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

II. Nutrients removed by crops

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The amounts of N, P and K in the crops grown in the experiment described by Widdowson, Penny & Cooke (1963) in part I of this paper were measured. The amounts of nutrients removed from the soil by each crop, and apparent recoveries from fertilizers and farmyard manure (FYM) are discussed here.

Amounts of nutrients applied

As fertilizers

All crops received 24·5 lb. of P and 93 lb./acre of K each year. Nitrogen dressings per acre differed for different crops; kale and permanent grass were given 112 and 224 lb. N, wheat and potatoes 67 and 134 lb. N, barley 50·5 and 101 lb. N and the clover-grass ley 17 and 34 lb. N.

As farmyard manure

The amounts of FYM given are stated in part I. The *total* amounts of fresh manure per acre used in the 5 years of arable cropping were: 85 tons for potatoes and kale, 45 tons for wheat and barley and 30 tons for the grass-clover ley. Permanent grass received 60 tons/acre over the 4 years discussed here. Table 1 shows the analyses of the FYM samples used in each year, and Table 2 the amounts of nutrients applied by the dressings.

Composition of soil

Chemical analyses describing the soil used are in the Appendix; they are not discussed here.

NUTRIENTS REMOVED FROM THE SOIL

As all the arable crops responded to P and K, and all except clover-grass ley responded to N, the analyses of the crops showed the maximum amounts of each nutrient that each crop could remove from the soil alone. Uptakes from soil were calculated from the contents of crops grown without one fertilizer, but with the other two. Thus N taken from soil was measured in crops given P and K, P uptake in crops receiving NK fertilizers, and K uptakes in crops with NP fertilizers. Table 3 shows the ranges and mean values measured over the years 1956–60 for arable crops and 1957–60 for permanent grass.

Nitrogen

The range in annual values for N uptake was greater with cereals (over 1:2) than with potatoes, kale and grass (about 1:1½). Permanent grass removed most N, about 1 cwt. N/acre each year; as there were (and are) *no* legumes in the sward this quantity must come from mineralization of reserves of soil N, from rain, and possibly by non-symbiotic fixation processes. As there is no reason to believe that simply dresssing grassland with PK fertilizer depletes soil nitrogen reserves, about 1 cwt. N/acre must become available every year from natural sources. Of the arable crops wheat removed most N (nearly 100 lb. N/acre in grain + straw); potatoes and kale both removed 70–80 lb. N, barley took up only about half as much N as wheat. The clover-grass ley

Table 1. *Chemical analyses of farmyard manure*

Cropping year	Dry matter (%)	N (% in dry matter)	P (% in dry matter)	K (% in dry matter)
1956	31·80	2·58	0·38	2·58
1957	25·02	2·40	0·47	3·65
1958	17·10	2·68	0·41	2·95
1959	32·80	2·09	0·56	3·50
1960	21·90	3·20	0·63	5·00

Table 2. *Amounts of nutrients applied by farmyard manure*

Year	Rate of application (tons/acre of fresh manure)	N (lb./acre)	P (lb./acre)	K (lb./acre)
1956	15	275	41	276
1957	15	202	40	307
1958	15	154	24	169
1959	15	230	62	386
	20	307	82	514
1960	15	236	46	368
	20	314	62	491

harvested in the arable rotation contained each year about 2 cwt. N/acre; the uptake by wheat showed that about 100 lb. N could come from mineralization of soil organic matter and other natural sources; the clover must therefore have fixed at least 1 cwt. N/acre/year.

Phosphorus

The range in annual uptake was greatest with cereals and kale (over 1:2) and about 1:1½ with clover-grass ley, potatoes, and permanent grass. The average amount of P removed was most with permanent grass; the 1 year ley, wheat and kale removed similar average amounts of P, potatoes removed least. (In spite of this difference between potatoes and kale, the response to fertilizer P was much greater with kale than with potatoes.)

Potassium

Year-to-year variability in the K removed by all crops was much greater than in N and P. The greatest range (over 1:7) was with wheat; the range with barley and potatoes was about 1:3. On average kale (the whole crop) removed most, and potatoes (tubers only) least K from soil. Permanent grass and the 1 year ley removed similar amounts, wheat removed more K than did barley.

RECOVERY OF NUTRIENTS FROM FERTILIZERS

The recoveries of nutrients applied as fertilizers were calculated by subtracting, for each nutrient, the amount in crops grown without the appropriate fertilizer (but in the presence of the other two fertilizers) from the amount in crops that were fully manured. These differences are called 'apparent' recoveries of fertilizer nutrients because applying a fertilizer may affect uptake of nutrients from soil; thus giving fertilizer P may change the root range so that a different amount of soil P is used. Fertilizer N may affect microbiological release of soil N from reserves and it may, by increasing the total pool of available inorganic N, lessen uptake of soil N by simple dilution. Fertilizer efficiencies, expressed by percentage recoveries of applied nutrients, are therefore approximate.

Nitrogen

Table 4 shows ranges and mean values for the nitrogen apparently recovered from fertilizer applied at the two rates tested (uptakes are derived from the expressions N_1PK-PK and N_2PK-PK). Values for clover-grass ley are not shown as N fixation by clover obscured fertilizer effects).

Table 3. *N, P and K removed from the soil (in lb./acre)*

(The data are for 5 years of arable crops and 4 years of permanent grass.)

Crop		Annual range	Mean of all years	Total removed	
			Nitrogen		
Wheat	grain	44–96	77	385	495
	straw	14–29	22	110	
Barley	grain	32–42	38	187	284
	straw	8–49	19	97	
Ley		186–258	226	1130	
Potatoes		62–91	80	400	
Kale		52–94	73	366	
Permanent grass		99–141	114	455	
			Phosphorus		
Wheat	grain	8–17	12	61	71
	straw	1–4	2	10	
Barley	grain	5–10	7	36	44
	straw	1–4	2	8	
Ley		12–16	14	68	
Potatoes		5–7	6	32	
Kale		6–16	11	56	
Permanent grass		13–21	17	69	
			Potassium		
Wheat	grain	4–22	14	70	165
	straw	5–40	19	95	
Barley	grain	8–21	12	61	125
	straw	4–22	13	64	
Ley		33–55	45	225	
Potatoes		11–30	20	101	
Kale		45–88	70	352	
Permanent grass		32–51	42	169	

Table 4. *Apparent recoveries of nitrogen applied as fertilizer*

(5 years of arable cropping and 4 years of permanent grass.)

		Recovery from low rate of dressing			Recovery from high rate of dressing		
		Range (lb./acre)	Mean (lb./acre)	% recovery	Range (lb./acre)	Mean (lb./acre)	% recovery
Wheat	grain	16 to 33	21	50	14 to 43	23	35
	straw	4 to 18	12		10 to 42	24	
Barley	grain	9 to 29	18	41	28 to 48	37	47
	straw	−12 to 8	3		−11 to 19	10	
Potatoes		−8 to 62	22	33	5 to 66	30	22
Kale		34 to 112	71	63	113 to 130	122	54
Permanent grass		31 to 55	40	35	111 to 130	120	54

On average permanent grass and kale recovered most fertilizer N. But even with these crops, which responded well to the second dressing of N, not more than one-half and two-thirds was recovered by grass and kale respectively. Potatoes used fertilizer N very inefficiently, only one-third of the low rate, and little more than one-fifth of the high rate was in the harvested crop. (Tops had died down at harvest and the N they returned to the soil could not be measured.) Cereals did not recover more than half of the N they received. These small recoveries show how inefficient nitrogen fertilizers often are.

Phosphorus

Table 5 gives the amounts of P apparently recovered from superphosphate supplying 24·5 lb. P/acre to all crops (estimated from P contents of crops grown on N_1PK and N_1K plots). On average kale and clover-grass ley both recovered nearly one-quarter of the applied P, permanent grass recovered little more than one-tenth. The cereals and potatoes recovered one-sixth to one-seventh of the applied P. Clearly with this manuring regime P is accumulating in the soil.

Potassium

Table 6 shows recoveries of fertilizer K. The crops apparently recovered much more of the K than of the P applied; with kale and wheat percentage recoveries are of the same order as those from fertilizer N. Clover was most efficient, apparently recovering four-fifths of the K applied, but this value reflects the effect of the K on the composition of the ley; with K fertilizer clover was vigorous and the sward had little grass, whereas without K there was less clover and more grass in the sward. Potatoes, kale and permanent grass recovered more than half of the K applied, barley recovered about one-quarter and wheat about one-third.

RECOVERY OF NUTRIENTS FROM FARMYARD MANURE

Three estimates were made of the nutrients taken up by crops from FYM. Comparing crops from completely unmanured plots with those from plots receiving FYM alone (i.e. D-0) gave the simple valuation of the nutrients in FYM shown in Table 7. (Only potatoes, kale and permanent grass received FYM in each year and data for the other crops are not given). FYM was also tested with both complete fertilizer mixtures and further estimates (Table 8) of nutrient uptake were made from the DN_2PK and N_2PK plots and from the DN_1PK and N_1PK plots.

Interpreting the results in Tables 7 and 8 is difficult because of the possible interactions between nutrients supplied by fertilizers and by FYM (discussed by Boyd (1961)). Extra N, P and K were taken up when crops receiving NPK fertilizers were also given FYM (Table 8) because the basal fertilizer dressings were inadequate for maximum yields; nutrient uptake may however have been increased because FYM improved physical conditions of the soil. Potatoes apparently recovered more N from FYM than did the other crops, probably because they benefited more than other crops from the massive doses of K (about 350 lb./acre annually (Table 2)) supplied by the FYM, there being large NK interactions with potatoes.

Table 5. *Apparent recoveries of phosphorus applied as fertilizer*

(5 years of arable cropping, 4 years of permanent grass.)

Crop		Range (lb./acre)	Mean (lb./acre)	Average % recovery
Wheat	grain	−0·1–7·6	3·1	16
	straw	0·5–1·3	0·8	
Barley	grain	1·1–5·9	2·9	14
	straw	0·3–0·8	0·5	
Ley		2·4–11·0	5·6	23
Potatoes		0·3–8·0	3·5	14
Kale		0·1–11·0	5·7	23
Permanent grass		−0·3–6·8	2·7	11

Table 6. *Apparent recoveries of potassium applied as fertilizer*

(5 years of arable cropping, 4 years of permanent grass.)

		Range (lb./acre)	Mean (lb./acre)	Average % recovery
Wheat	grain	2–8	5	35
	straw	17–42	27	
Barley	grain	0–11	6	25
	straw	15–26	18	
Ley		47–119	76	82
Potatoes		43–71	53	57
Kale		0–87	52	56
Permanent grass		61–71	65	70

Table 7. *The apparent effective contributions of the nutrients supplied by farmyard manure used in the absence of fertilizers, 1956–60*

	Mean recovery (lb./acre)	% recovery
	Nitrogen	
Potatoes	77	31
Kale	25	10
Permanent grass	33	17
	Phosphorus	
Potatoes	9	19
Kale	6	17
Permanent grass	4	10
	Potassium	
Potatoes	120	38
Kale	85	31
Permanent grass	102	37

The FYM dressings used in this experiment (averaging 17 tons/acre for potatoes and kale and 15 tons for grass) contributed the following average amounts of nutrients when used in the presence of the N_2PK fertilizer dressing: 42 lb. of N, 6 lb. of P and 115 lb. of K. The apparent effective contributions by the same weights of FYM when no fertilizers were given were similar and averaged 45 lb. of N, 7 lb. of P and 102 lb. of K. (This discussion ignores the large residual effects which the dressings of FYM must have had in the later years of the experiment.)

DISCUSSION

Nutrients removed from soil

The data in Table 3 showing the nutrients removed by several crops from the same soil in a field experiment are believed to be unique. All the crops responded to each nutrient (except that the clover-grass ley did not benefit from N), and 'basal' dressings of the other two nutrients were given in each comparison, so the amounts of nutrients in crops grown without appropriate fertilizer were the maximum amounts obtainable from the soil in a season.

Nitrogen. Of the arable crops barley obtained least N per acre (57 lb.), and wheat most (99 lb.); kale obtained about 70 lb. and potatoes about 80 lb. The wheat was autumn-sown and presumably removed most N because: (*a*) it used residual N remaining in soil in autumn (which might otherwise have been lost by leaching); (*b*) it was able to use all the N released by mineralization in early spring; and (*c*) its deeper root system might have recovered more N from the subsoil. Spring-sown barley has a much shorter growing season and a shallower root range than winter wheat. Potatoes and kale grow for similar periods though kale occupies the land longer in autumn. There is little reason to suggest that differences between crops in N uptake are from factors other than differences in lengths of growing seasons and in root morphology.

Phosphorus uptakes varied between 6 lb. with potatoes and 14 lb. with wheat. Kale gave very poor yields without P fertilizers but actually obtained more P from the soil than did potatoes and barley which responded less to fertilizer P. There is no simple explanation for these differences except that wheat, which secured most P, had the longest growing season and the deepest roots.

Potassium uptake was least (20 lb./acre) with potatoes and the crops died each year in July on plots where no fertilizer was given. Kale removed most K (70 lb.) and the yield was not seriously limited where K fertilizer was not given. Differences in K uptake probably involve physiological characteristics of the crops as well as differences in growing season and root range.

Permanent grass apparently recovered more N and P (114 and 17 lb. respectively) from soil than did any of the arable crops, but an intermediate amount of K (42 lb.). The behaviour of the permanent grass is not strictly comparable with that of the arable crops because the plots are in a separate strip and the fertilizer dressings have now changed the botanical composition of the sward. Both N and P uptake may have been influenced by the effect of these fertilizers on root range and length of growing season.

Fertilizer efficiency

The arable crops recovered from one-quarter (with potatoes) to two-thirds (with kale) of the N applied; these estimates are similar to most other published data and indicate the need for more work to develop more efficient ways of using N. There are no 'fixation' processes that conserve residues of fertilizer N in soil and unused N is mostly lost by leaching and denitrification before another crop is grown. The amounts of fertilizer P recovered were in the range usually recorded. Much potassium was recovered from the fertilizer dressings, particularly by the clover-grass ley and by permanent grass. The amounts of P and K from both fertilizers and FYM that are not taken up by crops are 'fixed' by the soil.

Farmyard manure

Outstanding increases in yields from FYM in the first year (1956) were examined by Williams, Stojkovska, Cooke & Widdowson (1960) who concluded that they were not from micronutrients supplied by the FYM. The manure used supplied some N and

Table 8. *Apparent effective contribution of the nutrients in farmyard manure used in the presence of PK fertilizers and with two levels of nitrogen*

Plots compared	With fertilizer N: At low rate DN_1PK-N_1PK	With fertilizer N: At high rate DN_2PK-N_2PK
	Mean uptake (lb./acre)	
	Nitrogen	
Potatoes	50	56
Kale	24	41
Permanent grass	36	29
	Phosphorus	
Potatoes	5	6
Kale	5	6
Permanent grass	3	5
	Potassium	
Potatoes	101	92
Kale	87	123
Permanent grass	110	131

P and much K and increased yields greatly; the largest gains from FYM were with crops like potatoes, clover and wheat that are sensitive to K deficiency.

The amounts of nutrients taken by crops from FYM were measured with and without NPK fertilizers; the two estimates were surprisingly similar, and showed that 10 tons of FYM provided about 30 lb. N, 4 lb. P and 75 lb. of K. For both N and K these amounts are similar to Boyd's (1959) estimate of the value of 10 tons of FYM in terms of *fresh* fertilizer dressings (34 lb. of N and 70 lb. of K); his values were derived from the responses by potatoes to fertilizers and FYM in field experiments on a wide range of soils and not from crop compositions. The P supplied (4 lb.) was much less than Boyd's equivalent in terms of a fresh fertilizer dressing (20 lb. of P). Because only about one-quarter to one-fifth of a fresh dresssing of P fertilizer is taken up by crops, the two estimates of the value of P in FYM are similar. The effects of FYM are, however, difficult to interpret because there are large interactions between nutrients supplied by manure and by fertilizers, particularly with crops that are sensitive to K-deficiency.

SUMMARY

1. The amounts of N, P and K recovered by five arable crops and by permanent grass from soil alone, and from fertilizer and farmyard manure (FYM) dressings were measured. All the crops responded well to P and K fertilizers and all except clover responded to N. Uptakes from soil alone are therefore the maximum amounts of each nutrient that each crop could remove when supplied with other fertilizer nutrients (the exchangeable Ca and Mg in the soil were adequate).

2. Permanent grass (free from legumes) obtained about 114 lb. N/acre each year from soil and other natural sources; winter wheat obtained 100 lb. N, kale and potatoes about 80 lb. N and spring barley only 57 lb. A 1 year ley of clover and grass fixed at least 1 cwt. N/acre/year. Permanent grass removed most P from soil (17 lb./acre a year), potatoes removed least (6 lb. of P) and other crops intermediate amounts. Most K was taken from soil by kale (70 lb. K/acre/year) and least (20 lb.) by potatoes. Annual variations in the amounts of nutrients recovered from soil by any one crop were much greater with K than with N or P.

3. Most fertilizer N was recovered by kale and least by potatoes; with these crops two-thirds and one-third respectively of the light dressing was recovered, percentage recovery from the higher rate of N tested was less. Kale and the 1 year ley recovered nearly one-quarter of the P applied, permanent grass recovered little more than one-tenth. Clover-grass ley recovered most fertilizer K, apparently taking up four-fifths of that applied. Potatoes, kale and permanent grass all recovered more than half of the fertilizer K given, cereals were least efficient although both responded well to K dressings.

4. Farmyard manure supplied large amounts of nutrients to all crops. Similar amounts of N, P and K appeared to be recovered from FYM whether or not NPK fertilizer was also used. A rough estimate was that crops like kale, potatoes and permanent grass, which received FYM each year, recovered about 30 lb. of N, 4 lb. of P and 75 lb. of K from a 10 tons/acre dressing.

REFERENCES

Boyd, D. A. (1959). *J. Agric. Sci.* **52**, 384.
Boyd, D. A. (1961). *J. Sci. Fd Agric.* **12**, 493.
Widdowson, F. V., Penny, A. & Cooke, G. W. (1963). *J. Agric. Sci.* **60**, 347.
Williams, R. J. B., Stojkovska, A., Cooke, G. W. & Widdowson, F. V. (1960). *J. Sci. Fd Agric.* **11** 570.

APPENDIX

Chemical composition of the soil used in the field experiment

(Sampling depth 0–9 in.)

	Cations in soil			Other total elements in soil		
	Total %	Exchangeable (m-equiv./100 g.)		%		Parts per million
K	1·03	0·23	C	2·4	Cu	22
Mg	0·24	0·93	Fe	2·6	Mn	1500
Na	0·35	0·17	N	0·26	Mo	2·6
Ca	0·48	16·1	P	0·076	Zn	80

The soil had pH 6·4 (in 1960) and contained no free $CaCO_3$. Total cation exchange capacity was 18·1 m-equiv./100 g. of soil and the base saturation was 91 per cent. P and K soluble in 0·3 N-HCl were 0·6 and 4·4 mg./100 g. of soil respectively.