THE EFFECT OF FARMYARD MANURE ON FERTILIZER RESPONSES

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The paper brings together fresh evidence on the relationship between farmyard manure (F.Y.M.) and fertilizers, a complex problem which has engaged the attention of the soil chemist and the practical farmer since fertilizers first came into common use. Whereas chemical analysis provides estimates of the total quantity of nutrients contained in F.Y.M., the question of how far these nutrients are available to the crop to which the manure is applied, and how much to subsequent crops, and the further problem of the relative importance of the nutrient and physical effects of F.Y.M. can only be approached by experiment.

Field experiments in which F.Y.M. and fertilizers have been applied factorially have been virtually confined to measuring the direct effect of F.Y.M. on the crop to which it was applied. Between about 1890 and 1910 many field experiments of this kind were made but almost all of these tested only a selection of fertilizer combinations, e.g. O, P, NP, NPK, and many prejudged the question under test by reducing the fertilizer dressings by one-half when applied with F.Y.M. Although numerous, their value at the present day is limited by the small quantities of fertilizer tested and by the likelihood that in over half a century there have been substantial changes in the normal composition of F.Y.M. and in the nutrient status of soils. From about 1910 onwards field experimental work fell off greatly, but in the nineteen-thirties and subsequently there was a renewal of interest in the role of F.Y.M. in relation to fertilizers and some valuable factorial experiments have been done at Rothamsted and, more recently, by the N.A.A.S., which considerably advance our knowledge and form the basis of the present paper.

In the nineteen-twenties and thirties writers of agricultural text-books often recommended the use of extra phosphate (P) with F.Y.M. on the grounds that its most active constituents were nitrogen (N) and potash (K). More recently there has been an increasing tendency for soil chemists to stress its P and K content; without denying that F.Y.M. can usually provide N to the crop to which it is applied, it has been asserted that no reduction in the N dressing of a crop should be made when F.Y.M. is also used. The experimental evidence for this conclusion was given by Crowther & Yates (1941) whose summary of all available fertilizer experiments carried out in this country since 1900 is still the chief source of information on the manurial requirements of arable crops in Britain. These authors found that P and K responses were reduced by about one-half (amended later to two-thirds for K; see Crowther, 1948) when F.Y.M. was also applied, but for N there was only a small reduction of about 10%. Crowther (1948) explained this as follows:

> In practice there is no need to cut down nitrogen fertilizers where farmyard manure is used, even though good farmyard manure supplies appreciable amounts of available nitrogen. To explain this result, it must be remembered that farmyard manure supplies other plant foods and improves the physical condition of the land, thus giving better crops, capable of responding to larger aggregate amounts of each of the plant foods, and especially of nitrogen. Moreover, dung is normally applied at a stage in the rotation where the land is most exhausted and most responsive to additional plant foods.

As the last sentence of the quotation implies, much of the evidence was drawn from comparisons between centres, but it appeared to be confirmed by those factorial experiments testing F.Y.M. and fertilizers available at the time. Crowther was unable to provide any very convincing explanation why F.Y.M. should effect N responses in this way, but not P and K responses. However, the above conclusions have been widely accepted and it has recently been claimed that further confirmation is provided by the Rothamsted experiments with F.Y.M. (Dyke, 1957) and by factorial experiments carried out by the N.A.A.S. (Edwards, Watkin & Webber, 1956).

An indication that the relationship between F.Y.M. and fertilizers might be more complex than had been supposed was obtained in the course of an analysis of the results of a large series of experiments on sugar beet (Boyd, Garner & Haines, 1957); on experimental sites to which a basal dressing of F.Y.M. had been applied the mean N response was little more than half that on sites not receiving F.Y.M. Comparisons between centres can easily be misleading, and since the relationship between fertilizers and F.Y.M. is of importance both for agricultural chemistry and in practical farming it seemed worth while to re-examine the experimental evidence, making use of recent series of experiments which were not available to Crowther & Yates (1941).

EXPERIMENTAL DATA

Experiments in which all combinations of F.Y.M., N, P and K have been tested factorially are virtually limited to the potato crop, for which there are five small series, giving a total of twenty-seven experiments altogether. Three of the series were carried out at Rothamsted and the other two by the N.A.A.S. Regional Soil Chemists in the West Midland and Yorks and Lancs regions; there is a further series from Yorkshire and an early series from Durham in which only four of the eight combinations of NPK were tested. Some details of the experiments are shown in Table 1.

A further seven experiments at Rothamsted could not be used, all but the first-order interaction of F.Y.M. with each nutrient having been confounded. Four other Rothamsted experiments, in the years 1932–36, supply some information on the interaction of F.Y.M. and N, but varying rates of N and of basal fertilizers prevent them being readily summarized; their results do, however, conform closely with those of the main series.

The main effects and interactions of fertilizers in the presence and absence of F.Y.M. are given for series 1–4 in Table 2.

In each series of experiments the application of F.Y.M. greatly reduced the main effect of K and also each of the interactions. The main effect of P was relatively unaffected by whether or not F.Y.M. was applied, whereas in three of the four series the application of F.Y.M. resulted in some increase in the main effect of N. Greater consistency could hardly be expected, in view of the few experiments in each series. Part of the apparent responses to fertilizers must of course be due to experimental errors, as well as to real differences in requirements from site to site and year to year; the wide variations between different samples of F.Y.M., according to the type of animal and the kind of food consumed, the amount of litter provided, the degree of rotting and conditions of storage, must also be borne in mind. It would be foolish, therefore, to read too much into the available experimental data, but the results do appear sufficiently consistent to allow some useful conclusions to be drawn. As the results may be more easily understood by the general reader when presented in terms of responses, Table 3 gives the mean response to each fertilizer nutrient, applied alone and with all combinations of the other two nutrients, and for plots with and without F.Y.M.; in arriving at these averages, each centre has been given unit weight and no attempt

Table 1. *Sources of experiments with farmyard manure and fertilizers for the potato crop*

Experiments due to	Location of sites	No. of exps.	Years	N (cwt.)	P_2O_5 (cwt.)	K_2O (cwt.)	F.Y.M. (tons)	Basal fertilizer	Notes
(1) Rothamsted Experimental Station	Harpenden, Herts	3	1937–39	0, 0·4, 0·8	0, 0·8	0, 1·6	0, 15	—	Experiments included also a comparison of normal and strawy dungs
(2) Rothamsted Experimental Station	Harpenden, Herts	6	1941–46	0, 0·6	0, 0·6	0, 1·0	0, 8, 16	—	—
(3) N.A.A.S. (West Midland Region)	Cheshire	6	1949–52	0, 0·8	0, 0·7	0, 0·7	0, 12–15	—	—
(4) N.A.A.S. (Yorks and Lancs Region)	Yorks and Lancs	8	1950–54	0, 0·4, 0·8	0, 0·45, 0·9	0, 0·75, 1·50	0, 12–15	—	Three sites on peaty soils
(5) Durham C.C. and Armstrong College	Durham	22	1904–07	0, 0·36	—	—	12	0·5 P_2O_5 and 0·5 K_2O	—
(6) Department of Agriculture, University of Leeds	Yorkshire	14	1939	0, 0·4	—	—	15	0·5 P_2O_5 (no K_2O)	All sites on ploughed-up grassland
(7) Rothamsted Experimental Station	Harpenden, Herts	3	1948–50	0, 0·6	0, 0·6	0, 1·0	15	—	Experiments also tested four planting dates

Sources of information

Rep. Rothamst. Exp. Sta. 1937 and 1938.
Rothamst. Field Exps. (Mimeo), 1939, 1941–46, 1948–50.
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Durham College of Science. *Reports on Field and Other Experiments*, 1903.
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has been made to adjust to a standard rate of dressing.

For all four series the response to N was least when no basal fertilizers, or basal P only, was applied, the overall mean response being about 1·0 tons per acre. With basal K, much larger responses were generally obtained and with the combined PK basal the overall mean response rose to 3·1 tons per acre. The response to N in the presence of F.Y.M. was less dependent on whether or not basal fertilizers were applied, although, even with F.Y.M., N responses were usually least when no basal P or K was applied. Except for the West Midland series, the effect of F.Y.M. was to increase the response of N applied alone. With basal PK, on the other hand, F.Y.M. reduced the N response in all four series; the reduction was greatest for the West Midland series, where N responses were halved, compared with an overall reduction of one-third.

The relation between P response and the presence or absence of other nutrients or F.Y.M. was essentially similar to that given above for N, except that the overall level of response was lower. P without K generally gave small responses or even, as in the Rothamsted series, slightly depressed yields; with K, and especially with both N and K, much larger responses were obtained in three of the four series, the West Midland series again being the exception. In the presence of F.Y.M., the response

Table 2. *Main effects and interactions of fertilizer nutrients in presence and absence of farmyard manure*

	No. of exps.	Mean yield	Potatoes (total tubers) tons per acre						
			N	P	K	NP	NK	PK	NPK*
(1) Rothamsted Experimental Station, 1937–39									
Without F.Y.M.	3	7·76	2·46	1·07	2·01	0·47	0·64	1·54	0·48
With F.Y.M.		10·94	2·61	0·78	0·15	0·22	0·16	−0·41	0·18
(2) Rothamsted Experimental Station, 1941–46									
Without F.Y.M.	6	7·48	1·25	0·44	3·32	0·25	0·58	0·61	0·33
With F.Y.M.		11·28	1·53	0·72	0·49	0·12	0·26	0·11	−0·25
(3) West Midlands									
Without F.Y.M.	6	9·16	2·15	0·50	2·58	0·12	0·84	0·23	−0·06
With F.Y.M.		13·37	1·48	0·32	1·12	−0·06	0·30	−0·33	−0·28
(4) Yorks and Lancs									
Without F.Y.M.	8	7·35	1·67	1·59	3·70	0·65	0·93	0·79	0·37
With F.Y.M.		9·96	2·83	1·15	1·78	0·07	0·38	0·16	−0·06
Mean									
Without F.Y.M.	23	7·90	1·78	0·94	3·10	0·39	0·78	0·70	0·26
With F.Y.M.		11·31	2·10	0·77	1·06	0·07	0·30	−0·05	−0·14

* It should be noted that in all four series the NPK interaction and the main effects o F.Y.M. had been wholly or partially confounded with comparisons between blocks or whole plots.

Table 3. *Mean responses to fertilizer nutrients with and without farmyard manure and with different combinations of basal fertilizers*

(Means of twenty-three experiments: tons potatoes per acre.)

Response to nitrogen

Basal fertilizer	—	P	K	PK	Mean
Without F.Y.M.	0·89	1·13	1·92	3·12	1·77
With F.Y.M.	1·61	2·01	2·48	2·09	2·05
$\frac{\text{Response with F.Y.M.}}{\text{Response without F.Y.M.}} \times 100$	181	178	129	67	116

Response to phosphate

Basal fertilizer	—	N	K	NK	Mean
Without F.Y.M.	0·32	0·36	0·99	2·07	0·93
With F.Y.M.	0·63	1·03	0·78	0·59	0·76
$\frac{\text{Response with F.Y.M.}}{\text{Response without F.Y.M.}} \times 100$	196	286	79	29	82

Response to potash

Basal fertilizer	—	N	P	NP	Mean
Without F.Y.M.	1·74	2·77	2·60	4·47	2·90
With F.Y.M.	0·69	1·55	0·84	0·97	1·01
$\frac{\text{Response with F.Y.M.}}{\text{Response without F.Y.M.}} \times 100$	40	56	32	22	35

to P, like the response to N, was only to a minor degree dependent upon the basal fertilizers. Consequently, the overall effect of F.Y.M. was to increase the effect of P applied alone or with N only, but to reduce very markedly the response to P in the presence of both N and K.

Potatoes are normally very responsive to K, and in series 1–4 the majority of the experimental sites would be classified as low or very low in available K. It is not surprising, therefore, that the overall increase in yields from this nutrient was 1·7 tons per acre even in the absence of the other nutrients, rising to 4·5 tons per acre where both N and P were applied. Where F.Y.M. was applied, the overall K response did not vary greatly about a mean of 1·0 tons per acre, a marked reduction compared with the responses without F.Y.M. The reduction was particularly large in the Rothamsted experiments, but in the Yorks and Lancs series the mean reduction was only about 50 %.

Results for two subsidiary series of experiments are summarized in Table 4. Bearing in mind that the Durham experiments are on single plots, the results are in reasonable agreement with those already discussed; in the presence of basal dressings of the other fertilizer nutrients the response to N was halved, while the effects of P and K were reduced to zero. The Yorkshire series is exceptional in that all the sites were on newly ploughed old grass; errors were rather larger than normal and there appear to be substantial differences between centres. In the absence of other fertilizers F.Y.M. tended to increase the P response. At first sight the results for N and K are not altogether in conformity with the main series, but this is due largely to the small responses obtained, whereby a quite small variation in the yield of the NP plots would have been sufficient to affect very largely the percentage reduction in response due to F.Y.M.

Six experiments at Rothamsted in the years 1945–50 tested the effects of F.Y.M. and fertilizers on potatoes planted at different dates; although originally designed to give information on the effect of these factors on the spread of virus in the crop, they also give useful data on crop yields. Summaries of the results have already been given in the *Rothamsted Report* for 1950, by Dyke (1956) and by Broadbent, Gregory & Tinsley (1952). Three of these experiments, carried out in 1948–50, are on a standard pattern, having four blocks each of sixteen plots, and testing all combinations of four planting dates (mean dates 3 April, 22 April, 10 May and 28 May) and F.Y.M., N, P and K, each at two levels (presence and absence). Table 5 presents the data in the same form as for Table 3, taking the 3 years' results together and combining the results for the first two ('normal') and the last two ('late') plantings; in preparing the table it has been assumed that the interaction DNP × (normal *v.* late planting) is zero. In 1948 the F.Y.M. was applied in the ridges at planting, the full amount of 15 tons fresh material being applied at the first

Table 4. *Effects of farmyard manure on fertilizer responses of potatoes (subsidiary experiments) (total yield in tons per acre)*

	Durham (22 centres)			Yorkshire (14 centres)		
Response to	N	P	K	N	P	K
Basal	PK	NK	NP	P	—	NP
Without F.Y.M.	1·86	0·95	1·63	0·74	0·89	0·55
With F.Y.M.	0·85	−0·12	−0·05	0·17	1·18	0·35

Table 5. *Responses to fertilizer nutrients with and without farmyard manure: Rothamsted* 1948–50

(Tons potatoes per acre.)

	Normal planting					Late planting				
Responses to nitrogen										
Basal fertilizer	O	P	K	PK	Mean	O	P	K	PK	Mean
No F.Y.M.	−0·73	0·84	1·43	2·11	0·91	1·55	0·78	0·32	2·24	1·22
With F.Y.M.	1·87	1·37	0·39	0·96	1·15	1·24	1·42	1·16	0·11	0·98
Response to phosphate										
Basal fertilizer	O	N	K	NK	Mean	O	N	K	NK	Mean
No F.Y.M.	−0·22	1·35	0·85	1·53	0·88	0·20	−0·39	0·91	2·85	0·89
With F.Y.M.	2·36	1·86	−0·40	0·17	1·00	−0·17	0·01	0·45	−0·60	−0·08
Response to potash										
Basal fertilizer	O	P	N	NP	Mean	O	P	N	NP	Mean
No F.Y.M.	1·21	2·28	3·37	3·55	2·60	1·40	2·11	2·35	3·57	2·36
With F.Y.M.	2·64	−0·12	1·16	−0·53	0·79	−0·15	0·47	−0·23	−0·84	−0·19

planting and the partially rotted residue at later dates; in the two following years the F.Y.M. was ploughed in during March.

One puzzling feature of the results is the very poor yield given by F.Y.M. alone in 1948 and 1949 (but not in 1946 or 1950) on the earlier-planted plots; although these experiments were subject to rather high errors it is difficult to ascribe the whole of this result to error. Apart from this, however, the effects of F.Y.M. and fertilizers follow a similar pattern to those already discussed in connexion with Table 3, although the general level of response is lower (both yields and responses were small in 1949 owing to drought).

We may compare the results of Table 5 with the conclusions of the authors quoted above, who had access only to the mean responses, neglecting interactions between nutrients. Thus it had previously been reported that the effect of phosphate was small and also that, in common with the effect of F.Y.M. and other nutrients, it was reduced by late planting—surprisingly in view of the ability of P to give crops a quick start in spring. This is confirmed for the main effect of P, which declined from 0·94 tons per acre at the normal plantings to 0·40 tons per acre at the late plantings; but the table shows that in the absence of F.Y.M. the crop gave just as good or better responses to P at late as at normal planting, and that, provided NK was also supplied, the response approached 3 tons per acre. In the presence of F.Y.M. on the other hand, there, was virtually no response to P except at normal planting and in the absence of K.

For N and K, also, the present data fail to show a reduction in response at the later times of planting, given a basal dressing of the other nutrients, but not of F.Y.M.; indeed the combined response to N, P and K was 4·17 tons per acre for the normal plantings and 4·55 for the late plantings. It should be mentioned that most of the previous work had been based on 4 years' results including the 1946 experiment (the 1945 and 1947 experiments did not include P as a factor; also there was no 'normal' planting in 1947), which did give some evidence of a reduction of fertilizer effects at late dates of planting; this may have been due in part at least to the circumstance that the third and last plantings were 10 days later than in 1948–50. Even accepting the evidence from this rather unsatisfactory experiment, the mean combined response to N, P and K for the 4 years including 1946 was virtually the same for normal as for late planting (4·52 tons per acre for the normal plantings against 4·34 tons per acre for the late plantings). The response to F.Y.M. alone actually showed some increase with late planting each year (including 1946) the mean increase being 1·1 tons per acre. At the same time the combined response to fertilizers in the presence of F.Y.M. fell sharply from 3·20 tons per acre at the normal plantings to 0·41 tons per acre at the late plantings.

In interpreting these results, an important factor may be the particularly short growing season available to the crop in these experiments; in 1946, 1948 and 1949 the tops were burnt off in mid-September; in 1950 they were almost completely destroyed at about the same time by a severe attack of blight, the remainder of the haulm being burnt off in late September. In such circumstances, the K supply to the plants must have been a critical factor, since plots without potash developed deficiency symptoms, sometimes with premature death of the haulm; whilst the crop was able to make use of the moderate quantities of nutrient provided by F.Y.M. or fertilizers alone, the extra quantities provided by the combined dressing must have so far delayed maturity as to give no further increase, or even slightly reduce yield.

DISCUSSION

An investigation of the joint effect of F.Y.M. and fertilizers involves a complex response surface, the details of which cannot be adequately described by experiments in which some or all of the factors occur at two levels (presence and absence) only. The foregoing results do, however, considerably extend and clarify previous work on the relationship between F.Y.M. and fertilizers. At the same time they fall into line with the results of other factorial experiments with N, P and K at three or more levels, carried out on responsive crops such as potatoes and sugar beet, in which it has been clearly shown that the response to any nutrient is to a large extent dependent upon the amounts of the other nutrients provided by the soil and in the experimental treatments. Thus, in a series of experiments on sugar beet, both the response to a given level of N, and the degree of curvature of the N response curve, were dependent upon the amounts of P and K supplied (Boyd, *et al.* 1957). In the same way, the series of experiments discussed above show that the effect of either N or P may be substantially increased when applied in the presence of F.Y.M., notwithstanding the fact that F.Y.M. itself provides some N and P, due to their interaction with the K supplied by F.Y.M. Where, however, a basal dressing of K fertilizer is provided, lack of this nutrient will no longer restrict N or P responses in the absence of F.Y.M., so that much the same response curve will be applicable in the absence as in the presence of F.Y.M. Where F.Y.M. is applied, the response to N or P will be measured on the flatter portion of this response curve and will therefore be less than the response to the same quantity of N or P tested in the absence of F.Y.M.

This explanation of the experimental results suggests that, in the design and analysis of factorial experiments testing F.Y.M. and fertilizers, it may be unwise to assume that high-order interactions are unimportant, or to treat F.Y.M. as if it were merely a fourth nutrient. The possiblity should also be borne in mind that, with unbalanced or very heavy rates of manuring, the exponential form of response curve may be inappropriate.

The foregoing results allow a fresh assessment to be made of the effective nutrient content of F.Y.M. Estimates were made by Crowther & Yates (1941), and Crowther (1948) stated that the amounts of plant food furnished by a dressing of 10 tons F.Y.M. per acre to the crop to which it was applied were 0·4 cwt. P_2O_5 and 0·6 cwt. K_2O per acre; he gave no figure for N. Subsequent examination of manurial experiments on sugar beet and potatoes has shown that, in the presence of adequate basal fertilizer, Crowther & Yates' standard response curves tend to overestimate the falling-off in response at high levels of manuring. This will result in an underestimate of the effective nutrient content of F.Y.M.; for example, the use of the 'standard' value of $k_K = 0{\cdot}8$ instead of the actual value (about 0·4) in series 4 reduces the estimate of the effective K content of F.Y.M. from about 0·7 cwt. K_2O to 0·45 cwt. K_2O.

Of the series examined in this paper, series 1–4 and 7 each give information on the effective contribution of P from F.Y.M. to the crop to which it is applied; the individual estimates range from 0·37 to 0·52 cwt. P_2O_5 per acre in 10 tons F.Y.M. and the mean of 0·42 cwt. P_2O_5 per acre agrees with the figure of 0·4 cwt. P_2O_5 previously given by Crowther. Series 1 and 6 gave negative response to K in the presence of F.Y.M.; the other series give values in the range 0·68–0·81 cwt. K_2O per acre in 10 tons F.Y.M. with a mean of 0·75 cwt., substantially higher than Crowther's estimate. For N the estimates range from 0·15 cwt. N per acre for the Yorks and Lancs series to 0·35 cwt. N per acre for the West Midland series with a mean value of 0·27 cwt. The amount of readily available N in F.Y.M. must, of course, vary with the source and age of the material, as well as with methods of storage and application. Thus the effective N content of a poor strawy dung may be very small indeed. Unfortunately, the present data, apart from the Rothamsted series, do not in general include descriptions and chemical analyses of the manures used in the experiments. In their discussion of the West Midland experiments (series 3), Edwards *et al.* (1956) mention that two of the centres had strawy dungs and a markedly positive DN interaction, whereas at a third centre, with a fresh and not very strawy manure, the DN interaction was strongly negative. It is doubtful, however, whether the whole of the observed differences in N response can be attributed to the differences in type of F.Y.M. Most of the Rothamsted experiments give information on quality and age of F.Y.M. and it is hoped that a full report on these results will be available in due course.

Having determined so far as possible the effective nutrients supplied by F.Y.M. to the crop to which it was applied, it is natural to ask what evidence there is for additional effects of F.Y.M. over and above what can be accounted for in terms of NPK. There is ample evidence from the Rothamsted classical experiments and the Saxmundham rotation experiment that when F.Y.M. has been applied annually for many years the colour, texture, workability and moisture absorption and retention of a soil are materially altered, and that nutrient levels are increased substantially. We cannot, however, conclude, as many writers of agricultural textbooks and advisory literature have done, that these remarkable and undoubted effects of long-continued heavy dressings of F.Y.M. can equally be ascribed to the occasional farm dressing. The reader is told that it is the physical effect of a dressing of F.Y.M.—the retention of moisture for light soils and the aeration of heavy soils—which is of primary importance, and the provision of plant nutrients, although important, is a secondary consideration. The proposition may be correct, but so far as farm crops are concerned, has yet to be verified from field experiments.

Apart from the supposed physical effects, the possible role of F.Y.M. as a supplier of elements other than NPK, for example, magnesium, should not be overlooked. Considerations of fertilizer placement may also affect comparisons of F.Y.M. and fertilizers, substantially decreasing or increasing their apparent effectiveness. The evidence provided by the present experiments is clearly insufficient, but so far as they go the results appear to show that the effect of F.Y.M. could be adequately accounted for in terms of the nutrients N, P and K only, without having recourse to any other effect of F.Y.M. However, the soils on which the experiments were conducted may not have been very sensitive to applications of organic matter and did not include any typical silt soils. It must also be borne in mind that we have here been concerned with a crop whose 'seed' is probably less dependent upon soil moisture supplies in the early stages of development than that of some other farm crops; it would be surprising if the close association of nutrients with organic matter, which characterizes F.Y.M., proved to have no special value for the more sensitive horticultural crops. Nevertheless, it remains true that, for the ordinary farm crops, large and unmistakable effects of the nutrients supplied by F.Y.M. have been demonstrated, whilst no comparable 'physical' effects of F.Y.M. have so far been revealed.

The possible effect of the text-books' emphasis on the physical effects of F.Y.M. becomes of importance when we consider the practical conclusions to be drawn from the foregoing results. Results of the survey of fertilizer practice have shown that, in general, farmers in Great Britain make no adjustment to their manurial programme according to whether or not a field has been dunged. It is true that, if we consider all potato-growing farms in a district, those growers who have adequate supplies of F.Y.M. usually use less fertilizer than is applied on farms where F.Y.M. is scarce. But this difference between farms is probably due to the fact that potato growing is often a secondary interest on farms where livestock to make the F.Y.M. are numerous. Within a farm, however, the majority of growers manure identically all their fields under a crop such as potatoes or sugar beet, regardless of whether or not F.Y.M. has been applied. The average amount of fertilizers applied to fields with and without F.Y.M. on sixty-four farms growing potatoes and fifty-one farms growing sugar beet are shown in Table 6.

Thus there was on the average very little adjustment of manurial dressings to take account of the nutrients supplied in F.Y.M. This is surprising when we consider that, at the rates quoted in Table 6, the immediately available nutrients may be worth about £5 per acre. Apart from the fact that fields tend to be dunged in some sort of rotation, there is no evidence that, as Crowther put it, a field tends to be dunged just because it is more exahusted.

In looking for an explanation of this aspect of farm practice we have to bear in mind not only that the immediate physical effects of F.Y.M. may have been overstated, but also that advice on the manurial equivalent of F.Y.M. has neither been unanimous nor easy to apply in practice. For many years N and K were regarded as the main constituents and growers were advised to add superphosphate to obtain a balanced dressing. More recently they have been recommended to reduce their P and K dressings when applying F.Y.M., but to retain the same level of N as on undunged land. Although it has received wide publicity, few farmers in fact have followed this advice because it requires the use of two different compound fertilizers, or two separate applications, one of a compound and one of 'straight' N.

The experimental results described in this paper give the effective contribution of nutrients from 10 tons F.Y.M. as about 0·3 cwt. N, 0·4 cwt. P_2O_5 and 0·75 cwt. K_2O per acre. The ratio of N to other nutrients is rather less than in most compound fertilizers in use at the present time, but the difference is certainly not large enough to warrant buying an alternative fertilizer for dunged land. Instead it will be sufficient to reduce the amount of fertilizer applied. A rough working rule for potatoes, roots and green crops would be to use the same compound fertilizer whether or not F.Y.M. is applied, but to reduce the amount by one-third to one-half for moderate fertilizer dressings and by one-quarter for heavy dressings (a 12 ton dressing of F.Y.M. has been assumed). In terms of those compound fertilizers most widely used on potatoes and root crops, 12–15 tons average F.Y.M. will supply the equivalent of about 4 cwt. of a compound having the N-P_2O_5-K_2O ratio 12:12:18, or about 5 cwt. of a 9:9:15 compound.

SUMMARY

Farmyard manure affected the response of the potato crop to fertilizers similarly in seven series of experiments (sixty-two in all) at Rothamsted, and in the West Midlands and north of England.

In the absence of F.Y.M. there were large interactions between each of the fertilizer nutrients, but with F.Y.M. the interactions were small. These interactions appear to have been ignored by previous workers, who claimed that N responses are unaffected by dressings of F.Y.M. In fact, F.Y.M. increased the response to N applied alone, but decreased the N response where basal P and K fertilizers were also applied. For P the results were similar to those for N.

Most of the experimental sites were low in K, and K responses were very large, especially in the presence of basal NP fertilizer. Farmyard manure greatly reduced the response to K, particularly in presence of basal NP fertilizer.

A few Rothamsted experiments with F.Y.M. and fertilizers and several times of planting showed that the large responses to F.Y.M. alone and to fertilizers used in combination (but without F.Y.M.) were not

Table 6. *Use of fertilizers on fields receiving* N *not receiving farmyard manure*

	Potatoes				Sugar beet			
	F.Y.M. (tons)	N (cwt.)	P_2O_5 (cwt.)	K_2O (cwt.)	F.Y.M. (tons)	N (cwt.)	P_2O_5 (cwt.)	K_2O (cwt.)
No F.Y.M.	—	1·09	1·10	1·58	—	0·92	0·84	1·17
With F.Y.M.	13·0	1·00	1·00	1·51	13·3	0·92	0·83	1·12

reduced by late planting. The result conflicts with previous reports of these data, in which interactions between nutrients were ignored. The combined effect of F.Y.M. and fertilizers at late planting was little more than their separate effects, presumably due to delayed maturity, the influence of which would be exaggerated by the early burning-off of haulm in this series of experiments.

Most of the experiments were limited to testing fertilizers at two levels (presence and absence), so the effective quantities of nutrients provided by F.Y.M. for the crop to which it was applied could only be estimated approximately; the average amounts suggested for normal F.Y.M. are 0·3 cwt. N, 0·4 cwt. P_2O_5 and 0·75 cwt. K_2O in 10 tons F.Y.M.

These results lead to the practical conclusion that, in manuring potato crops on average land, much the same plant food ratios will be appropriate whether or not F.Y.M. is given, and the amount of fertilizer applied can be decreased to allow for the nutrients contained in the F.Y.M.

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ADDENDUM

Since this paper was completed, Reith & Inkson (1958) have presented results for a further series of factorial experiments with F.Y.M. and fertilizers in north-east Scotland, 1947–54. The authors claimed that for N their results confirmed those of Crowther & Yates; however, their Table 3 gives results very similar to those presented here: i.e. in the absence of F.Y.M., PK basal greatly increased the response to N, but was ineffective where F.Y.M. was also applied. The authors appear to have appreciated that these results, based on individual plot yields, were inconsistent with their main conclusions drawn from main effects and first-order interactions only, but do not seem to have realized their significance.

REFERENCE

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