, DN_1PK, D, N_1PK and N_2PK.

Growth of the crops and nutrient deficiency symptoms

Low available K in this soil severely limited potato yields; unless potash was given the leaves of potatoes showed typical K-deficiency symptoms and the plants usually died by late July. Potatoes on other plots grew normally and the tops lasted until late September. Potato blight was prevalent in 1958 and in 1960, but spraying limited damage. Each year slugs severely damaged the potato tubers; damage was greatest when a dry summer followed a wet one, perhaps because in wet summers the preceding grass-clover ley had a high slug population. After digging the ley the slugs were well placed to overwinter and to eat the potatoes in the following summer.

Table 2. *Relative responsiveness of arable crops and grass to each nutrient tested in the presence of other nutrients*

	Percentage increases in dry matter produced: From N	From P	From K
Wheat grain	15	8	45
Wheat straw	9	17	46
Barley grain	29	28	34
Barley straw	22	25	21
Potatoes	17	34	222
Kale	60	31	15
Ley	(Neg.)	15	60
Permanent Grass	14	(Neg.)	12

Winter wheat, sown after the potatoes had been harvested, was attacked by slugs in each autumn, despite frequent dressings with metaldehyde bait. The wheat grew best in autumn on plots dressed with superphosphate or FYM; but in May and June it only grew well on plots receiving K, either in fertilizers or in FYM (or both); at harvest wheat on plots with N, P, and NP treatment had weak and short straw which ripened slowly and became lodged.

Kale responded dramatically to P when the seedlings were small and many plants died on plots where no phosphate was given, but by July plants growing without P fertilizer had improved, presumably because they then had a larger root system which could better use soil P. Nitrogen then gave most benefit and by August the leaves of kale grown without N fertilizer had the red and yellow colours typical of N deficiency.

During dry weather in April barley grown without K as fertilizer or FYM became yellow, then the leaf tips and margins became white and later were

Table 3. *Main effects and interactions of N, P and K fertilizers on arable crops grown in 1956–60*

	Dry matter (cwt./acre)							
	N	P	K	NP	NK	PK	NPK	S.E.
Wheat†	3·7	6·9**	20·2**	−1·6	4·4*	3·0	3·6	1·94
Barley†	7·3**	8·0**	8·2**	0·8	1·1	0·6	2·7	2·09
Potatoes	3·3	5·4**	25·4**	−0·6	2·0	5·3**	2·9	1·70
Kale	16·9**	10·8**	0·8	2·0	4·7	1·4	2·3	2·67
Ley	−0·1	6·1**	27·1**	−0·4	−2·8	3·2	1·6	1·68

† Yields of wheat and barley were of grain plus straw.

Table 4. *Mean increases in yield (cwt. of dry matter/acre) from farmyard manure tested with and without NPK fertilizers in 1956–60*

		With NPK fertilizer	
Plots compared	Without NPK fertilizer D-O	N at low rate DN_1PK-N_1PK	N at high rate DN_2PK-N_2PK
Wheat grain	10·9	−0·4	2·4
Wheat straw	22·8	7·8	1·1
Barley grain	14·0	4·2	−1·2
Barley straw	17·8	4·5	10·8
Potatoes	50·7	26·4	28·7
Kale	22·1	13·6	20·1
Ley	33·2	6·6	3·8
Permanent grass	15·3	11·4	14·5

necrotic; afterwards these K deficiency symptoms disappeared and new leaves grew normally. In May barley without phosphate grew slowly, the leaf sheaths became purple and the leaves yellowed. Later these symptoms were less visible, but at harvest plots without P and K yielded poorly.

The compositions of the 1 year leys varied from plot to plot. Clover seedlings were established under barley on all plots, but the clover leaves were larger and greener on plots with FYM or K fertilizer. After the barley was harvested the leaves of clover without added K or FYM became yellow and then speckled, later there were necrotic spots and much leaf tissue died. Many clover plants died where no K was given and they were replaced by weeds and grasses. From 1958, therefore, one part of Italian ryegrass seed was sown with four parts of Broad Red clover seed to keep the plots free from weed; ryegrass needs K less than clover, and it survived without K manuring and occupied the areas where clover failed. Ryegrass-dominant leys therefore grew on plots without K while clover dominated the leys grown on most other plots. The proportion of grass to clover was also increased by N.

Permanent grass showed few symptoms associated with N, P or K deficiency but the treatments soon changed the composition of the sward. Plots dressed with FYM and/or NPK fertilizers yielded well and soon contained only the tall, high-yielding grasses—cocksfoot, timothy and meadow foxtail. Where FYM was given, sorrel and other weeds were common. Other plots yielded poorly and most of the tall grasses died, these swards were soon composed almost entirely of fine-leaved fescues and meadow grasses. The effects were apparent in two years and seemed complete by 1960. The original sward contained no clover and none had appeared in any of the plots by 1960.

Table 5. *The effects of fertilizers and farmyard manure on the size of barley grain in 1958*

Treatment	Total yield of grain (cwt./acre of dry matter)	Percentage of grain larger than 2·42 mm. (grade 1)	Yield of first grade grain (cwt./acre of dry matter)
0	20·8	53	11·0
N_1	16·8	29	4·9
P	22·2	56	12·4
K	20·7	68	14·1
N_1P	20·9	39	8·2
N_1K	27·4	72	19·7
PK	26·9	84	22·6
N_1PK	36·7	70	25·7
N_2PK	40·0	74	29·6
D*	31·9	80	25·5
DN_1PK*	34·8	72	25·1
DN_2PK†	20·1	63	12·7

* Badly lodged † Severely lodged

DISCUSSION

The experiment shows that small plots can be used to obtain satisfactory results from medium-term rotation experiments provided that all work is done very carefully. This may be useful where land is limited. Normal rotation experiments with

large plots of agricultural crops grown on farm scale usually need large fields of uniform land and the number of treatments tested is often therefore limited. By using small plots elaborate experiments may be done more easily; more information and better experimental control will be obtained than from the same effort used on normal experiments in larger plots occupying much more land. The small plots have not introduced any difficulties simply because of their size.

No other experiment at Rothamsted measures fertilizer responses by arable crops grown in rotation on soil containing so little soluble P and K. The only comparable experiments are the Six Course Rotations at Rothamsted and Woburn described by Yates & Patterson (1958); these were both on soils richer in P and K and the fertilizer tests were not made continuously on the same plots. In the Rothamsted Six Course Experiment only potatoes responded well to P and K, but all crops except clover responded well to N. In the 'reference plot' experiment described here all the arable crops responded to P and K and all except clover ley responded to N. The results give a unique opportunity for comparing quantitatively the responsiveness of several crops grown in rotation on the same land. Unfortunately, the permanent grass occupies unreplicated permanent plots, the results with grass are therefore more liable to error, and the responses of the arable crops and permanent grass cannot be compared.

The experiment illustrates well how crops differ in their needs for N, P and K fertilizers. Kale responded little to K fertilizer, but N and P fertilizers greatly increased yield; on the same soil wheat yielded badly without K (although the two crops contained similar amounts of K) but N had little effect on yield. The reputation of potatoes and clover for needing heavy potash manuring was justified by this experiment; without K potato tops died in July and many clover plants died after the barley had been harvested. Potatoes, kale and barley benefited most from phosphate manuring.

FYM greatly increased yields of all crops, but potatoes benefited more than any other, presumably because they had the most need for extra K. Much more K was applied to plots dressed with FYM than to plots with K fertilizer. Extra fertilizer K is therefore being tested in the second rotation (1961–1965) so that yields from FYM and from NPK fertilizers may be compared.

SUMMARY

1. A 'reference plot' rotation experiment was begun at Rothamsted in 1956 on a field where grass had grown for many years. The soil contained very little HCl-soluble P and K but much N. The soil had been acid, but was limed to pH 6·5 immediately before the experiment started; this pH has been maintained. Very small individual plots (0·00128 acre) were used and nearly all work was done by hand. The results showed that such small plots can be used to do complicated rotation experiments satisfactorily provided that all work is done carefully and movement of soil over plot boundaries is prevented.

2. Responses to combinations of N, P and K fertilizers and farmyard manure (FYM) were measured on wheat, kale, barley, grass-clover ley, and potatoes grown in rotation. Two rates of N were tested. A strip of permanent grass had the same treatments as the arable crops.

3. Winter wheat yielded most dry matter, but wheat yields were increased least, proportionally, by added nutrients. Potatoes gave the smallest yield without manure and responded most to nutrients, yields being increased almost sixfold by NPK fertilizer plus FYM. Kale, barley and grass-clover ley were intermediate in their unmanured yields and in their responses.

4. All crops except the grass-clover ley responded to N; kale responded most and wheat least. Potatoes kale and barley responded roughly equally to P and needed this nutrient more than did wheat and the ley. Potatoes responded most to K, yields of wheat and clover ley were also small without K, but barley and kale needed K less. Interactions between nutrients were large with most crops, particularly with N on kale and K on potatoes, wheat and clover.

5. FYM greatly increased yields of all crops but responses were less when fertilizers were also given. Potatoes responded most to FYM whether or not fertilizers were also used. FYM also caused large increases in yields of grass-clover ley, kale, and permanent grass.

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APPENDIX

Mean yields (cwt./acre of dry matter) from combinations of N, P and K fertilizers and FYM (D) tested on five arable crops from 1956–60 and on permanent grass from 1957–60

	Treatments											
	0	N_1	P	K	N_1P	N_1K	PK	N_1PK	N_2PK	D	DN_1PK	DN_2PK
Wheat grain	28·6	32·0	31·9	34·4	27·9	37·4	35·2	40·5	37·0	39·5	40·1	39·4
Wheat straw	37·0	38·0	42·6	47·5	40·8	50·6	54·6	59·4	60·6	59·8	67·2	61·7
Barley grain	17·7	20·3	22·0	19·7	22·8	24·0	23·8	30·6	34·7	31·7	34·8	33·5
Barley straw	15·3	20·6	20·3	22·5	23·8	23·0	23·5	28·7	31·7	33·1	33·2	42·5
Potatoes (total tubers)	14·7	19·5	18·3	35·8	16·1	38·8	44·1	51·8	56·6	65·4	78·2	85·3
Kale (total produce)	37·8	50·4	47·6	34·9	59·5	52·2	42·7	68·5	79·5	59·9	82·1	99·6
Ley	42·8	47·6	47·7	71·2	48·5	67·1	79·4	77·5	77·9	76·0	84·1	81·7
Permanent grass	47·8	50·2	43·0	46·2	61·1	75·0	59·8	68·4	81·8	63·1	79·8	96·3