To return to the subject of farm-management economics, it is of interest to compare the cost of starch equivalent produced from the use of nitrogen on grass with figures for other feeds (Hamilton, 1955–6). If the 15 lb. dry matter produced by 1 lb. N is equivalent to 10 lb. S.E., Table 1 shows that the cost per ton of S.E. is £15, which is not much higher than Hamilton's figure of £11 for normal grazing and £14 for early bite grazing and compares favourably with that of any other feed. Moreover, as already noted, there is no evidence of diminishing returns up to very high levels of nitrogen application. There is abundant evidence, therefore, that cheap cattle food can be produced by the efficient use of nitrogen on grassland. Full exploitation of this knowledge depends on a mastery of the techniques of grass utilization, a subject outwith the scope of this paper.

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Fertilizer nitrogen and milk production from grassland
A review of experience on commercial farms

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The resolution of problems of productivity in farming involves two distinct phases in the collection of the information required to establish and define improved efficiency. The first phase may be described as purely technical and is concerned with the accumulation of physical data by research and experiments in which the

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effects of different amounts of particular resources and combinations of them are compared. The second stage of investigation is to attempt to evaluate these physical relationships in economic terms in the context of commercial farming practice. Seldom can a new technique of production be introduced which does not have important repercussions throughout a wider sector of the whole farm economy than that directly involved in the change. Such considerations are especially pertinent in respect of grassland which is exploited through cattle and sheep, so that the final effects of changes in methods of grass production and use can be gauged only when the conversion into livestock products is completed. A comprehensive and valid picture of the influence of grassland manuring on milk production can thus best be obtained by practical farm-scale investigation whereby the effects on grass production and livestock output and on profit can be assessed.

Response of grass to nitrogen fertilizer

One widely practised manurial technique of increasing grass yield is the top-dressing of suitable swards with nitrogen fertilizer at the end of winter to induce earlier and more vigorous growth of spring herbage. The general nature of the effects of this treatment is illustrated in Table 1.

Table 1. *Effect of late winter application of nitrogen fertilizer on yield and protein content of the first spring growth of grass*

		Dry-matter yield (cwt./acre)			Crude protein in dry matter (%)		
Year	No of trials	A	B	C	A	B	C
1949	18	10·0	16·7	—	15·9	17·5	—
1954	14	8·0	12·9	16·4	16·3	17·8	19·8
1955	13	8·0	12·6	15·8	16·9	18·6	20·8
Mean for 1949, 1954 and 1955		8·8	14·8		16·3	18·0	
Mean for 1954 and 1955		8·0	12·7	16·1	16·6	18·2	20·3

A, no fertilizer; B, fertilizer at the rate of 35 lb. N/acre; C, fertilizer at the rate of 70 lb. N/acre.

As a rule by the time the treated herbage is ready for grazing the yield of dry matter is about two-thirds greater than that from grass receiving no nitrogen fertilizer —from 50 to 100% according to rate of application—and the crude-protein content is also increased 10–20% by the treatment, despite the more mature stage of growth of the treated herbage at the time of use. Provided such herbage can be grazed when it becomes available, it is clearly of great value since it is relatively cheap compared with indoor winter feed and in addition it generally stimulates milk production.

Lack of space precludes citation of examples of the effects on yield and nutritive quality of herbage of other modes of applying fertilizer nitrogen. In general terms, the shorter the period between such application and use of the herbage the greater the effect on nutritive quality and especially on protein content but the smaller the increment of product and vice versa. On grass to be conserved as hay or silage the usual scale of increment is in the proportion of 25–30 parts of dry matter to 1 of applied nitrogen or, expressed in farming terms, an extra ton of silage or one-third of a ton of hay from a dressing of some 2 cwt. Nitro-Chalk/acre or its equivalent.

Top-dressing with nitrogcn fertilizer to extend the grazing season by improving yield and quality of herbage in autumn and defer the use of more costly winter feeding is also profitable. This technique often proves more advantageous than its counterpart for earlier spring grazing.

Each of these particular uses of nitrogenous fertilizer on grassland may be intrinsically justified when assessed as an individual technique or process—a principle which also applies, of course, to many other means of improving the productivity of grassland. But what is the result in commercial dairy farming of the combined effects of applying these various techniques to intensify milk production from grassland? This paper is not directly concerned with experiments but with the practical application of research findings to grassland management as exemplified by economic data derived from a group of farms on which the policy has been to expand milk production by improving the use of grassland. The data relate mainly to average changes that have occurred over a period of years and are the result of fairly continuous intensification of grassland use, which in turn has been based largely on increasing application of fertilizer nitrogen. The results have therefore been mainly assessed by measuring the scale of change in output, e.g. milk production, associated with the rate of variation in input factors, e.g. nitrogen applied to grassland, for the whole group of farms. These farms are essentially grass dairy farms since milk constitutes over 57% of the value of the gross output, and over 80% of the livestock feed area is in grass.

Importance of grass in cow-feeding practice

The influence of fertilizers on milk output from grassland, though exerted directly through the yield and quality of herbage grown and eaten, will be determined mainly by the interplay of two factors: (1) the degree of reliance on grass in the total feed of cows and (2) the density of stocking, i.e. the area of grass provided per cow.

The degree of reliance on grass in the feeding of cows is most simply illustrated by expressing, in terms of starch equivalent, the estimated contribution from grass as a percentage of the annual consumption of energy provided by all feeding-stuffs. The average proportion obtained on these farms is shown in the first column of Table 2.

There are naturally great differences between individual farms in the degree of reliance on grass in feeding cows, varying from 100 down to 55%. There is good evidence to presume that continuation of the rising trend will not be limited by potential further increase over the annual yields of utilized grass so far achieved. Certainly greater reliance on grass in future will depend much more on higher density of stocking and on relative costs of grass and other foods—in relation to changes in the price of milk—than on limitations of further increase in the yield of grass.

It is not possible to compare the extent to which grass is relied on as a source of feed on this group of farms with that in the national dairy herd but it is certain the proportion is much less in the latter. This generalization holds true for both summer and winter feeding; in so far as the National Milk Costs Investigation for 1951–2 (Milk Marketing Board, 1955) is representative of average practice, grass products provide about 35% of nutrients fed in winter compared with the 45–50% on this group of farms. Even the latter proportion, however, provides for no more than 'maintenance' despite the relative cheapness of conserved grass. The analogous difference between these groups in reliance on grass in summer is probably greater since it is still common practice to feed supplements to an unnecessary degree to cows at grass. To some extent this practice also applied on the farms in this investigation although hundreds of records of individual cows have shown that grazing alone will provide for yields exceeding 400 gal. in the summer period and for sustained daily production of upwards of 4 gal.

The overall average contribution from grass in the feeding of cows has risen steadily along with a continuous rise in milk production per acre (total food area) and also in average herd yield. These trends are also depicted in Table 2.

Table 2. *Proportion of grass in the total food of cows, milk production per acre and per cow and rate of nitrogen fertilizer used*

Year	Percentage of S.E. supplied by grass	Milk production (gal./acre)	Mean herd yield per cow (gal.)	N applied to grass (lb./acre)
1949	55	207	709	30
1950	57	227	717	44
1951	61	233	709	50
1952	63	239	734	53
1953	68	256	718	63
1954	66	253	735	70

Results from many individual farms indicate that these associated trends can be increased to still higher levels. This experience is particularly important in view of the relative cheapness of grass as a food; on these farms the comparative cost of starch equivalent in the main groups of foods has remained fairly constant over the years at the following ratios:

Grazing	1·0	Roots	3·0
Silage and hay	2·0	Cereals	3·0
Kale: grazed	1·5	Dairy cake	5·0
cut	2·5		

The other means of exploiting greater production of grass is by increasing the density of stocking, which is measured as the area used to produce the food consumed annually per cow (or its equivalent by other grazing livestock). Milk output per acre is obviously determined primarily by the yield of food obtained per acre which at any particular degree of reliance on grass in the total feed will be reflected in the stocking density. The general relationship of area requirements for food and milk produced per acre over the period are shown below:

	1949	1950	1951	1952	1953	1954
Grass (acres)	2·1	2·0	1·9	2·0	1·8	1·8
Total food (acres)	3·5	3·2	3·1	3·1	2·8	2·9
Milk production (gal./acre)	207	227	233	239	256	253
Profit from farm land (£/acre)	6·4	7·2	7·5	8·5	12·3	9·6

A gradual reduction in the area required to provide the cow feed is evident, most of it having been obtained through higher yields of utilized nutrients from grass. This is the main cause of the increased production of milk per acre of cow food, which in turn has been reflected in the upward trend of profit per acre of the farm land used for milk production.

The density of stocking of the grass feed area was the most potent influence on the scale of milk output (and profit) per acre because grass was the most important component of the total feed area; its relationship with milk output is as follows:

Feed area (acres/cow)	Milk yield (gal./acre) 1949	1950	1951	1952	1953	1954	No. of cows/100 acres
2·5	252	254	261	278	288	283	40
3·0	230	236	239	249	253	247	33
3·5	207	217	218	220	219	211	28
4·0	186	199	196	191	185	174	25
Mean decrease in milk yield/0·5 acre increase/cow	22	18	22	29	34	36	

Profitability of increasing milk production from grassland

The close relationship between milk production and profit per acre is illustrated by the data for the latest 2 years available:

Milk production (gal./acre of cow feed)	Profit (£/acre) 1953	1954
200	5·4	3·8
225	6·7	4·7
250	8·0	5·8
275	9·3	7·0
300	10·5	8·3
325	11·8	10·1
350		12·1

The profit/acre relates to the area required by the cows and their replacements, i.e. total dairy cattle and not the milking herd only.

Although costs per acre are not shown they rose with increasing yield of milk but in recent years at a slower rate so that average cost per gallon actually declined as yield per acre increased. This is a rather unexpected finding, but in every year profit and milk production per acre have increased almost *pari passu* and the data suggest that in 1954 the maximum potential profit could only be obtained above the 350 gal./acre level of production.

If utilized grass yield is assessed in terms of starch equivalent per acre, the general effect of increasing the rate of nitrogen application is illustrated in the figures for 1954, the most recent year available:

Nitrogen application as sulphate of ammonia (cwt./acre)	S.E. (cwt./acre)
1	15·8
2	17·8
3	19·7
4	21·7
5	23·6

The average utilized increment for each successive 23 lb. nitrogen was 2 cwt. starch equivalent per acre and over the 6-year period it has been very close to this figure, varying between 2 cwt. and 3 cwt./acre, and with no evidence of appreciable falling off in the response to nitrogen up to 115 lb./acre.

The starch-equivalent yield is, however, only an intermediate step to the more pertinent criterion of milk production per acre. The association between milk output per acre and nitrogen fertilizer applied is set out in Table 3.

Table 3. *Rate of application of nitrogen fertilizer to grassland, and milk production*

Nitrogen application as sulphate of ammonia (cwt./acre)	Milk yield (gal./acre)					
	1949	1950	1951	1952	1953	1954
1	199	208	213	206	216	211
2	225	229	231	231	241	230
3	250	250	248	257	266	250
4				282	291	271
5					315	289
Increment/1 cwt. sulphate of ammonia	25	21	17	25	25	19

Thus an average increment in milk production per acre has been obtained of 23 gal. for each increase in nitrogen equivalent to 1 cwt. sulphate of ammonia, or 1 gal. increase per 1 lb. additional nitrogen. Obviously the whole of the increments cannot be attributed simply to application of nitrogen fertilizer at increasing rates; an extra 20 odd gal. milk per acre will not be a more or less automatic sequence to the application on grass of 1 cwt. of sulphate of ammonia per acre. The greater outputs are the outcome of all the factors directly involved in the more intensive use of grassland which is founded on, and brought into play so to speak, by a higher rate of nitrogen application.

SUMMARY

The productivity of grassland is largely determined by the availability of soil nutrients within a particular environment; these can be regulated by fertilizer application but nitrogen has much the most potent influence on grass production.

Given appropriate grassland and livestock management, the output of utilized feed per acre of grassland can be increased by nitrogen-fertilizer application on commercial dairy farms at an almost linear rate up to over 100 lb. nitrogen/acre.

Grass is the cheapest food for grazing livestock and is generally the most economical basis for increasing the stock-carrying capacity of the farm and thereby expanding output per acre. With the dairy herd, increasing the stocking density is likely to increase output more effectively than increasing the degree of reliance on grass in feeding.

On these farms each £10 rise in the value of gross output, mainly derived from milk, was associated with a rise in profit of £3/acre. With each successive increment of 25 gal. milk/acre, the profit per acre increased by from £1 to £2—this profit increase being greatest at the higher levels of milk output per acre.

There are many other aspects of the effects on milk production of fertilizer application to grassland which cannot be discussed within the confines of this paper. For example, there is the crucial problem of whether it is more advantageous to increase output by purchasing feed or by enhancing yield per acre on the farm itself. On this group of farms over the past 2 years the comparison shows that both gross output and profit per acre have been increased much more by greater outlay on fertilizer applied to grassland than by a similar increased expenditure on purchased food. In other words, £1 spent on fertilizer applied to grass gave a better return in milk production than £1 spent on purchased food. This finding has special topical significance in view of the national problem of cheapening agricultural production without at the same time contracting its scale or profit while if possible reducing the present degree of reliance on imported foods for grass-eating livestock. In existing circumstances there appears to be a clear case for improved efficiency in those forms of livestock production that are based on the use of grass and little doubt that its more intensive exploitation on dairy farms offers financial advantage to the producer.

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The measurement of pasture output

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Pasture output a function of management

Most systems of pasture evaluation take little account of two of the main characteristics of pasture output, namely that it is made up of a number of harvests in any