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THE ECONOMICS OF FERTILISER APPLICATION TO PERMANENT PASTURES FOR BEEF PRODUCTION

by R. BENNETT JONES and KEITH E. HOCKNELL

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THE ECONOMICS OF FERTILISER APPLICATION TO PERMANENT PASTURES FOR BEEF PRODUCTION

SUMMARY

Does it pay to put fertilisers on permanent pastures for beef production? The answer to this question is important because permanent grass accounts for one third of the total crops and grass area of England and Wales and its economic potential needs to be fully utilised.

There is ample evidence that permanent grass does respond to fertilisers but the gain has usually been measured as grass (dry matter or grazing days), not as beef.

In 1958 and 1959 supervised field trials were conducted on commercial farms in the Market Harborough area to measure the liveweight gain on fertilised and unfertilised fields on the same farms. Over 600 head of cattle were involved in the experiment in each year.

In 1958 the cost of the fertiliser applied to the treated fields on twelve farms was £3 16s. 3d. per acre at 1962 prices (N. 25 units, P. 62½, K 62½). The liveweight gain on these fields averaged 367 lb. per acre compared with 330 lb. on the untreated fields, which carried less stock. The additional 37.0 lb. of liveweight gain was worth £2 11s. 6d. to the farmer (again at 1962 prices), so that taking these farms as a group the application was clearly not worth while, though for three individual farms it was profitable.

In 1959 the treatment was modified (N. 24 units, P. 36, K. 24). This cost £2 5s. 0d. per acre. The liveweight gain per acre on the treated and untreated fields averaged 307.1 and 269.7 lb. respectively, so that the additional liveweight attributable to the treatment was 37.4 lb., virtually the same as in 1958, in spite of the reduced P. and K. application. This gain was worth £2 12s. 0d. to the farmer, so that in this second year the fertiliser had apparently more than paid for itself.

These average results were thus inconclusive, and there was also considerable variation between farms in each year.

More striking results have been obtained from recent work in Ireland which indicate that, on average, a margin of over £6 per acre over the cost of fertiliser may be obtained on permanent pasture grazed by fattening cattle.

It is also suggested that it may be possible, by appropriate manuring to prolong the grazing season by getting an earlier bite and more late keep. This would enable graziers to buy stores cheaper and to finish more cattle in the early summer when prices are more favourable.

The need for further experimental work is stressed. More information is needed regarding the response of pastures to a range of stocking rates and of fertiliser applications.

It is clear that stocking rate is a dominant factor determining the rate of *gain per acre*. Liveweight gain *per head* does *not* vary between fertilised and unfertilised fields. It follows that extra stock must be introduced if advantage is to be derived from the use of fertilisers on pastures grazed by beef cattle.

CHAPTER 1

INTRODUCTION

Since the Second World War there has been an increasing awareness that the grass crop can make an important contribution as a nutrient source for ruminant animals. During this period fertiliser applications have become an accepted means of achieving an increasing output from grassland. This is particularly so in the case of milk production from temporary grass. Experimental evidence also suggests that the output of beef can be raised quite considerably by fertilising leys. For instance, Prendergast, Barry and Brady[1] found that, due mainly to an improved carrying capacity and, to a lesser extent to an increase in the length of the grazing season, output was improved by 138 lb. liveweight gain per acre (116.6 lb. from bullocks and 21.5 lb. from sheep) per 100 lb. of elemental nitrogen applied to a ley in its fourth to seventh harvest years and based on Aberystwyth-bred "pasture" strains. Application of nitrogen varied between 7 and 12 cwt. per acre per annum applied in dressings throughout the year. Tayler and Rudman[2] applied 15.5 per cent nitrogen at the rate of 0, 6 and 12 cwt. per acre to a rye grass/white clover sward in its fourth and fifth years. The fertiliser was applied in three dressings; one in April or May and the other two between July and September. Herbage in excess of grazing requirements was conserved and fed back to the cattle later in the year. In the first year of the experiment 79 lb. and 102 lb. of extra liveweight gain, and in the second year 216 lb. and 226 lb. of extra liveweight gain were obtained from the 6 and 12 cwt. dressing respectively. A difference of 90 lb. of liveweight gain per acre between rye grass/cocksfoot/white clover swards which had received 2 cwt. and 12 cwt. per acre of "nitro-chalk" was measured by Holmes and Herriot.[3]

Since the botanical composition, and hence the potential productivity, of the sward of leys is likely to differ from the sward of permanent pasture and since the general level of management may also be superior, it is a matter of doubt whether or not these findings are relevant when making recommendations on the manuring of permanent pastures for beef production.

The purpose of this study is to attempt to determine whether or not it pays to fertilise permanent pastures grazed by fattening beef cattle. This will be done by reviewing some of the experimental data concerning fertiliser applications to permanent pastures and by an experiment which will be described later.

Permanent Pasture in England and Wales

For many years one feature of agricultural land usage in England and Wales has been the large acreage of permanent pasture. From 1875 depressed conditions among farmers caused large areas of arable land

1 PRENDERGAST, J. J., BARRY, P. J. and BRADY, J. J. Comparison of Aberystwyth-bred 'pasture' strains of herbage plants with ordinary 'commercial' strains. *Eire, Department of Agriculture Journal.* (1957-58). Vol. 54, pp. 90-156.

2 TAYLER, J. C. and RUDMAN, J. "Extended autumn grazing for beef." *Agriculture.* (May, 1959). Vol. 66, No. 2, p. 59.

3 HOLMES, J. C. and HERRIOT, J. B. D. "Beef production from the grazing ley under two levels of nitrogen manuring." *Animal Production.* (1960). Vol. 2, No. 3, p. 213.

to be put down to grass. From 1880 to 1940 there was a steady increase in the acreage. During the war years the area of permanent pasture declined but has since risen again so that in 1958 there were some eight million acres in England and Wales. Table 1 shows the acreages of permanent pasture for a number of years. Since the war permanent pasture has accounted for approximately one third of the total acreage of crops and grass.

The quality of much of this permanent pasture, as measured by botanical composition of the sward, is poor. Baker[4] found that in 1959 only eight per cent of the permanent pasture acreage in England could be classified as "first grade". Table 2 shows the percentage distribution of the area of permanent pasture within seven quality grades.

AREA OF PERMANENT PASTURE IN ENGLAND AND WALES 1935-59

TABLE 1

Year	Area of Permanent Pasture	
	'000 acres	Percentage of total of crops and grass
Average 1935-39	11,214	45
Average 1940-45	8,375	34
Average 1946-50	7,693	32
1951	7,959	33
1952	7,776	32
1953	7,662	31
1954	7,993	33
1955	8,126	33
1956	8,056	33
1957	8,143	33
1958	7,930	33
1959	8,070	33

DIFFERENT SWARD TYPES IN THE PERMANENT GRASSLAND OF ENGLAND, (excluding rough grazings).

TABLE 2

Sward Type	Percentage of permanent grassland area		
	1939	1947	1959
First grade rye grass	3	3	8
Second grade rye grass	7	8	12
Agrostis/rye grass	25	30	22
Agrostis with rushes	4	4	8
Agrostis	49	44	38
Fescue	9	7	9
Nardus and Molinia	3	4	3
TOTAL	100	100	100

4 BAKER, H. K. "Permanent grassland in England." *Proceedings of the Eighth International Grassland Congress.* (1960). p. 396.

Various estimates have been made of the yields that are likely to be obtained from permanent pastures. Davies[5] suggested that the best quality English pastures could produce 300-400 lb. of liveweight gain per acre per annum when grazed by mature cattle and sheep, and pointed out that the average output was probably not more than 130 lb. A more recent estimate made by Bancroft-Wilson and Orton[6] was that permanent grass yielded 15.0 cwt. per acre of utilised starch equivalent (U.S.E.). By comparison temporary grass produced a yield of 21.1 cwt. per acre U.S.E., but these figures relate to an above average sample of farms and the permanent grass received less fertiliser than the leys.

A series of experiments conducted by Davies and Williams[7] showed that the output of beef from the best quality permanent pastures was similar to that from leys, but output from leys was as much as 50 per cent greater than from poorer quality permanent pastures. The only national figures available concerning yields from permanent and temporary grassland are for hay alone. For the years 1948-1958 inclusive the average yield of hay was 22.5 cwt. per acre from permanent grassland while for temporary grass the average yield was 30.1 cwt.

One characteristic of the management of permanent grassland is the small dressings of fertilisers which are applied. Table 3 shows the average rates of application of the three major plant nutrients (nitrogen, phosphate and potash) to temporary and permanent grassland in 1957. Examination of the table indicates that applications of all fertiliser nutrients to permanent grassland are considerably lower than those given to temporary grass.

This management aspect is especially marked for the fattening pastures of the East Midlands. Rates of fertiliser application to permanent pastures in East Leicestershire, an area where some of the best known fattening pastures are to be found, are lower than the average for permanent grass in lowland districts. The overall average rates of fertiliser application reported in 1958 are 0.06, 0.13 and 0.02 cwt. per acre of N, P_2O_5 and K_2O respectively. Only a small percentage of the pasture acreage actually received a dressing of fertiliser—16, 18 and 5 per cent of the acreage were dressed with N, P_2O_5 and K_2O respectively.

5 DAVIES, W. "Permanent grass and leys in Britain." *Proceedings of the Fifth International Grassland Congress.* (1949). pp. 179-187.

6 BANCROFT-WILSON. J. A. and ORTON, F. J. "Grassland recording." *Agriculture.* (1960). Vol. 67, No. 6, pp. 282-286.

7 DAVIES, W. and WILLIAMS, T. E. "Animal production from leys and permanent grass." *Jour. Roy. Agric. Soc. Eng.* (1948). Vol. 109, p. 148.

AVERAGE RATES OF FERTILISER APPLICATION IN 1957

(Cwt. per acre N, P_2O_5 and K_2O)[1]

TABLE 3

Area	Overall average rates of application		
	N	P_2O_5	K_2O
Temporary Grass:			
Arable districts	0.24	0.18	0.17
Grassland districts (Lowland England)	0.19	0.24	0.15
Grassland districts (Wales and English Uplands)	0.10	0.31	0.11
England and Wales	0.19	0.24	0.15
Permanent Grass:			
Arable districts	0.14	0.12	0.08
Grassland districts (Lowland England)	0.07	0.16	0.06
Grassland districts (Wales and English Uplands)	0.03	0.18	0.04
England and Wales	0.07	0.16	0.06

1 *Survey of fertiliser practice 1957 (Part II).* National Agricultural Advisory Service and Rothamsted Experimental Station. (1958).

Fairly detailed accounts of the general management of fattening pastures in the renowned Welland Valley area and in Leicestershire have been published by Davies[8] and Auty[9]. Many of these pastures have not been ploughed in living memory but the best are reputed to be capable of fattening two bullocks per acre in a grazing season. Generally, fairly heavy 2 to 3 year old store cattle are purchased in the spring, grazed extensively, and are sold off throughout the summer and autumn as they fatten. This provides a means of adjusting the stocking rate to the declining level of available herbage as the grazing season progresses. Few cattle are over-wintered as most farms within the region lack suitable buildings, and the relatively small acreages of arable crops which are grown do not leave large quantities of by-products. Most pastures are not grazed by cattle during the winter since the land tends to be heavy and poaching would reduce the productivity of the sward in the following spring and summer. Sheep flocks are often carried on farms in the Midlands grazing area and these are used to "clean-up" the fattening pastures in the autumn and winter.

Even though higher yields can be expected from temporary grassland and despite a wealth of favourable propaganda, coupled with a ploughing grant designed to encourage "taking the plough round the farm" there remains a large acreage of permanent grassland. The continued existence of this large area of permanent grass can be explained in part by limitations of altitude, climate, topography or soil type. Nevertheless there exists a considerable acreage of permanent grass on land suitable for other agricultural uses and the presence of such grass cannot be explained as being due to limitations imposed by natural

8 DAVIES, J. LLEFELYS. *Grass farming in the Welland Valley.* Agricultural Economics Research Institute, Oxford. (1928).

9 AUTY, R. M. *The Land of Britain — the report of the Land Utilisation Survey of Britain.* (1943). Part 57 — Leicestershire.

causes. A tradition of grassland management and a system based on "dog and stick farming", with an adequate personal income for the farmer even though per acre profits may be low may hinder any great reduction in the acreage of permanent grassland. The element of uncertainty is almost certainly less with a permanent grass system than with a ley system. For instance, the incidence of certain diseases or complaints, such as hypomagnesaemia and bloat, is lower on permanent pasture, and risks such as are incurred in the establishment of a ley are avoided. These uncertainties can be largely overcome by a high level of management, but on farms maintaining a high proportion of permanent grass, management of this quality may be lacking and the effort and risks involved may be thought to outweigh the rewards to be expected.

CHAPTER 2

THE RESPONSE OF PERMANENT PASTURES TO FERTILISER APPLICATIONS — A SHORT REVIEW

Few data have been published which show the relationship between the level of fertiliser application and the output of beef from permanent pastures. However, some experimental data are available which show that yields from permanent grassland, under grazing, or simulated grazing conditions, can be raised by the application of fertiliser nutrients.

Probably the best known and some of the earliest work on fertilising permanent pastures is that resulting from a series of trials on Tree Field, Cockle Park, initiated by Sommerville in 1896. The main findings of these trials from that date until 1954 have been summarised by Pawson[1]. Throughout the period over which the trials have been conducted the experimental plots have been grazed by sheep and the pasture output has been measured in terms of liveweight gains. Although the design (there were no replications of treatments) and conduct of these trials have been criticised, the results demonstrate the large response from phosphate dressings on poor permanent pastures. For example, for a six year period 1948-53 the average liveweight gain was 41.5 lb. per acre on the control plot, while a liveweight gain of 101.4 lb. was obtained on a plot receiving $7\frac{1}{2}$ cwt. superphosphate (100 lb. P_2O_5) per acre in 1948 and 1951. The response to potash dressings was much lower. For the same period the output from a plot receiving slag plus 100 lb. of muriate of potash per acre in 1948 and 1951 was only 2.2 lb. per acre higher than for a plot receiving slag alone.

Since the inception of the Cockle Park experiments several workers have shown the beneficial effects of phosphate manuring on permanent pastures.

1 PAWSON, H. C. *Cockle Park Farm.* Oxford University Press, London, (1960). Chapter 3, pp. 44-64.

Brown[2] found that 2,000 lb. of superphosphate (16 per cent) applied annually since 1924 increased production (expressed in therms using Armsby's standards) between 1932 and 1935 by an average of 70 per cent when grazed by dairy heifers. In these experiments increases in relative total production were found to be greater from phosphate and nitrogen dressings than from potash fertilisation (see Table 4).

TOTAL PRODUCTION OF VARIOUSLY FERTILISED PERMANENT PASTURES AS MEASURED BY GRAZING WITH DAIRY HEIFERS

TABLE 4

Fertilisation	Average relative total production Years 1932-35
None	100
Superphosphate (16 per cent.) at 2,000 lb. per acre since 1924	170
The same plus muriate of potash at 400 lb. per acre	198
The same plus potash plus nitrogen at 28 lb. per acre	284
The same plus potash plus nitrogen at 56 lb. per acre	255

The results of experiments carried out by Norman[3] on downland permanent pastures showed that various phosphate dressings applied over a three year period produced yield increases in terms of dry matter and crude protein, and carrying capacity as measured by sheep grazing days. In common with many others, Norman noted that the cover of legumes and the more desirable grass species was increased by the phosphate applications. In this experiment the increases in dry matter yields and stock carrying capacity on plots fertilised with potash only were quite marked, being in the order of 11 per cent from a one cwt. per acre dressing of muriate of potash.

Neenan, Murphy and Conway[4] reported the results of experiments on the application of phosphates to permanent pastures in Eire. In the first year of the experiments they found that the response to phosphate (applied as 2-4 cwt. of superphosphate per acre, depending upon the initial phosphate status of the soil) varied from one centre to another, but was generally smallest where the dry matter yield was already high.

In the second and third years of the investigation the range of treatments and centres was extended. Table 5 shows the treatments given and the dry matter yields measured in 1958 and 1959.

2 BROWN, B. A. "The effects of fertilisers on the soil, the botanical composition and chemical composition of the herbage and the seasonal and total production of grassland in Connecticut." *Proceedings of the Fourth International Grassland Congress, (1937)*. p. 313.

3 NORMAN, M. J. T. "Intervals of superphosphate applications to Downland permanent pasture." *Jour. Agric. Sci.* (1956). Vol. 47, pp. 157-171.

4 NEENAN, M., MURPHY, W. E. and CONWAY, A. "Some Economic Aspects of the application of phosphates to permanent pastures in Ireland." *Jour. Brit. Grassland Soc.*, (1961). Vol. 16, pp. 46-53.

TREATMENTS AND DRY MATTER YIELDS FROM PERMANENT PASTURES IN 1958 AND 1959

TABLE 5 per acre

1958 Treatments	1958 Yield of D.M. (cwt.)	1959 Treatments	1959 Yield of D.M. (cwt.)
Control	44.8	Control	46.6
cwt. 4 superphosphate	53.0	cwt. 3 superphosphate	54.0
1½ muriate of potash	49.0	3 superphosphate and 1 sulphate of ammonia	58.7
1½ muriate of potash and 4 superphosphate	56.0	6 superphosphate and 1 sulphate of ammonia	62.6
1½ muriate of potash and 4 superphosphate and 1 sulphate of ammonia	65.1		

Once again a fairly high response to phosphate, measured as yield of dry matter, was observed. The response to potash was of lesser magnitude. The authors suggest that "the most outstanding feature of the results is the spectacular response to very small applications of nitrogen. . . . . . It would seem that under pasture conditions the response to phosphate is limited by other factors of which nitrogen deficiency seems to be the most important".

The results of manuring permanent pastures, in Northern Ireland[5], showed that dry matter yields (measured by sample clippings when the pastures were grazed under an "on-and-off" system) were increased by 14 cwt. per acre when fertilised with a basic dressing of 4 cwt. per acre of superphosphate plus an additional one cwt. per acre sulphate of ammonia, two cwt. per acre nitro-chalk, and one cwt. per acre muriate of potash compared with a similar sward manured with 4 cwt. per acre of superphosphate only. The yield of the latter sward was 48 cwt. of dry matter per acre.

While fairly consistently high responses to phosphate fertiliser applications on permanent pastures, measured in terms of herbage production, have been observed, the responses to potassic manuring would seem to be much more variable. Simpson and Robertson[6] stated that "an extensive series of experiments on swedes, oats, potatoes and grassland have shown a definite inverse relationship between available phosphorus and the yield response of crops to phosphatic fertilisers". With regard to potassium it is " . . . . . safe to predict a lack of crop response to applied potassium on soils 'high' in available potassium. Crops grown on soils 'low' in available potassium may or may not respond to treatment".

5 "Output of food from Grassland." *Monthly Agricultural Report.* (1952). Vol. 26, Part No. 9, pp. 266-271. (Government of Northern Ireland, Ministry of Agriculture).

6 SIMPSON, K. and ROBERTSON, G. M. "Soil Analysis as a Guide to Fertility." *Scottish Agriculture.* (1958). Vol. 38, No. 3, pp. 121-124.

Walsh, Kilroy and McDonnell[7] investigated the response of grazed pastures to potassic fertilisation in a nation-wide series of field trials conducted in Eire. Visual observations of response recorded within the first year of laying down the trials were taken as the main criterion of evaluation. The results of these observations were that in 44 per cent of the trials definite responses were recorded, responses were doubtful in 31 per cent and definitely no response was recorded in 25 per cent. The general conclusions, concerning potassic manuring of pastures, drawn by these workers were:—

(a) Where conditions with regard to the botanical status of the pasture were right (i.e. a suitable proportion of clover) there was a close correlation between the K value in the soil and response. Definite responses were found up to K values of 3 (low) with responses up to K values of 5 (medium) in some organic and impeded soils.

(b) Where at low K values no response was obtained, lack of response could be explained either by (i) absence of clover in the sward; (ii) extreme deficiency of some other nutrient, especially P or C_a; or (iii) rapid fixation of K in the surface soil.

The main response occurred in terms of clover, grass being affected mainly through increased clover growth and therefore increased nitrogen availability. On new leys under grazing conditions the response was generally much more rapid and more obvious than on old permanent pasture.

Gardner et al.[8] reported work on the nitrogenous manuring of permanent pastures. Results are given as cow-equivalent grazing days, the swards being grazed on a rotational system. In 1927 production from the plots which had received nitrogenous fertiliser (a total of 4 cwt. sulphate of ammonia per acre) averaged 231 cow days per acre; production from the plots which had no nitrogenous fertiliser was 148 cow days per acre. In the following year production averaged 192 and 159 cow days per acre from the nitrogen dressed plots and plots which had not received nitrogenous fertiliser respectively. In the latter year 3 cwt. per acre of sulphate of ammonia were applied to the fertilised plots.

The results of a continuation of these experiments[9] show that for a three year period (1928-1930) the annual average production from plots given a dressing of 3 cwt. sulphate of ammonia per acre per annum was 189 cow days per acre. Production from plots which had received no nitrogenous fertiliser averaged 153.5 cow days per acre. The authors stated that " . . . . over a period of years the percentage increase due to 3 cwt. of sulphate of ammonia applied at intervals to old-established grazing land in Hertfordshire is not likely to exceed

7 WALSH, T., KILROY, J. and McDONNELL, P. M. "Some Aspects of the Potassic Manuring of Pastures." *Eire Dept. of Agric. Journal.* (1957) Vol. 54, pp. 44-62.

8 GARDNER, H. W., HUNTER-SMITH, J., REID, J. W. and WILLIAMS, H. R. "Some observations on the nitrogenous manuring of grassland." *Jour. Agric. Sci.* (1929). Vol. 19, pp. 500-523.

9 GARDNER, H. W., HUNTER-SMITH, J. and WILLIAMS, H. R. "Further observations on the nitrogenous manuring of grassland." *Jour. Agric. Sci.* (1931). Vol. 21, pp. 780-798.

30: it may be a little higher in dry, and less in wet, seasons". Leguminous species had been supressed on the nitrogen plots and at the end were not more than one fifth of the controls.

Gardner[10] found that over a period of six years 3 cwt. per acre of sulphate of ammonia applied to permanent pasture in February produced, on average, an extra 6.05 cwt. of dry matter in April compared with plots which had not received a nitrogen dressing (average production from these plots was 7.5 cwt. of dry matter per acre). When cut in May average production from the control plots was 10.4 cwt. of dry matter, that from the plots which had received 3 cwt. of sulphate of ammonia averaged an extra 2.54 cwt. at that time.

Castle and Reid[11] presented the results of applying nitrogen to a permanent pasture sward over a period of five years. The main findings are shown below (all figures are the annual averages for the five year period).

Nitro-chalk applied (cwt. per acre)	9.0
Total Dry Matter yield per acre:	lb.
Not fertilised	6,040
Fertilised	8,490
Yield of Dry Matter per lb. of Nitrogen applied ...	15.2

In opinion of the authors "these results obtained under practical conditions and over a period of five years confirm . . . . that on the farm substantial increases in yield can be obtained by the application of 7.5—12 cwt. of nitro-chalk per acre on grassland where the P_2O_5 and K_2O staus is maintained by regular applications of mineral fertiliser".

Cave[12] reporting the results of a series of experiments conducted in Eire found that nitrogen applications to old permanent pastures gave quite marked responses when measured in terms of liveweight gain of bullocks—see Table 6. The basal manuring was 4 cwt. superphosphate and 2 cwt. muriate of potash per acre.

LIVEWEIGHT GAINS PER ACRE AT VARIOUS LEVELS OF NITROGEN APPLICATION

TABLE 6

Nitrogen applied (Calcium ammonium nitrate)	Liveweight gains
cwt. per acre	lb. per acre
Nil	340
2	412
4	476
6	530
8	556
12	530

10 GARDNER, H. W. "The response of permanent grassland to nitrogen and the efficiency of its recovery." *Jour. Agric. Sci.* (1959). Vol. 29, pp. 364-378.

11 CASTLE, M. E. and REID, D. "Effects of fertiliser treatments and cutting managements on yield and quality of grass and clover swards." *Monograph No. 9 Chemical Aspects of the Production and use of Grass (Symposium at Dublin* 15-18th *September,* 1959). Society of Chemical Industry (1960).

12 CAVE, W. E. *The Farmers Weekly,* June 16th, 1961. p. 78. See also *Technical Progress Report 1959/60.* Soils Division, An Foras Taluntais, 33 Merrion Road, Dublin 4. p. 99.

Commenting on these experiments, Cave said "on the no-nitrogen and low-nitrogen plots there was quite a lot of clover but it was not vigorous and the no-nitrogen plots were obviously nitrogen starved. On the high-nitrogen plots in the old permanent pasture, Yorkshire fog was noticeably less and rye grass noticeably more than on the no-nitrogen plots".

Work reported in Northern Ireland in 1955[13] indicated that the application of 2 cwt. of sulphate of ammonia, 3 cwt. of superphosphate and 1 cwt. of muriate of potash per acre to permanent pasture could increase the liveweight gain per acre from 346 lb. to 422 lb., a 22 per cent response. In the same experiment bullock grazing days were increased from 132 to 174 (a 32 per cent increase) and the yield of utilised starch equivalent was raised from 15 cwt. to 20 cwt. per acre (a 33 per cent increase).

The data that are available provide no real guide upon which firm recommendations on the manuring of permanent pastures for beef production can be based. The available experimental results do provide an indication that phosphate and nitrogenous fertilisers in particular are likely to increase production from permanent pastures. In general potash does not give such a large response and the response is likely to be much more variable. Some authorities do not recommend the use of heavy nitrogen dressings because the resultant suppression of clover and the subsequent loss of nitrogen from this source may not be offset by a sufficiently high gain from the applied nitrogen, hence a depressed yield results. However, from the experimental data that have been published it would seem that for permanent pastures this effect is not so important as for leys, possibly because of the very small contribution that clover nitrogen makes to many unfertilised permanent pasture swards.

CHAPTER 3

THE RESPONSE TO FERTILISER APPLICATIONS OF SOME EAST MIDLANDS FATTENING PASTURES

(1) Plot experiments

In 1957, workers[1] at the University of Nottingham used Friesian steers to measure, in terms of liveweight gains, the value of contrasting levels of fertiliser application to grassland. Evenly matched groups of bullocks were grazed on a standard sward, one group on paddocks which received 103 units N., 54 units P_2O_5 and 54 units K_2O per acre, the other on paddocks of similar acreage which received only 31 units N. per acre. The ley was of Cockle Park type and of high potential productivity. The animals were strip grazed but herbage was not rationed. The results of this experiment are set out in Table 7.

13 "Manuring of Grassland for Beef." *Monthly Agricultural Report.* (1955). Vol. 30, Part No. 1, pp. 11-12 (*Government of Northern Ireland, Ministry of Agriculture*).

1 IVINS, J. D., DILNOT, Jean and DAVISON, J. "The interpretation of grassland evaluation in relation to the varying potential outputs of grassland and livestock." *Jour. Brit. Grassland Soc.* (1958). Vol. 13, pp. 23-28.

TABLE 7

	Fertiliser Treatment	
	High	Low
	lb.	lb.
Total liveweight gain per acre	445	449
Liveweight gain per bullock	158	156
Dry matter consumption per bullock per day	22.9	20.8
Total consumption of dry matter per bullock	1,469	1,335
Dry matter per lb. of liveweight gain	9.3	8.6
Calculated S.E. per lb. liveweight gain	4.0	3.4
Cold carcase weight per bullock	609	601

No significant differences in either liveweight gains or carcase weights were found. It was calculated that after deducting generous requirements for maintenance, the bullocks on the high fertiliser plot had 4.0 lb. of starch equivalent available for the production of one pound of liveweight gain while the bullocks on the low fertiliser plot had 3.4 lb. available. On the assumption that bullocks in a half-fat condition gaining 2 lb. a day require only 3 lb. of S.E. in excess of maintenance per lb. of liveweight gain, it appeared that the bullocks in both groups were overfed, and that the limitations of the animal set the ceiling to the output of animal products despite the fact that higher fertiliser applications had resulted in a higher production of possibly superior and more palatable herbage.

In 1958[2] the experiment was repeated on 10 acres of a first year ley using pure-bred Hereford bullocks in a forward store condition. Half the cattle were implanted with hexoestrol to increase their growth potential. All the stock were fattened off grass during the summer months.

The fertiliser treatments were applied early in March at the following rates:

	N units	P_2O_5 units	K_2O units
Low fertiliser plots	22	18	18
High fertiliser plots	72	54	54

The bullocks were divided into four matched groups and two groups were implanted with 45 mgms of hexoestrol on the 1st May. Weight checks were made at weekly intervals.

The average daily rate of gain on each of the four plots is given in Table 8.

2 DAVISON, J. "The animal/pasture complex in relation to the evaluation of grassland." University of Nottingham, unpublished Ph.D. thesis. (1958).

AVERAGE LIVEWEIGHT GAIN PER BULLOCK PER DAY

TABLE 8

Treatment	Liveweight gain per bullock per day
	lb.
High fertiliser/No hormones	1.53
Low fertiliser/No hormones	2.75
High fertiliser/Hormone treated	2.35
Low fertiliser/Hormone treated	2.74

A highly significant difference was established between the liveweight gains of the bullocks on the high and low fertiliser plots with the heavier rate of application being associated with the lower rate of gain. There was no significant difference between the liveweight gains of the hormone treated and unimplanted bullocks nor was there any significant interaction between the hormone and fertiliser treatments.

The conclusion was drawn from the above two and other experiments that yields of animal products from grassland are determined by either the potential productivity of the animals or the potential productivity of the sward. In these cases the animal potential proved the limiting partner.

The animal potential is dependent on the genetic qualities of the livestock (i.e. on their inherited capacity for producing meat or milk), on their health and stage of fattening or lactation and on all the features of animal husbandry which can influence the level of animal output.

The grass potential is dependent on the quantities of herbage available and its nutritive value and is determined by sward composition, stage of growth, rainfall and all features of husbandry which determine herbage production.

Leading graziers have always recognised that grass potential and animal potential should be matched by adjusting the stocking rate to the amount of keep available. It is obvious that if the grass potential exceeds the animal potential, e.g. at the late spring flush, grass will not be fully utilised and this was the case in the trials quoted above. Conversely, if the animal potential exceeds the grass potential, the animal production will decline or be limited unless the deficit is made good by feeding concentrates or other supplements. This frequently happens in very early spring or late autumn, or on poor grassland or where the stock consists of high yielding spring calvers.

If the potential of a sward is improved by reseeding, fertiliser application, etc. then the animal potential must be increased or the surplus herbage must be conserved. The most direct way of influencing animal potential is to vary the stocking rate.

(2) A supervised field trial

A simple experiment, to be carried out on a number of commercial farms, was launched in the spring of 1958 by University of Nottingham Department of Agricultural Economics. On each farm two fields (or on some farms one divided field) were set aside for the experiment. One field was fertilised (Area A), and the other (Area B) was not fertilised and acted as a control. Both fields were grazed by beef cattle and the objective was to discover whether the response (if any) on Area A would be sufficient to pay the cost of the fertiliser applied.

Selection of Farms

In 1958 twelve farmers co-operated in the investigation. In 1959 twenty farmers offered their co-operation, including nine of those who had co-operated in the previous year. The distribution of the co-operating farms is shown on the map (Figure 1). While a number of farms are outside the area arbitrarily defined as the Market Harborough Fattening Pastures, with the exception of three farms (situated at Burton Lazars, Empingham and Saddington), the fields used in the study were considered to be representative of permanent "fattening" pastures within the East Midlands. When selecting the farms for the investigation the following factors had to be considered.

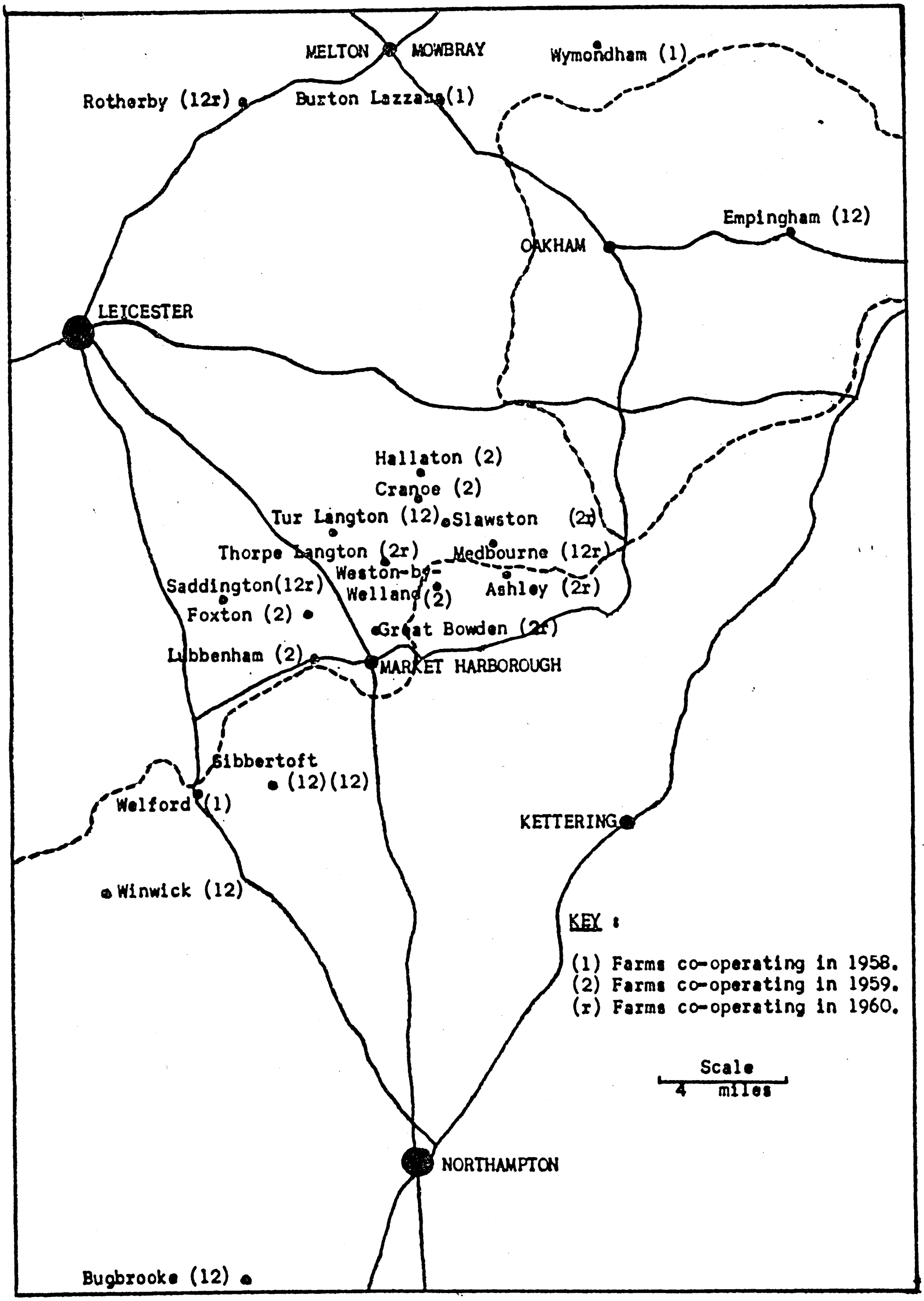
The factor of first importance was that two matching fields of permanent pasture should be available (or where one field was divided, that this could be done fairly) on each farm. The fields eventually chosen for use were matched with respect to previous manurial treatment, past grazing treatments, with special emphasis on winter grazing immediately prior to the commencement of the experiments. The fields were also matched with regard to uniformity within each field, the ephemeral "quality as a fattening pasture" as assessed by the farmer, and size, to avoid as far as possible wide discrepancies in the numbers of cattle grazing the fertilised and not fertilised fields on each farm during the course of the experiment.

To be selected for co-operation farms had to have suitable cattle. That is, where possible, fattening stores (one farm was included in the investigation on which yearling cattle to be sold as stores grazed the experimental fields), and a sufficient number of cattle in relation to the size of the experimental fields in order to be able to choose reasonably well matched bunches to graze each field and to maintain a suitable stocking rate. It was hoped that grazing of the experimental fields would be confined to cattle alone but in some instances sheep also grazed the fields for short periods. This occurred especially in 1959. Nevertheless, when the need to do this arose equal numbers of sheep grazed both fields.

Co-operating farms also needed suitable holding-pens or buildings which were near to the experimental fields and convenient facilities for weighing the cattle on a portable weighbridge (namely, ease of access, and firm level ground on which to set down the weighbridge).

Finally, and by no means of least importance, because of the limited labour resources available from the Department of Agricultural Economics, the co-operating farmers had to be able and willing to provide labour to assist at the weighings of the cattle.

FIGURE 1
LOCATION OF CO-OPERATING FARMS.



The Fields

The average sizes of the experimental fields on the twelve co-operating farms in 1958 were 10.3 acres and 11.3 acres for the fertilised and not fertilised fields respectively. On the twenty farms co-operating in the following year the average size of the fertilised fields was 10.7 acres and that of the not fertilised fields was 11.3 acres.

In August 1959 botanical assessments were carried out by Grassland Husbandry Officers of the National Agricultural Advisory Service on the experimental fields on eleven of the co-operating farms. The dominant sward species on all of these fields was Agrostis. Other grass species present in the swards, in order of dominance, include perennial rye grass, Yorkshire fog, crested dog's tail, cocksfoot, fescue species, timothy, meadow grass species, and sweet vernal. The clover content of the swards was generally low. On each farm there were virtually no botanical differences between the swards of the fertilised and not fertilised fields.

Soil tests with respect to lime (CaO), phosphate (P_2O_5), and potash (K_2O) were carried out on the experimental fields. Of the twelve farms co-operating in 1958, only two showed a phosphate analysis of "low" and only one farm had a soil with a "low" potash content. Seven of the farms had lime requirements of over 25 cwt. per acre. Five of these farmers who co-operated again in 1959 corrected these deficiencies during the winter of 1958-59. There were no differences between fields with regard to CaO, P_2O_5 and K_2O, on any of the twelve farms.

Of the eleven farms which co-operated in 1959 only, four had phosphate contents of "slightly low" or "low" on both fields and on one additional farm there was a "low" phosphate content on the not fertilised field. Two unfertilised fields had "low" potash contents. The lime status on all fields was satisfactory.

The Cattle

In the first year of the investigation some 600 cattle grazed the experimental fields, and in 1959 the fields were grazed by 690 cattle.

Cross-bred Herefords (with either Shorthorns or Friesians) were the predominant breed of cattle which grazed the experimental fields in both 1958 and 1959. These were mainly purchased, two-year-old, Irish reared cattle. Other breeds included Aberdeen Angus (and their crosses), Friesian, South Devons, Welsh Blacks, and some other various breeds and cross-breds. The majority of the cattle were steers. The cattle were typical of those found on East Midland grazing farms.

The cattle were as evenly matched as possible with regard to breed, weight, condition, sex, method of wintering, or if purchased, place of origin.

However, some difficulties, due to differences between the size of the fields and stocking rates, were experienced in matching cattle to graze the experimental fields. In such cases, when the cattle could not be matched head for head, bunches of cattle were matched for uniformity within a group and between groups, i.e. where differences between cattle occurred these differences were distributed in equal ratios between groups. The average weights of the cattle placed on the experimental fields are presented in Table 9.

AVERAGE LIVEWEIGHTS OF CATTLE PLACED ON THE EXPERIMENTAL FIELDS

TABLE 9 lb. per head

Year	Area A	Area B
1958	918	900
1959	932	922

Fertilisers Applied

For each year of the investigation a compound fertiliser, containing each of the three major plant nutrients, was chosen.

In 1958 five cwt. per acre of a 5 : 12½ : 12½ compound fertiliser were applied to Area A in the spring of that year. A high phosphate-potash compound was chosen in the hope that this would promote clover growth, and so enhance the production of herbage from the sward via the nitrogen fixing ability of the clover. Since knowledge of both the likely response of the pastures to fertiliser application and the sensitivity of the experimental technique in measuring the response was very limited, a liberal fertiliser dressing was applied.

Three cwt. per acre of an 8:12:8 compound fertiliser were applied to Area A in the second year of the investigation. On farms which co-operated for both years the fertiliser was applied to the same field in each year. The fertiliser dressing was modified in the light of experience concerning the experimental technique gained during 1958, and in consultation with specialist officers in whose view the compound fertiliser applied in 1958 may have had a higher potash content than was necessary.

Management of the Experimental Fields

All management decisions throughout the course of the investigation were made by the co-operating farmers. The farmers were, however, encouraged to apply the fertiliser as soon as they deemed suitable in the spring, and to stock both of the experimental fields as heavily as they thought possible.

The "average dates" of fertiliser application and of the commencement of the grazing season are presented in Table 10. In each year, and on each farm, the grazing began on the same day on both fields.

AVERAGE DATES OF FERTILISER APPLICATION AND COMMENCEMENT OF THE GRAZING SEASON

TABLE 10

Year	Date of fertiliser application	Date of commencement of grazing season
1958	18th March	1st May
1959	15th March	19th April

The co-operating farmers were encouraged to manage the cattle on the experimental fields as they would under normal farming conditions, adjusting stocking rates and selling cattle etc. as and when they thought necessary. The cattle placed on the fields were weighed on a portable weighbridge at the beginning of the grazing season, and subsequently at approximately six-weekly intervals and at the end of the grazing season. If a farmer wished to move any cattle on or off the fields between the regular weighings these cattle were weighed at the time of moving.

The end of the grazing season on each field was either taken as the date when, even after adjusting stocking rates to the declining herbage production, the farmer began to offer supplementary feed, or when all stock were finally removed from the fields. This procedure prevented difficulties which might have arisen over the accurate recording of the amounts of supplementary feeds eaten (and the assessment of its quality), and of making a residual calculation of the liveweight gain from grass after calculating the theoretical gain which could be attributed to the supplementary feeds.

(3) Results

Table 11 shows the average stocking rates and length of grazing season for both years of the investigation.

AVERAGE STOCKING RATES AND LENGTH OF THE GRAZING SEASONS

TABLE 11

Year	Stocking Rates (beasts per acre)		Length of the grazing season (days)	
	Area A	Area B	Area A	Area B
1958	1.13	1.02	163	163
1959	0.88	0.77	151	142

The average liveweight gains per acre for the twelve farms which co-operated in the investigation in 1958 and for the twenty farms which co-operated in 1959, and the differences in liveweight gain between fields for each year are presented in Table 12.

AVERAGE LIVEWEIGHT GAINS PER ACRE AND AVERAGE DIFFERENCE IN LIVEWEIGHT GAINS BETWEEN FERTILISED (A) AND NOT FERTILISED FIELDS (B)

TABLE 12 lb. per acre

Year	Average liveweight gains		Differences (A-B)
	Area A	Area B	
1958	367.0	330.0	37.0 (±) 18.2[1]
1959	307.1	269.7	37.4 (±) 11.0[2]

[1]Difference significant ($p=0.1$)
[2]Difference significant ($p=0.05$)

It is realised that, in 1959, the differences in liveweight gains per acre between fields need not be attributed solely to the influence of the fertiliser applied in the spring of 1959 on the nine farms which were included in the investigation for both years. It is possible that some of the resultant difference may be imputed to the residual effects, if any, of the fertiliser application made in the spring of 1958 as well as to the direct effect of the fertiliser dressing given in the spring of 1959.

In Table 13 the average liveweight gains (and differences), together with the average stocking rates, have been grouped into those for the nine farms which were included in the investigation for both years, and for the eleven farms which co-operated in the latter year only.

AVERAGE LIVEWEIGHT GAINS, DIFFERENCES IN LIVEWEIGHT GAINS AND STOCKING RATES FOR TWO GROUPS OF CO-OPERATING FARMS

TABLE 13

Farms	Average liveweight gains (lb. per acre)			Average stocking rates (beasts per acre)	
	Area A	Area B	Difference (A-B)	Area A	Area B
9 farms—1958	386.3	352.3	34.0	1.16	1.02
—1959	331.9	288.6	43.3	1.03	0.84
11 farms—1959 only	286.8	254.1	32.7	0.75	0.71

From the periodic weighings of the cattle which grazed the experimental fields it has been possible to make a calculation of the average monthly liveweight gains per acre for each month throughout the grazing season. The results of these calculations, for each field (fertilised and not fertilised) and for each year, are presented below in Table 14.

AVERAGE LIVEWEIGHT GAINS PER ACRE FOR EACH MONTH OF THE GRAZING SEASON ON FERTILISED AND NOT FERTILISED FIELDS IN 1958 AND 1959

TABLE 14

	April	May	June	July	Aug.	Sept.	Oct.	Nov.
1958								
Fertilised field, (Area A)	8.4	82.8	103.2	63.6	46.9	43.1	19.4	—
Not fertilised field, (Area B)	7.1	70.4	96.9	55.7	42.9	40.3	16.8	—
Difference (A—B)	1.3	12.4	6.3	7.9	4.0	2.8	2.6	—
1959								
Fertilised field, (Area A)	43.3	110.3	68.7	41.5	28.3	11.4	2.4	1.2
Not fertilised field, (Area B)	34.6	96.9	65.9	36.6	23.9	8.4	1.6	0.8
Difference (A—B)	8.7	13.4	2.8	4.9	4.4	3.0	0.8	0.4

It can be seen that the greatest benefit was derived from the fertiliser application in the early months of the grazing season. This was most marked in the dry summer of 1959, when by the end of June 68 per cent of the eventual difference in liveweight gain between the two fields had accumulated. At the same time in 1958 this percentage was 54.

Throughout the grazing season, in each year of the investigation, a higher average stocking rate was carried on the fertilised fields than on the not fertilised fields. As was to be expected, the stocking rates on the experimental fields were highest during the early months of the grazing season. The differential between stocking rates was biggest too during these months.

(4) Residual Response

In 1960 seven of the farmers, who had co-operated in 1958 and 1959, offered to co-operate in an extension of the investigation in an attempt to measure any residual response there may have been to the fertiliser applied in previous years. Three of these farmers had applied fertiliser to Area A in 1958 and 1959. The other four had applied fertiliser in 1959 only.

The experimental technique followed was identical to that employed in the previous years of the investigation.

The "average date" of the beginning of the grazing season was May 3rd, and the average length of the grazing season was 121 days.[3] As before, grazing commenced on the same day on both experimental fields on each farm. The length of the grazing season was also the same on both fields on each farm.

In all, 201 cattle grazed the experimental fields during 1960. The average weight of these cattle when the grazing season began was 933 lb. for those grazing the experimental fields which had been fertilised in previous years, and 954 lb. for those grazing the not fertilised fields.

The average liveweight gains per acre and the average stocking rates of the experimental fields in 1960 are presented in Table 15.

AVERAGE LIVEWEIGHT GAINS PER ACRE AND STOCKING RATES OF THE EXPERIMENTAL FIELDS IN 1960

TABLE 15

Average liveweight gains (lb. per acre)			Average stocking rates (beasts per acre)	
Area A	Area B	Difference (A-B)	Area A	Area B
254	264	(−) 10	1.01	1.03

Although the farmers said they had detected a slight improvement in the clover content of the swards which had received fertiliser in 1958 and/or 1959, in 1960 there was no discernible increase in available herbage over the not fertilised pastures. This is borne out by the recorded figures for average liveweight gains per acre. These show no significant difference between the fields which had received fertiliser in the year (or years) prior to 1960 and the fields which had received no fertiliser.

(5) Discussion

It should be noted, when considering the results of this investigation, that the summer of 1958 was one of the wettest on record and that 1959 was one of the driest. Rainfall data for the two years, as measured at the School of Agriculture, are presented in Table 16. The influence of

3 The length of the grazing season in 1960 was a somewhat "artificial" measure due to complications arising from attestation which became compulsory in that year.

rainfall in determining the output of meat from permanent pastures can be seen by studying the results obtained for the nine farms which co-operated in both years. The mean difference of 63.7 lb. of liveweight gain per acre between the not fertilised fields in 1958 and 1959 is much greater than the response measured to the fertiliser application in either year.

In each year the fertiliser applied contained relatively high proportions of phosphate (P_2O_5) and potash (K_2O). Although in 1959 the quantity of phosphate applied was reduced from 62½ units per acre to 36 units per acre and the quantity of potash was reduced from 62½ units to 24 units, the quantities of nitrogen applied were practically the same in each year, 25 units per acre and 24 units per acre respectively in 1958 and 1959. Even though the weather was very different between years, and a considerably reduced quantity of phosphate and potash was applied in 1959, the response to the fertiliser applications, as measured by the extra liveweight gain per acre, was practically the same in both 1958 and 1959. However, in 1958 the extra liveweight gain represented an 11 per cent increase in output above the not fertilised fields, while in 1959 this percentage was 14.

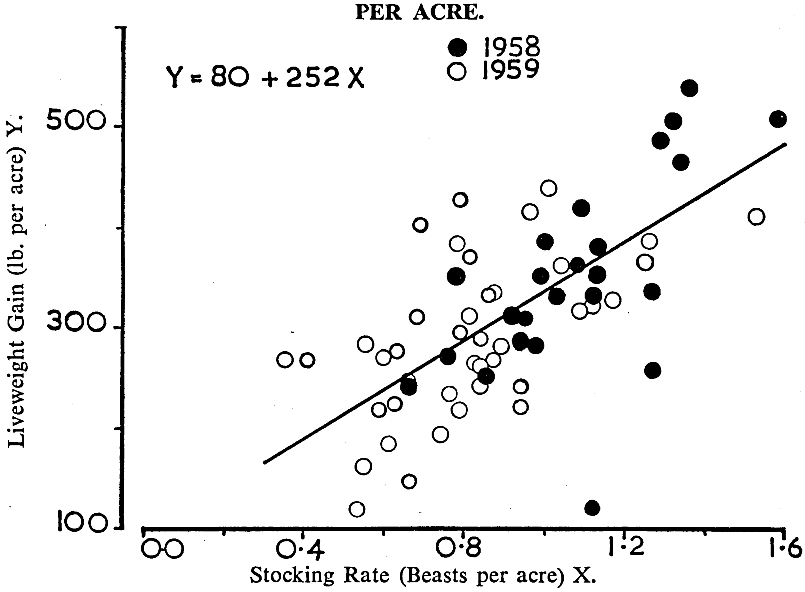
The fields to which the fertiliser dressings had been applied in the dry year (1959) provided, on average, an extra nine days grazing compared with the not fertilised fields. However, in 1959, this lengthening of the grazing season was of slight importance in its effect on the difference in liveweight gain. The extension of grazing occurred at the end of the grazing season when average liveweight gains per acre were very low anyway (see Table 14).

The greatest benefit of the fertiliser application was acquired in the early months of the grazing season. Nevertheless, on the evidence accrued in the two years of the investigation, the fertilisers did not lead to the production of an "earlier bite" in the spring, as reflected by the dates of the commencement of the grazing season. The value of any "earlier bite" which may have been produced is probably discounted to some extent by graziers since the "turning-out" date is influenced by factors other than the amount of herbage available. These factors include a traditional "turning-out" date, and climatic conditions. Wet weather could lead to poaching of pastures on heavy soils and the prevalence of cold winds may cause farmers to delay the purchase of store cattle to avoid a set back in their condition when turned out on the fattening pastures. Any extra herbage available in the spring due to the fertiliser application was most likely reflected in the higher stocking rate when grazing eventually began, rather than by earlier grazing.

The fertiliser applications in both years had no discernible effect upon the quality of the animals eventually sold off from the experimental fields. In the opinion of the co-operating farmers the cattle fattened equally well on both fertilised and not fertilised fields. In 1959 there was some indication that a slightly higher percentage of the cattle were sold from the fertilised fields, rather earlier than from the not fertilised fields, i.e. they gained weight at a slightly higher rate.

FIGURE 2

RELATIONSHIP BETWEEN LIVEWEIGHT GAIN AND STOCKING RATE PER ACRE.



Although fairly heavy applications of phosphate and potash were administered in 1958 and 1959 no residual response, in terms of liveweight gain, could be measured in 1960.

Ivins et al.[4] demonstrated that, when cattle were grazed at a fixed rate of stocking, no extra liveweight gain was derived from fertilised as opposed to not fertilised plots. These workers, therefore, concluded that the capacity of an individual animal to gain weight is limited and higher liveweight gains per acre can only be obtained by putting on extra stock to eat extra grass which may be available. Figure 2 shows the relationships between stocking rates per acre and liveweight gains per acre on the experimental fields in 1958 and 1959 respectively. In the wet season of 1958 practically the whole of the response to the fertiliser application—35 lb. out of 37 lb.—could be attributed to the extra stock which were carried on the fertilised fields. Some 20 lb. of the response to the fertiliser dressing in the dry season of 1959 could be assigned to the difference in stocking rates between the two groups of fields. This relationship between stocking rates and liveweight gains is what would be expected in so far as extra herbage available would normally be utilised by stocking more heavily, provided the cattle continued to make satisfactory progress.

It should be stressed that the response to fertiliser applications measured in this investigation was obtained with the standard of grassland management, interpreted in its widest sense, practised on typical grazing farms. The only deviation from normal practice was the application of fertiliser.

4 See above — pp. 13-15.

RAINFALL DATA FOR THE YEARS 1958 AND 1959[1]

TABLE 16

	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Year
1958													
Rainfall (inches)	2.21	2.65	1.60	0.66	1.76	3.53	4.19	1.93	2.47	2.20	1.24	2.54	26.98
Rainfall as a percentage of average 1885—1915	134	191	110	47	100	201	193	85	165	95	67	115	124
1959													
Rainfall (inches)	2.44	0.10	1.30	2.14	0.30	0.76	1.00	0.69	0.01	1.78	2.23	3.08	15.83
Rainfall as a percentage of average 1916—1950	112	6	92	127	16	52	42	31	1	84	101	160	69

[1]SOURCE: University of Nottingham, Reports of the School of Agriculture for 1958 and 1959.

CHAPTER 4

AN ECONOMIC APPRAISAL OF FERTILISER APPLICATIONS TO PERMANENT PASTURES FOR BEEF PRODUCTION

Whether or not it pays to fertilise permanent pastures grazed by fattening cattle depends, in the main, upon the cost of the fertilisers applied, the amount of extra liveweight gain resulting from the fertiliser application, and on the unit value of the extra liveweight gain. Some other factors which may influence the economic worth of the practice will also be mentioned.

The financial results of the East Midlands investigation, expressed simply as the cost of fertilisers applied and the value of the extra liveweight gain, are presented below in Table 17.

FINANCIAL RESULTS OF FERTILISING SOME EAST MIDLAND FATTENING PASTURES

TABLE 17 per acre

	1st Year	2nd Year
Extra liveweight gain (lb.)	37.0	37.4
	£ s. d.	£ s. d.
Cost of fertiliser applied	3 16 3	2 5 0
Value of extra liveweight gain	2 11 6	2 12 0
Margin	(—) 1 4 9	7 0

The compound fertiliser (5:12½:12½) applied in the first year of the investigation has been charged at 15s. 3d. per cwt., that applied in the second year (an 8:12:8 compound) has been charged at 15s. 0d. per cwt. These prices are based on manufacturers' 1961/62 quotations for February delivery in six ton lots, net of subsidy payments.

The value of liveweight gain has been credited at the rate of 155s. 9d. per live cwt. and is an average of the weekly standard prices for the summer of 1962 on the assumption that 10 per cent of the cattle are sold in June; 15 per cent are sold in July; and 25 per cent are sold in each of the months August, September and October. These percentages are suggested by the experiences of farmers who co-operated in the investigation.

By this simple means of appraising the financial results, it can be seen from the table that the heavy dressing of fertiliser applied in the first year, 5 cwt. per acre of a high phosphate-potash compound, did not produce a response sufficient in value to cover the cost of the fertiliser applied. Despite the trend towards rising fat cattle prices, there would have to be substantial further alterations in the prices of both fertiliser and fat cattle before fertiliser applications, at the level used in the first year of the investigation, would become profitable. A price reduction of £3 per ton for the fertiliser and a further rise of 5s 0d. per live cwt. above the 1962 price for fat cattle, would still leave a deficit of some 8s. per acre.

In the second year of the investigation the value of the response resulting from the smaller dressing of the cheaper compound left a small positive margin above the cost of the fertiliser. Given the price alterations suggested in the preceding paragraph the margin arising from this fertiliser treatment would be increased to 17s. 8d. per acre.

It should be noted that the fertiliser applications resulted in higher liveweight gains per acre only by virtue of the fact that the carrying capacity of the pastures was increased. Average liveweight gains per head were practically identical on both fields: 328 lb. and 324 lb. on the fertilised and not fertilised fields respectively in 1958, and in 1959 for the fertilised and not fertilised fields the respective average gains per head were 349 lb. and 350 lb.

In each year of the investigation the average stocking rate on the fertilised fields was slightly more than 0.1 beast per acre higher than on the not fertilised fields. Therefore, to obtain the extra liveweight gain from fertilising the pasture a greater capital investment in store cattle is required. A typical price for 8 cwt. stores purchased from mid-April to mid-May might be £70. Hence, to maintain the higher stocking rate for the five month grazing season, interest charged at 5 per cent per annum, would add a further 3s. 0d. per acre to the costs of applying fertiliser to the pastures.

The costs of spreading the fertilisers have not been charged in the financial appraisal outlined above. On most farms the necessary machinery and labour would be available and the costs of these services would be fixed for the farm. A very small extra cost for fuel would be incurred. This is likely to be within the region of 6d. to 8d. per acre (Culpin[1] suggests that the rate of working for an 8 ft. fertiliser distributor is two acres per hour. Wood[2] gives figures for fuel costs of 1s. 4d. and 1s. 0d. per hour for paraffin and diesel engined tractors respectively). The margin would be decreased, or the deficit would be increased by this small amount. If the full labour, machinery and fuel costs were charged as variable costs, then it is likely that the small positive margins in the second year would be negated.

The extra liveweight gains per acre on the individual farms in the sample are shown in Tables 18 and 19. Using the prices of fertiliser and beef quoted above it can be calculated that in 1958, 55 lb. of liveweight gain were required to pay for the fertiliser and in 1959, 32 lb. of extra gain were required if a loss was to be avoided. It can be seen that in 1958, three of the twelve farms in the sample achieved profitable gains and that in 1959, half of the 20 farms in the sample did so.

The data that are available do not make it possible to recommend how the rates of fertiliser application should be altered with changes in

1 CULPIN, C. *Farm Mechanisation: Cost and Methods.* Crosby Lockwood and Sons, Ltd., London, (1951) p. 25.

2 WOOD, R. O. "Changes in the Economy of Tractor use." *Farm Management Notes.* (1959). No. 21, p. 13. University of Nottingham, Department of Agricultural Economics, Sutton Bonington.

LIVEWEIGHT GAINS PER ACRE AND STOCKING RATES PER ACRE ON INDIVIDUAL FARMS IN 1958

TABLE 18

Farm No.	Liveweight gain per acre			Stocking rate—beasts per acre		
	With Fertiliser	Without Fertiliser	Difference	With Fertiliser	Without Fertiliser	Difference
	lb.	lb.	lb.	No.	No.	No.
1	541	381	160	1.36	1.13	0.23
7	258	122	136	1.27	1.12	0.15
3	420	332	88	1.09	1.03	0.06
16	312	271	41	0.92	0.76	0.16
13	287	253	34	0.94	0.85	0.09
6	510	479	31	1.58	1.29	0.29
15	310	285	25	0.95	0.98	(−)0.03
12	252	245	7	0.78	0.66	0.12
10	337	332	5	1.27	1.12	0.15
11	353	351	2	1.13	0.99	0.14
2	365	386	(−)21	0.98	1.00	(−)0.02
8	466	527	(−)61	1.34	1.32	0.02
Average	367	330	37	1.13	1.02	0.11

Farms above the line obtained profitable gains (at 1962 prices), since the liveweight gain per acre exceeded the 55 lb. required to cover the cost of fertilisers i.e. £3 16s. 3d.

LIVEWEIGHT GAINS PER ACRE AND STOCKING RATES PER ACRE ON INDIVIDUAL FARMS IN 1959

TABLE 19

Farm No.	Liveweight gain per acre			Stocking rate—beasts per acre		
	With Fertiliser	Without Fertiliser	Difference	With Fertiliser	Without Fertiliser	Difference
	lb.	lb.	lb.	No.	No.	No.
31	315	186	129	0.84	0.61	0.23
3	365	264	101	1.25	0.84	0.41
10	318	220	98	1.09	0.79	0.30
24	404	313	91	0.69	0.68	0.01
16	328	244	84	1.17	0.84	0.33
25	334	265	69	0.86	0.82	0.04
30	278	219	45	0.63	0.59	0.04
20	429	384	59	0.79	0.78	0.01
1	363	323	40	1.04	1.12	(−)0.08
26	370	335	35	0.81	0.87	(−)0.06
12	195	164	31	0.74	0.55	0.19
28	148	119	29	0.66	0.53	0.13
6	411	387	24	1.53	1.26	0.27
8	439	416	23	1.01	0.96	0.05
13	285	267	18	0.55	0.35	0.20
22	244	243	1	0.94	0.94	—
21	269	270	(−)1	0.87	0.60	0.27
11	283	312	(−)29	0.89	0.81	0.08
27	197	236	(−)39	0.79	0.76	0.03
29	167	226	(−)59	0.41	0.63	(−)0.22
Average	307	270	37	0.88	0.77	0.11

Farms above the line obtained profitable gains (at 1962 prices), since the liveweight gain per acre exceeded the 32 lb. required to cover the cost of fertilisers i.e. £2 5s. 0d.

the prices of fertiliser and fat cattle. All that can be done is to calculate changes in the deficit or margin at the single rate of application.

It is likely that the level of response to the fertilisers applied in the second year of the investigation, even with more favourable price relationships, is such that uncertainty factors may preclude the application of fertilisers to permanent pastures in commercial farming practice. The prices which an individual producer receives for fat cattle are subject to a fairly wide variation from the "average" or standard guaranteed price. In a farmer's mind the chances of receiving lower than average prices may be such that the possibility of making a small positive margin by fertiliser application is not considered worthwhile.

The results of this investigation show that it did not pay to fertilise some East Midlands fattening pastures for beef production with the particular combination of fertilisers used and at the prevailing prices of fertilisers and fat cattle.

When the data obtained in 1954 in Northern Ireland[3] are priced in the same way as in Table 17, the value of the response (76 lb. of liveweight gain per acre) at 1962 fat cattle prices was enough to cover the cost of the fertilisers[4] and to leave a margin of £1 15s. 9d. per acre. Results in 1955 and 1956 were better. The average margin per acre for the three years exceeded £6.[5]

While, from the results of this experiment it would appear that application of fertilisers to permanent pastures is a profitable practice, the validity of a recommendation based on this data is limited. The response was measured in a small scale trial, the experimental area was limited to two 3½ acres plots.

Reports issued by Provincial Agricultural Economic Departments including those by Richardson[6], Hallett[7] and Luxton and Tyers[8] have all stressed the importance of the gross feeder's margin in determining the profitability of grass fattened cattle. The feeder's margin—the difference between the purchase price of the store cattle and the price received when the cattle are sold fat—depends on three factors, the cost of the store animal, the liveweight gain per head, and the price per cwt. received for the fat animal. All other costs have to be met out of the gross feeder's margin.

The application of fertilisers to permanent pastures is unlikely to affect the feeder's margin by influencing the liveweight gain per head, but it is conceivable that fertiliser applications could affect the feeder's margin by other means. If, for instance, an "earlier bite" could be

3 "Manuring of Grassland for Beef." *Northern Ireland, Min. of Agric. Monthly Agric. Report.* (1955). Vol. 30, pp. 11-12.

4 The fertilisers applied were:
   2 cwt. per acre sulphate of ammonia, at 11s. 3d. per cwt.;
   3 cwt. per acre superphosphate, at 9s. 0d. per cwt.; and
   1 cwt. per acre Muriate of potash, at 20s. 6d. per cwt.
   Total cost—£3 10s. 0d. per acre.

5 Private communication.

6 RICHARDSON, P. P., *The Fattening of Cattle on Grass* 1951 *and* 1952: *A Study of Management, Costs and Returns.* University of Nottingham, Dept. of Agric. Econ. (1953). F.R. No. 123.

7 HALLETT, G., *Profitable Cattle Fattening*: *A Study of Grass Fattening on Welsh Farms.* University College of Wales, Aberystwyth, Dept. of Agric. Econ (1958).

8 LUXTON, H. W. B. and TYERS, K. G., *Cattle Fattening on Grass*: *A Study in Southwest England 1958.* University of Bristol, Dept. of Econ. (Agric. Econ.), Bristol II Province. (1959). Report No. 114.

obtained, then it might be possible to purchase stores earlier and cheaper, especially since the spring rise in store cattle prices is quite steep. In the East Midlands investigation the fertilisers applied did not, in the opinion of the co-operating farmers, produce an earlier bite. It is, of course, possible that an earlier application would have been more effective. The fertiliser application also failed to exert a measurable influence on the date of sale of fat cattle. Earlier sales could have some financial benefit, provided a satisfactory liveweight gain per animal had been attained, because of the declining level of fat cattle prices throughout the summer period. Further experimental evidence is required to ascertain if, and under what conditions, these suggested benefits could be obtained.

Although it has been shown that herbage production from permanent pastures can be increased by the application of straight phosphatic and nitrogenous fertilisers (these are relatively cheap fertilisers and so a worthwhile response to their application is more likely to be profitable), because of technical difficulties associated with the interpretation of the data in their present form, before the profitability of such applications can be assessed, further data relating the level of fertilisers used directly to the output of beef are needed.

CHAPTER 5

SUPERVISED FIELD TRIALS AS SOURCES OF INPUT-OUTPUT INFORMATION

The experiment described in Chapter 3 was a supervised field trial undertaken on commercial farms. It appears to have been one of the first trials involving livestock to be conducted along these lines. It is therefore appropriate to consider the merits and disadvantages of this type of investigation in comparison with the plot experiments normally undertaken by experimental farms and research institutes.

Under ideal experimental conditions, an investigator would be able to control all the conditions affecting the output or the behaviour of the plant or animal being studied. He would then proceed to vary, in turn, each of the factors thought to affect the performance of the plant or animal in question and to measure the changes in output resulting from a given variation in each factor.

Ideal conditions are seldom achieved even in laboratories because of the difficulty of securing absolute uniformity in materials, temperature, management and so on. To secure accurate and reliable results, experiments must be repeated or "replicated" to ensure that differences in factors which are not being measured do not bias the results obtained. An investigator studying the response of a crop to fertiliser treatments wants to be sure that the yield differences he has measured are in fact due to the use of fertilisers and not to differences between the control and the treated plots in soil, drainage or aspect. He will therefore repeat his experiments with control and treated plots randomly placed in the trial fields. The investigator working with animals also replicates his trials whenever possible. With cattle at grass this may be extremely difficult because of the area of land required, particularly if more than one level of treatment (in addition to a control) is to be tested.

Farmers often complain that although experimental stations have shown a particular practice to be profitable, conditions on commercial farms are so different that experimental results cannot always be applied with confidence. In other words, the responses recorded under experimental conditions cannot always be obtained under commercial conditions.

The difficulties of translating experimental results into commercial practice depend on the difference in conditions between commercial and experimental farms. The most obvious of these are the size of the unit and the level of management.

Many experiments are confined to very small plots. If livestock are involved, this may create problems regarding shelter, exercise, worm and disease infestations and control of grazing which might not arise to the same extent or in the same way on a commercial farm. On the other hand, the level of management may well be higher on the experimental farm where the workers concerned may well be specialists. The quality of management will be particularly important if the effect of a treatment can be modified by managerial actions. It is clear, for example, that the return from fertilising grassland will be limited if the "manager" fails to conserve the extra herbage or to provide more stock to eat it.

The solution to this problem may be to plan experiments which minimise the differences between conditions on "commercial" and on "experimental" farms. One method is to use the "farmlet" approach. This involves dividing an experimental farm into blocks, ranging from 20-50 acres in size, and applying a different "treatment" or system of farming to each block. This has the disadvantage of limiting the number of treatments and replications which may be handled. On the other hand, it enables the effect of the proposed treatment to be studied on a "farm" as opposed to a field or plot basis. Many plot experiments have suggested that particular practices are profitable—but the grazing season has been short and the question of what is to be done with the stock throughout the remainder of the season has been left unanswered.

The other possible research method now under review is the use of supervised field trials of the type described in Chapter 3. The experiment is conducted on commercial farms under conditions similar to those facing ordinary farmers. This makes it possible to study the response to fertiliser application over much larger areas and using many more animals. The experiment may provide valuable demonstration material since the control and the treated areas are side by side and the difficulties of interpreting experimental results into practical terms are minimised. The deficiency of survey data, namely that the level of output may be influenced by factors other than those under study, is largely overcome by having a "control" at each centre. It is reasonable to suppose, if the control and the treated fields are selected at random, that soil conditions, rainfall, aspect, previous treatment and management will not differ significantly between systems.

To be successful, supervised field trials demand close co-operation and good relationships between the investigator and the farmer. The investigator must be confident that agreed practices have been applied in the right way and at the right time. He must trust the farmer to keep an accurate record of the number of stock on each field.

It is clear that on every farm the control field should be managed in accordance with the system usually followed. The management of the treated field is a more debatable point. In the East Midlands experiment described above, no rate of stocking was prescribed, but all the co-operating farmers were advised to stock the treated field more heavily than the control. It is possible that a better response would have been obtained had the investigators made a heavier rate of stocking a condition of participation in the experiment. However, if managerial conditions are imposed then one of the major advantages of a supervised field trial, i.e. that the management level is typical of the farming system under review, is removed. On the other hand, it is also possible that the farmers who co-operated in this trial were above-average managers and therefore untypical.

The significance of field trials could perhaps be made more clear by attempting to record related information in more detail. For the type of experiment described above, this might have included more detailed soil and pasture analysis and a measurement of the amount of dry matter on offer on each field. Co-operating farmers could reasonably be asked to allow the investigator more freedom regarding the choice of field to be treated, the division of the available stock and other factors which should be randomised if bias is to be eliminated.

The main disadvantages of field trials is the difficulty of testing the output from input at various levels. The economist requires input-output data at several levels of input. All experiments comparing a single level of application with a control beg the question — Would it be more profitable to use more (or less) of this manure (or feed or any other input)? Detailed multi-treatment experiments can only be undertaken on experimental farms. Even so, many experiments using three or more levels of application, are very expensive. Supervised field trials could be a very useful "follow-up" to detailed experiments by providing an economical means of testing the applicability to commercial farms of the conclusions drawn from the more exact and detailed investigations of the research institutes.

CHAPTER 6

CONCLUSIONS

The experiments described and discussed in Chapters 3 and 4 of this report *appear* to indicate that it does not pay to fertilise permanent grass for fattening cattle.

It is true that on these particular farms the type of fertiliser applied and the rate of application did not, on average, yield a sufficient response, in terms of extra liveweight gain, to pay for the fertiliser. This does not mean that this type of fertiliser applied to more responsive kinds of sward, or other types of fertiliser applied at different rates or with more varied rates of stocking, would not show an economic return.

There is a good deal of evidence, such as that reviewed in Chapter 2, to show that permanent grass does respond to fertiliser applications. Unfortunately there is little data on the response, in terms of liveweight gain, of the grazing animal. Pounds of dry matter or days of grazing are of value only if they can be converted into gallons of milk or pounds of meat.

A number of points of particular relevance have emerged from recent research work. The most prominent is the correlation between liveweight gains per acre and stocking rate per acre. It is now clear that additional liveweight gain per acre cannot be realised unless animal potential is expanded by increasing the carry of livestock per acre. Throughout the East Midlands experiments it was found that the liveweight gain per *head* of the cattle was the same on both the fertilised and unfertilised fields. It is possible that the response measured in previous experimental work where the difference in productivity was measured in terms of liveweight gain would have been greater had the rate of stocking of the experimental and control fields or plots been varied (or varied over a wider range).

A second point to note is that experiments elsewhere (see Chapter 2) have shown that the response to applications of phosphate and potash have been marked on soils with a low P and K status and that it has not been so marked or certain on soils with a satisfactory P and K status. It should be noted that the experimental fields in the East Midlands investigation had a generally satisfactory P and K status.

Other research workers have commented on the "spectacular response to very small applications of nitrogen" and have suggested that there are conditions where the response to phosphate may be limited by a deficiency of nitrogen. The quantity of nitrogen applied in the East Midlands investigation may be described as small—25 units—the equivalent of only about 1.2 cwt. of sulphate of ammonia. The extra liveweight gain recorded may in large part have been due to this small application of nitrogen—it is certainly true that the extra liveweight gain per acre in 1959 was equal to that of 1958 despite the fact that applications of P and K in the second year were nearly halved.

Recent experimental work in Eire (see p. 12 above) has suggested that an economic response can be obtained to heavy applications of nitrogen to permanent pasture, additional to a basic dressing of 4 cwt. of superphosphate and 2 cwt. of muriate of potash per acre. In the following table the response obtained has been valued at the price used in Chapter 4.

NET VALUE OF RESPONSE TO APPLICATIONS OF NITROGEN

TABLE 20

Cwt. of sulphate of ammonia per acre	Cost at 11s 6d. cwt.		Cost at 21s. 0d. cwt.		Extra gain per acre lb.	Value at 155s. 9d. per live cwt.		Margin per acre above cost of fertiliser			
								at 11s. 6d. cwt.		at 21s. 0d. cwt.	
	s.	d.	s.	d.		s.	d.	s.	d.	s.	d.
2	23	0	42	0	72	100	2	77	2	58	2
4	46	0	84	0	136	189	2	143	2	105	2
6	69	0	126	0	190	264	3	195	3	138	3
8	92	0	168	0	216	300	5	208	5	132	5
12	138	0	252	0	190	264	3	126	3	12	3

On the basis of these figures, and counting only the cost of the extra fertiliser, an economic return was obtained to an application of 8 cwt. per acre of sulphate of ammonia if the cost of the fertiliser, less subsidy, is taken to be 11s. 6d. per cwt. If the subsidy is ignored and the sulphate of ammonia is charged for at the full price of 21s. 0d. per cwt. then it pays to use only 6 cwts. per acre.

It is true that these results are for one year only and are drawn from small plot experiments. This implies that they should be tested and tried under conditions approaching as closely as possible to those prevailing on commercial farms.

An objection frequently voiced against the use of heavy dressings of nitrogen on grass is that it leads to the suppression of the clover in the sward. This is undoubtedly true on clover-rich pastures where the response to moderate dressings of nitrogen has often proved disappointing because the artificial nitrogen appears to do no more than replace the nitrogen previously furnished by the clover in the sward. On the other hand it is unfortunately true that many permanent pastures are sadly devoid of clover. On these pastures, the cheapest and quickest way of providing the nitrogen which the clover cannot yield may be to apply nitrogenous fertilisers.

When the spring flush of grass is at its height, most farmers have as much grass as they can cope with effectively. The real problem of grassland management is to prolong the grazing season and the skill of the manager can be measured largely by his success in doing this. Where ley-farming is practised the use of special purpose seed mixtures will do much to provide additional grazing earlier in the spring and later into the autumn. The farmer who relies on permanent grass can extend his grazing season by appropriate manuring and by controlled grazing. He may set aside a suitable field, keep it clear of stock for a spell in autumn and winter, apply manure in February or March and secure enough grass to turn out his stock two or three weeks earlier than would otherwise be possible.

This aspect of management may be of considerable importance to graziers. Store prices are at a peak in the spring when the majority of graziers buy the cattle to stock their pastures. Fat cattle prices are low in the autumn as supplies of grazing dwindle and graziers are compelled to sell off their stock. The farmer who can buy his stores before the peak of demand and who can choose his time of sale in the autumn is clearly in an advantageous position. Another benefit which may be derived from a better supply of spring grass is selling cattle at an earlier date and so avoiding part of the seasonal decline in beef prices.

There was no clear evidence in the East Midlands investigation that these advantages are obtainable but this is a matter which clearly merits further study.

The seasonal movements of store and fat cattle prices are such that a saving of £3 a head may be made by buying stores towards the end of March instead of at the end of April. If such animals can be fattened and marketed at the beginning instead of at the end of June, the price should be about 7s. 0d. per cwt. or about £3 10s. 0d. a head better. The gain from extending the length of the grazing season in the autumn is not likely to be marked as the seasonal up-swing of fat cattle prices does not begin until nearly the end of October when the liveweight gain to be expected from grass is very meagre.

More experimental work is required to measure the response, in terms of liveweight gain, to widely varying levels of nitrogen application, in association with appropriate amounts of P and K, and to test the possibility of extending the length of the grazing season by the use of fertilisers and appropriate management.

APPENDIX

INPUT-OUTPUT RELATIONSHIPS

To answer the question "Does it pay to fertilise this or that?" the economist needs information about the physical yield changes that follow from changes in the quantity of fertiliser applied and also a knowledge of the prices of both inputs and outputs.

There is, fortunately, seldom any difficulty in attaching suitable prices to items of both input and output. The major problem lies in the measurement of the quantity of output and its attribution to particular inputs.

Appropriate physical input - output information, covering an adequate range of observations, is frequently both difficult and expensive to obtain. It is, therefore, of the greatest importance that applied scientists should possess a clear understanding of the information which is required by an economist before he can answer the question: Does it pay to do this or that?

The supervised trial described in this report was an input-output study of the simplest possible type. The answer it has yielded deals with only a very small part of the question. It will be apparent from the following summary of the relevant economic theory that a full answer to the question posed can only be based on an elaborate series of controlled experiments with varying levels of fertiliser inputs and with various combinations of different nutrient sources.

INPUT-OUTPUT RELATIONSHIPS[1]

(a) Theoretical and Methodological Concepts

Generally, the agricultural production process is a complex one; the output of any given product being a function of many resources or inputs. Algebraically, this process can be represented thus:

$$Y=f(X_1, X_2, X_3|X_4........X_n)$$

where Y is the output of products depending upon the levels of the variable inputs X_1, X_2 and X_3, and upon the level of the fixed inputs X_4 to X_n.

This simple function can be further elaborated so that the output of beef from permanent pasture, as dependent upon the level of fertiliser applied, can be represented in a generalised form by a function:

$$Y=f(F_1|F_2........F_n, X_1........X_n||Z_1........Z_n)$$

In this function Y is the output response, F_1 is the fertiliser nutrient under investigation, F_2 to F_n are other fertiliser nutrients, and X_1 to X_n are the other factors including soil type, botanical composition of the sward, stocking rate and system of grazing. The level of these factors, together with F_2 to F_n, can be held constant while the level of F_1 is varied. The factors Z_1 to Z_n, which include rainfall and temperature at critical times of the growing season, cannot be controlled.

The most simple form of input-output information which can be obtained from this function is when the output of beef from non-fertilised pasture is compared with that from pasture fertilised at one level of application of a single fertiliser nutrient. Then, given this knowledge and a knowledge of relevant prices a decision can be made as to whether or not it pays to apply fertiliser at this level of application. This simple data does not indicate whether a higher or lower level of fertiliser application would have been more profitable or less profitable. Nor does this data indicate what adjustments in the rate of application should be made if the prices of beef and/or fertiliser change. Hence, Heady (1956) states that "the central methodological problem in fertiliser use on a single crop is the prediction of the mathematical form and probability distribution of the response function".[2]

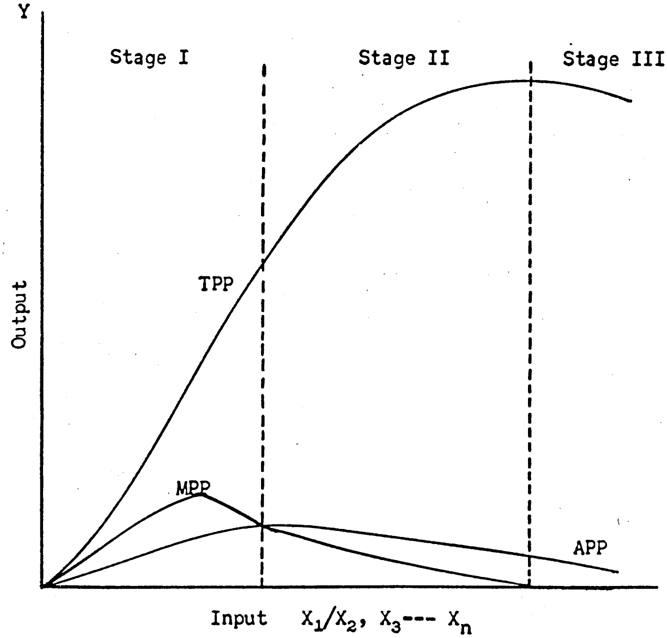
The output of, say, beef from permanent pasture can also be measured at several levels of application of a single fertiliser nutrient, with all other inputs held constant. The relationship between output and input derived from such data must be conceived in terms of the law of diminishing returns, (see figure A). This law states that the addition of a variable input to fixed inputs results first in total returns which increase at an increasing rate (Stage I of the production process), second in total returns which increase at a decreasing rate (Stage II of the production process), and third in total returns which decrease with the increases of the variable inputs (Stage III of the production process).

1 Extract from an unpublished M.Sc. Thesis by HOCKNELL, K. E. *Economics of Fertiliser Application to Permanent Pastures with Special Reference to Beef Production.* University of Nottingham. (1961).

2 For a consideration of appropriate mathematical functions reference is made to Johnson (1953), Mason (1956) and Ferrari (1959).

FIGURE A

HYPOTHETICAL INPUT-OUTPUT RELATIONSHIP SHOWING AVERAGE (APP), MARGINAL (MPP), AND TOTAL (TPP) PHYSICAL PRODUCTIVITY IN STAGES I, II AND III.



Production is irrational in Stages I and III since a rearrangement of resources will give either a greater product from the same collection of resources or the same product with a smaller aggregate outlay of fixed and variable resources. Provided that the value of the product is greater than zero, then, the physical scientist can state that in a competitive business a quantity of the variable input should be used so that production is at least carried to the edge of Stage I, i.e. into Stage II. And without reference to prices it can be stated that it does not pay to use quantities of the variable input which would carry production into Stage III.

It is doubtful if there are many practical examples when the response of grassland to fertiliser application is within Stage I of the production process, unless soils are particularly deficient in a particular nutrient element. Application of small quantities of lime to very acid soils may show increasing returns. Generally there are sufficient reserves of nutrient elements in the soil so that even where no fertiliser is applied production is already in Stage II, or very small quantities of fertiliser need be applied before production is in Stage II.

If fertiliser application to grassland is going to move production into Stage III the most likely situation is, probably, one in which the total product does not decline, but remains constant with additional inputs. (This is an irrational area of production since the same product can be obtained with smaller quantities of the variable input—fertiliser). Circumstances in which the total product actually falls with increasing fertiliser inputs to grassland are more difficult to conceive.

Constant returns, when nitrogenous fertiliser has been applied to grassland over certain ranges of application, have been observed. Williams and Lloyd (1952) measured a linear response (in terms of dry matter) to nitrogen on a grass-clover sward up to the level of application of 6 cwt. of sulphate of ammonia per acre per annum.

However, since production within Stages I and III is irrational, and since fertiliser response data from grassland are usually within Stage II of the production process, it is within this area of returns increasing at a decreasing rate to additional fertiliser inputs (or the area of rational production) that the agricultural economist is primarily interested. It is within this area that economising principles have to be used to decide what is the "best" level of fertiliser application. And it is also within this area that a detailed knowledge ". . . . of the mathematical form and probability distribution of the response function" is needed to make possible an economically valid decision on how much fertiliser to use.

The optimum level of fertiliser application (i.e. where the margin between total returns and total fertiliser costs is maximised) is where the marginal cost of fertiliser equals the marginal return. It can be seen that besides a knowledge of the physical relationships between inputs and outputs, a knowledge of the prices of inputs and outputs is also required. The point where fertiliser application is optimum can be represented as

$$dY/dF = Pf/Py,$$

or cross multiplying, as

$$dY.Py = dF.Pf$$

where dY is the increment in yield, dF is the increment of fertiliser and Py and Pf are the unit prices of the output and fertiliser, respectively. Alternatively to maximise profits to the farm as a whole the level of fertilisation can be adjusted so that the return to the last £1 spent on fertiliser equals the return to that £1 if it had been invested elsewhere.

Seeing that the uncontrollable factors (Z_1 to Z_n), in the generalised function influence the action of the nutrient factor F_1, response curves may vary between years. Knowledge of the distribution, between years, of these curves is necessary to make an economically valid decision as to the amount of fertiliser to apply, that is in considering the risk and uncertainty factors involved.

The residual response to a fertiliser dressing, whether it be a true residual effect or an effect brought about by, say, ecological changes in the pasture, can also have a considerable bearing upon the level of fertilisation recommended. If a high residual response is likely, then even if unfavourable weather conditions in the year of application should cause the response from the fertiliser to be uneconomic in that year, a high residual response may make the application profitable as a whole.

When two or more fertiliser nutrients can be varied for a single crop, two economic problems are involved:

(a) the least cost combinations of nutrients for given yield levels, and

(b) the most profitable level of fertilisation when nutrients are combined in least cost combinations at all yield levels.

The physical data required to solve these problems are appropriate fertiliser-crop response production surfaces.

Where two fertiliser nutrients are involved in the production of a crop (it is assumed that all other factors are fixed), at least three hypothetical production surfaces may be considered. Two of these, that representing perfect substitutability between nutrient elements and that representing perfect complementarity, are the limiting forms.

FIGURE B

HYPOTHETICAL PRODUCTION SURFACE WITH PERFECT SUBSTITUTION BETWEEN FERTILISER NUTRIENTS.

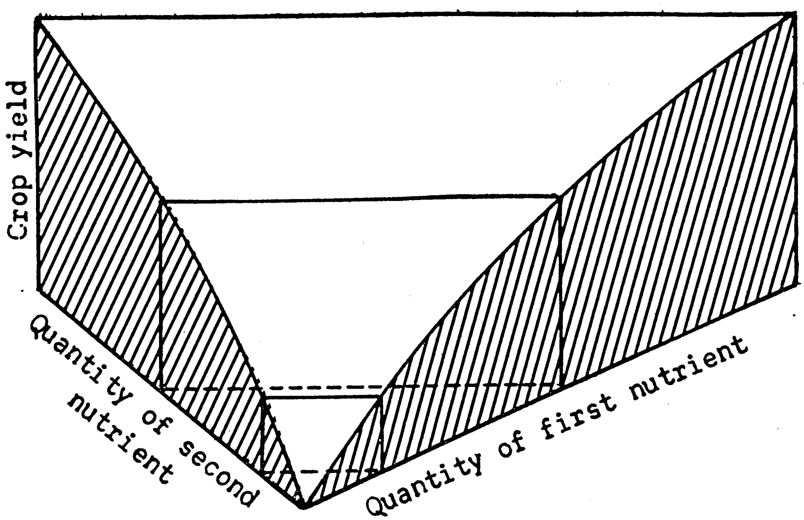


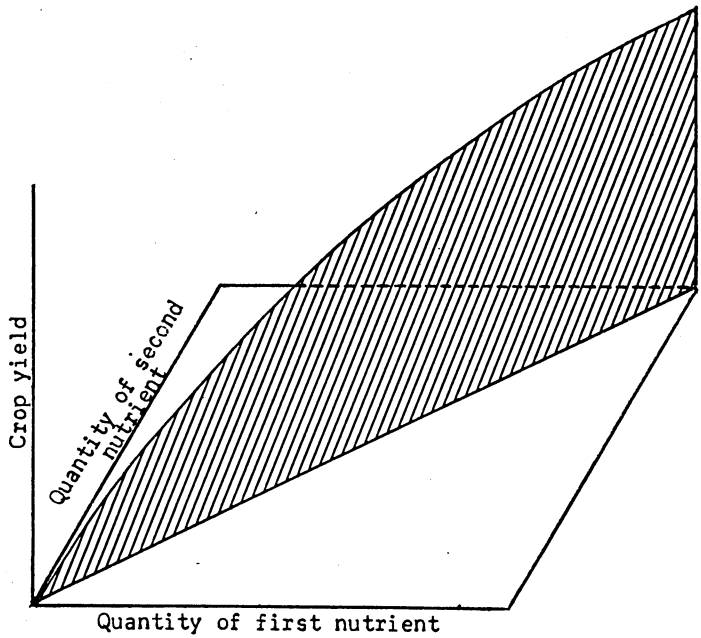
Figure B represents the geometric form of a hypothetical production surface with perfect substitution between fertiliser nutrients. While it is unlikely to have much applicability to two such differing nutrient elements as nitrogen and potassium, it is applicable for one nutrient obtained from different sources (e.g. nitrogen from sulphate of ammonia and nitro-chalk). Similarly, over certain ranges, and for certain crops, e.g. mangolds and sugar beet, sodium may substitute for potassium at constant or virtually constant rates.

The characteristic of this surface is that each nutrient element is a perfect substitute for the other in producing a given level of yield, so that if either element is increased alone, or if the two elements are increased in constant proportions increasing yields are obtained (albeit at a decreasing rate) with each increment of fertiliser applied.

The opposite extreme in possible fertiliser-yield relationships resembles the " law of the minimum hypothesis." This model, the surface of which reduces to a " knife edge," is shown in figure C and supposes that fertiliser elements must be combined in fixed proportions. Since one element does not substitute for the other, a given crop yield cannot be maintained by replacing one element by another. If one element is held constant, addition of the other will add nothing to the total yield.

FIGURE C

HYPOTHETICAL PRODUCTION SURFACE WITH PERFECT COMPLEMENTARITY BETWEEN FERTILISER NUTRIENTS.

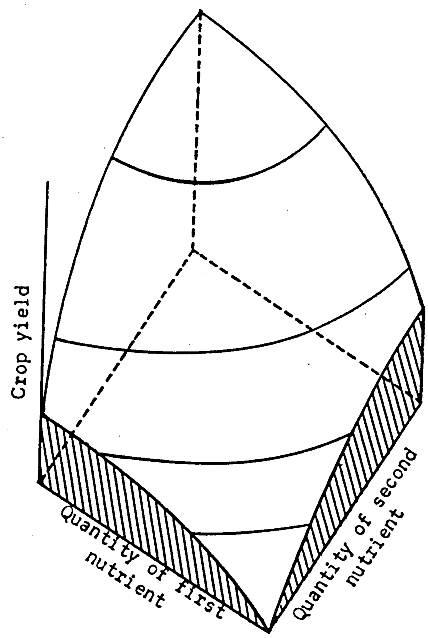


In practice, this must occur infrequently otherwise agronomists would not have been able to demonstrate increasing returns to a single fertiliser nutrient in a large number of such experiments and over a considerable range of levels of application of single nutrient fertilisers.

A third type of production surface, some modification of which is most likely to occur in practice, is that represented geometrically by the model shown in figure D.

FIGURE D

HYPOTHETICAL PRODUCTION SURFACE SHOWING BOTH SUBSTITUTION AND COMPLEMENTARITY BETWEEN FERTILISER NUTRIENTS.



The convex surface indicates diminishing returns to each nutrient alone or to both elements combined in fixed proportions. The curved contour lines suggest that, while the nutrients do not replace each other at constant rates (as in the first model) they do not require use in fixed proportions (as in the second model), but that they replace each other at a diminishing rate to produce a given yield.

Figure E shows the types of yield contours or yield isoquants (lines connecting points of equal yield) which are associated with this type of production surface. For small increases in yield due to inputs of fertiliser, the given yield level may be obtained by one or other of the fertiliser nutrients or by some combination of the two. But at higher yield levels the substitution possibilities are more limited, so that the maximum yield may be attained by a single combination of nutrients only (i.e. the yield isoquant for the maximum yield reduces to a single point).

Figure F shows a yield isoquant map on which two fertiliser/yield isoclines have been drawn. (An isocline is a line connecting all points of equal slopes or substitution rates on a family of yield isoquants). Along the isocline labelled $r = 1.0$ one pound of the second nutrient, F_2, replaces one pound of the first nutrient, F_1. At all points along the isocline labelled r=3.0 one pound of the nutrient F_2 replaces three pounds of the nutrient F_1. These isoclines indicate the least-cost combinations of nutrients for different yields when the price of the nutrient F_2 is in the first case equal to, and in the second case three times greater than the price of the nutrient F_1. The cost of fertiliser is at a minimum for a given yield when the condition of the following equation is satisfied

$$dF_1/F_2=P_2/P_1$$

in which dF_1/dF_2 is the marginal replacement ratio between nutrients (dF_1 refers to the amount of the nutrient F_1 replaced and dF_2 refers to the amount of the second nutrient added to produce a given yield) and P_1 and P_2 are the unit prices of the first and second nutrients respectively.

An isocline also represents an expansion path showing the least-cost (and highest profit) combination of nutrients, for a given nutrient price ratio, to use as higher yields are attained. When the nutrients are combined in least-cost combinations the optimum level of fertilisation, as for a single nutrient, is the point where the marginal cost of applying fertiliser just equals the marginal return.

FIGURE E

CONTOUR MAP OF A PRODUCTION SURFACE SUCH AS THAT SHOWN IN FIGURE C.

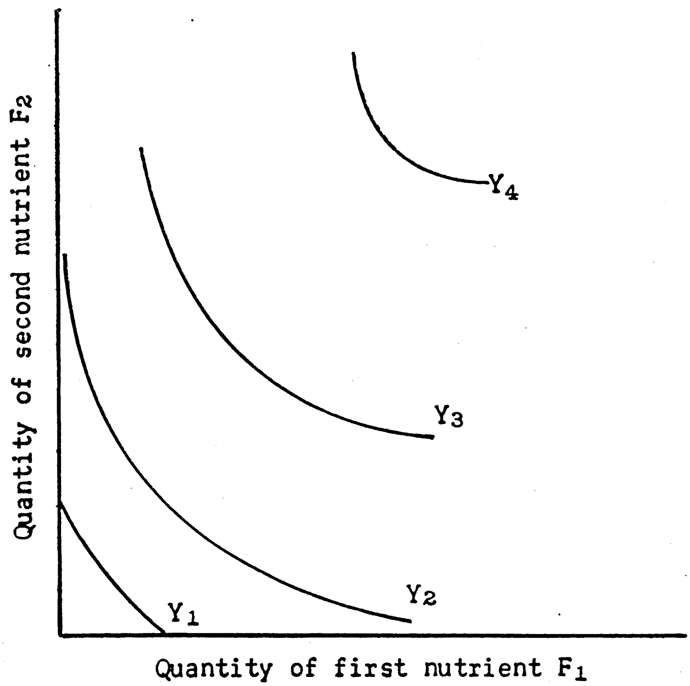
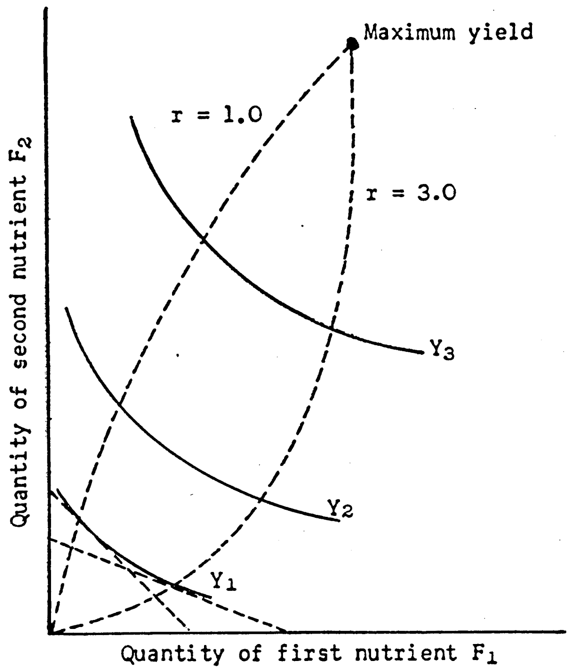


FIGURE F

CONTOUR MAP OF A HYPOTHETICAL PRODUCTION SURFACE SHOWING TWO ISOCLINES.



Isocline maps may take on several distinct forms. Heady, Pesek and Brown (1955) have shown that for corn (maize) the appropriate isoclines are fairly straight and that for alfalfa the relevant isoclines bend sharply. The different forms can only be established by experiment. Two isoclines, those connecting all points with zero substitution rates, are called "ridge-lines". They denote complementarity of nutrients, and converge, along with other isoclines to the point of maximum yield where nutrient substitution is impossible. If the "ridge-lines" are not far apart, if within their boundaries the isoclines are fairly straight and the isoquants have only a slight curvature with slopes not too different from the nutrient price ratio, then within the "ridge-lines" several nutrient ratios will be only slightly different from the least cost combination. If the circumstances are reversed, savings from changing nutrient ratios along an isocline will be correspondingly greater.

Although the theoretical and methodological concepts, upon which valid recommendations for economic fertiliser use can be based, have been briefly defined there are obstacles to obtaining adequate data. Some of the problems involved in securing fertiliser use data have been discussed by Pesek (1956). Problems of experimental design, organisation and choice of site apply to all crops, but additional difficulties arise which are peculiar to grassland research. Some of these will be mentioned briefly in the following section.

(b) Sources of Physical Input-Output Data

Two sources of physical input-output exist, namely, controlled experiments and surveys.

In the design and conduct of controlled experiments the endogenous factors (F_2 to F_n and X_1 to X_n) are held constant. Hence, only the effects of the fertiliser nutrient under study (F_1) and the exongenous factors (Z_1 to Z_n) influence the measured output. Data obtained from such experiments are the most reliable sources of physical input-output information. However, in pasture research the determination of output, which can only be given a value when measured in terms of animal products, presents particularly difficult problems. A multiplicity of factors associated with the production of herbage and with animal production, interrelated by the system of grazing and stocking rates, are likely to affect animal output from grassland.

Grazing experiments are inherently expensive and this deters the determination of output from different levels of fertilisation under all possible other conditions. The problem is then one of deciding how

FIGURE G

HYPOTHETICAL PRODUCTION FUNCTIONS FOR TWO GRAZING SYSTEMS AND TWO STOCKING RATES.

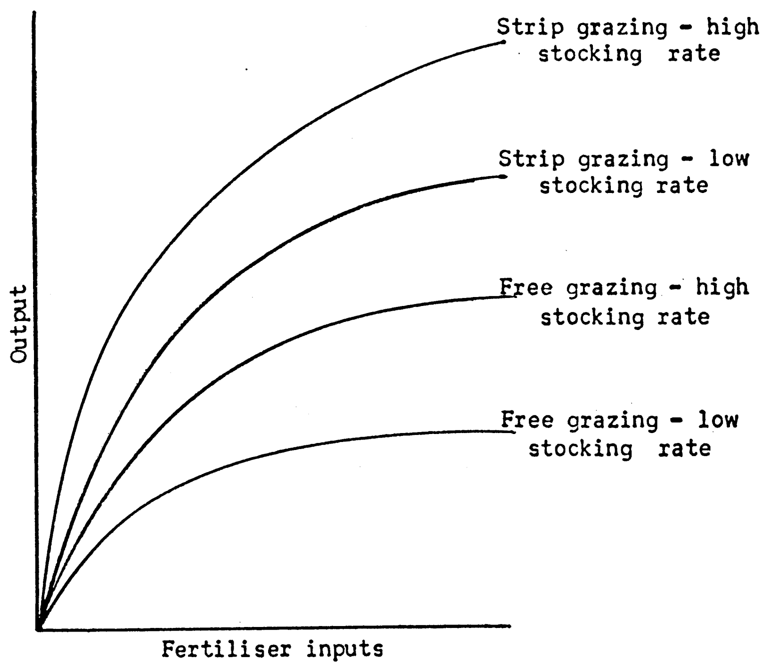
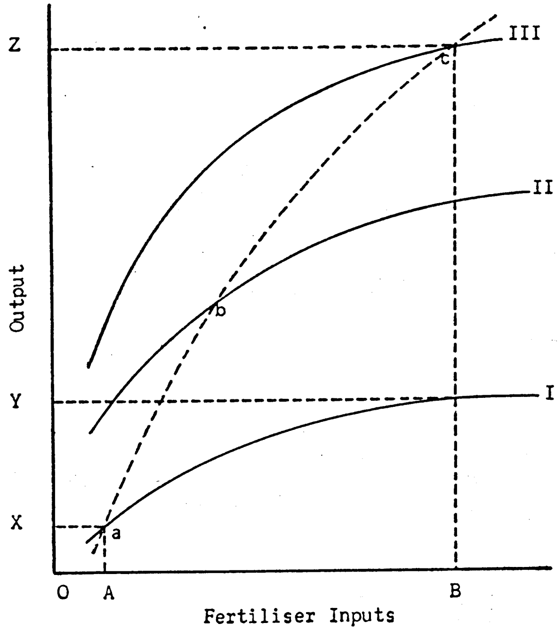


FIGURE H

A HYPOTHETICAL ANALYSIS OF FARM SURVEY DATA.



relevant the results of experiments acquired under a few precisely defined conditions are to the commercial farm, bearing in mind the wide variations in conditions and practices found on farms.

Theoretically, for each fertiliser element studied, there will be a family of production functions for, say, system of grazing, differing stocking rates, etc. This can be illustrated as in figure G. The validity of economic recommendations concerning optimum fertiliser application, based upon the results of a single experiment, will depend upon the magnitude of change in the production function when other conditions differ from those of the experiment.

Probably the output influencing factor of greatest importance when discrepancies between experimental and farm conditions occur, is the stocking rate. Currie (1949), Ivins et al. (1958), Eddowes and Harris (1960), McMeekan (1960), and others, have all emphasised the importance of stocking rate in maximising the output of animal products from grassland. Under experimental conditions the stocking rate may be predetermined or may be left to the judgment of the experimental worker. Neither method need necessarily result in a stocking rate which would be deemed suitable by the commercial farmer.

Indeed, some factors may preclude the two assessments from being the same. For instance, a research worker may only consider a small number of animals grazing a small acreage for, perhaps a short period of time, but the grazier has to choose and adjust his stocking rates within the concept of an overall farm policy. As an example, in the spring an experimental area can be stocked to full capacity and maximum output can be obtained from the spring flush of growth. Later in the season as herbage production declines the experimenter can draft some cattle into areas outside the experiment. It may not be expedient for the grazier to stock to the maximum capacity early in the season because he may later be left with unfinished cattle and insufficient grass on which to feed them and maintain a satisfactory rate of growth.

Data obtained from surveys may provide standards by which an assessment can be made of the relevance of experimental results to the ordinary farm.

On occasions results obtained from surveys have been used as a source of physical input-output data. As a source of such data surveys suffer obvious limitations since many of the endogenous factors of the production function are not controlled. Heady (1952) explained how distorted findings relative to resource productivity can arise, from the use of survey data, by means of an "apparent" production function which overestimates the average and marginal productivities of the resource.

In figure H the points a, b, c, have been plotted from imaginary average data of fertiliser inputs and corresponding outputs obtained from farm records. I, II and III are hypothetical production functions indicating, say, three levels of management, or three levels of soil fertility. The apparent input-output curve is abc. However, this is not a true production function since the line abc connects three points on separate functions. If a farmer on function I was to increase his level of fertiliser application from OA to OB, instead of increasing his output from OX to OZ as indicated by the "apparent" function abc, he would only increase it to OY. Hence, the productivity of the fertiliser input would be over-estimated by the use of this data. Clarke and Bessell (1956) recognised this situation when presenting the relationship between nitrogen usage and milk yields per acre ascertained from a grassland management investigation. They stated that "the average increment of 28 gallons (of milk per acre) for each unit increase (one cwt. of sulphate of ammonia per acre) in the nitrogen usage . . . cannot be ascribed solely to heavier use of nitrogen, it is due to a higher level of farming intensity founded on such nitrogen usage."

LITERATURE CITED

CLARKE, J. and BESSELL, J. E. *Profits from Dairy Farming*. Bul. No. 7. I.C.I. Ltd., London. (1956). Ch. 3, p. 21.

CURRIE, J. R. "Pasture Management." *Proc. Agric. Econ. Soc.* (1949). Vol. 8, No. 2, pp. 121—138.

EDDOWES, M. and HARRIS, R. *The Measurement of Output from Grassland*. Tech. Bul. G.I. Harper Adam Agricultural College, Dept. of Agric. (1960).

FERRARI, T. J. *Factors Affecting Growth and Methods of Expressing Growth Response Data. Economic Optimum Fertiliser Use*. E.P.A.—O.E.E.C. (1959). Project No. 393, pp. 65—75.

HEADY, E. O. *Economics of Agricultural Production and Resource Use*. Prentice-Hall Inc., New York. (1952). Ch. 10, p. 311.

HEADY, E. O., PESEK, J. T. and BROWN, W. G. *Crop Response Surfaces and Economic Optima in Fertiliser Use.* Iowa State College. (1955). Research Bul. 424.

HEADY, E. O. *Methodological Procedures in the Economic Analysis of Fertiliser Use Data.* Iowa State College Press. (1956). Ch. 1, p. 3.

IVINS, J. D., DILNOT, JEAN and DAVIDSON, J. (1958). "The Interpretation of Data of Grassland Evaluation in Relation to Varying Potential Outputs of Grassland and Livestock". *Jour. Brit. Grassland Soc.* (1958). Vol. 13, No. 1, p. 23.

JOHNSON, P. R. "Alternative Functions for Analysing a Fertiliser Yield Relationship." *Jour. Farm Econ. (U.S.A.).* (1953). Vol. 35, No. 4, pp. 519—529,

MASON, D. D. *Methodological Procedures in the Economic Analysis of Fertiliser Use Data.* Iowa State College Press. (1956). Ch. 5, pp. 76—98.

McMEEKAN, C. P. "Measuring Output by the Acre or the Cow." *Reports of papers 8th Inter. Grass Congress.* 'The Times,' July 25th, 1960.

PESEK, J. J. *Methodological Procedures in the Economic Analysis of Fertiliser Use Data.* Iowa State College Press. (1956). Ch. 6, pp. 107—112.

WILLIAMS, R. and LLOYD, J. R. "An Experiment on the Nitrogenous Manuring of Grass." *N.A.A.S. Quart. Rev.* (1952). Vol. 5, No. 18), pp. 271—276.

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