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I must, at the outset, say that your association has certainly placed no real limits on me by requesting me to prepare this paper. The brief is extremely wide, viz., 'The Economic Optimum Use of Fertilisers in Ireland'. There is not much one can say about fertiliser use that does not come under that heading. For that reason I hope you will pardon me, if I impose some restrictions on myself, in order to keep the ideas, the problems, the examination and the discussion to a fairly manageable level. In order to achieve this it is worth taking a look at fertiliser use in general and as a consequence to narrow down the field to some of the major difficulties which are of direct interest to all of us whether we are looking at them from the viewpoint of the farmer, adviser, manufacturer or researcher.

It is as well, at the outset, to look at the overall situation with regard to fertiliser use in Ireland, and to see if we can draw some conclusions from this which will give us a better understanding of the problem as it faces each of us. A brief glance at trends with respect to fertiliser use shows several interesting developments.

In 1960 the total national expenditure on fertilisers and lime was £8.275 m. By 1968 the figure had increased to £18.767 m. This represents an increase of 127%, and even allowing for a price increase of between 14 and 15%, the quantity of fertiliser and lime has gone up by 98%. That is to say, the amount has almost

doubled. Looking at it another way, in 1960, national expenditure per acre on crops and pasture was about 15s whilst in 1968 it had increased to 32s.

Such a substantial increase in the usage of an important input in our agriculture implies that considerable changes will have occurred in technology in the 1960's, i.e., in the way in which we go about the job of producing our agricultural output. Some aspects of this change are shown in Table 1.

Table 1 : Inputs 1960-68

	1960 (£m.)	% of total costs 1960	1968 (£m.)	% of total costs 1968	Change 1960-68 (£m.)	% of change
Animal feed	19.5	22.8	43.3	31.9	+23.8	47.4
Fertilisers	8.3	9.7	18.8	13.0	+10.5	20.9
Machinery	13.7	16.0	23.3	17.2	+9.6	19.1
Wages	18.9	22.0	18.8	13.8	-0.1	-0.2

This table shows some selected inputs. Obviously there are many others, but those in Table 1 have been selected because of their predominance. The changes which occurred in the relative importance of fertilisers and the other inputs in the national agricultural production process between 1960 and 1968 demonstrate clearly the changing technology.

In 1960 fertilisers accounted for less than 10% of the total costs in agriculture. By 1969 they accounted for almost 14%. This in itself may not seem a very significant change but when one considers that it has taken place in a relatively short period of time its significance increases greatly. Furthermore, of the changes in costs which occurred in the past eight years, the

change in fertilisers accounted for 21%. And this is not all. In 1960 fertilisers were the fourth largest current input, in terms of cost, in Irish agriculture. By 1968 they were joint third with wages, are rapidly catching up on machinery and, if the present trend continues, could by the early 1970's be second only to animal feed in importance. It is generally accepted that mechanisation is taking place at a very rapid rate in recent years. It is, therefore, worth noting from Table 1 that, of the changes in input levels which have occurred since 1960, fertilisers account for 21% as against 19% for machinery. Only the percentage of animal feed has changed more in that time than that of the fertiliser input.

It is obvious then that fertiliser use is increasing quite rapidly and is likely to assume even greater significance in the years ahead. There is, however, another side to this coin. It is not enough to examine the extent at which fertiliser use is increasing across the national spectrum. We must also attend to the efficiency associated with these changes. Long-run growth of fertiliser use will only be successful if accompanied by efficient use. It is useful, therefore, to examine any changes in agricultural productivity which have taken place during this period of fertiliser use expansion. Data relating to this aspect are shown in Table 2.

The data in Table 2 highlight many of the dynamic developments in Irish agriculture. In the first instance gross agricultural output has increased from £193.1 m. in 1960 to £303.0 m. in 1968. Normally one expects that increased output can only be generated, in the short run, not only by increasing inputs but also by accepting that the productivity of the whole mix

Table 2 : Output costs, 1960-68

	1960	1968
Gross agricultural output (£ m.)	193.1	303.0
Costs as % of output	44.3	44.8
Ratio of output to fertiliser	23.3	16.1
Ratio of output to animal feed	9.9	7.0
Ratio of output to machinery	14.4	13.0
Ratio of output to wages	10.2	16.1
Ratio of output to area of crops and pasture	17.2	25.5

of inputs will begin to fall off. This has not happened in our case as it can be seen that, even though output increased by over half, costs as a proportion of output barely increased at all, remaining at about 44% in the period. This is a clear indication that the efficiency of the agricultural sector of the economy has increased greatly since 1960. The reason for this is that technological change, as represented by the input mix, has gone on at a much faster pace than is generally realised. And there is no doubt that one of the significant factors in this dynamism has been the role played by fertilisers. It is very evident that the substitution of animal feed, fertilisers and machinery for land and labour has been gaining momentum. It is also very evident that the role played by fertilisers in increasing the productivity of land and labour has been a major one.

The ratio of output to land has changed from 17.2 in 1960 to 25.5 in 1968. The ratio of output to wages has likewise increased from 10.2 in 1960 to 16.1 in 1968. These have been major advances. Increased fertiliser use has contributed in large measure to these developments. Table 2 shows that the ratio

of output to fertiliser expenditure has changed from 23.3 in 1960 to 16.1 in 1968. This reduction must be expected in the short run, due to the law of diminishing returns. It does not mean that fertilisers are being inefficiently used over agriculture as a whole. It merely shows that as the level of an input is stepped up its productivity may be reduced. The fact remains that the ratio is still high and the most important aspect is that it has helped significantly to increase the productivity of land, labour, seed and livestock. It also indicates that we are moving towards, not necessarily close to, the point of economic optimum use, and it is therefore a most desirable trend in terms of the national economy as a whole. The downward trend in the ratio of output to fertiliser expenditure does, however, mean that as we move towards overall economic optimum use, greater emphasis must be placed on the efficiency with which future developments take place.

Having already examined the role of fertilisers in the overall agricultural sector, the outlay on this important input as a proportion of the costs of some major farm enterprises is quite revealing. These data are shown in Table 3.

Table 3 : Fertiliser costs as percentage of total costs for different enterprises

Enterprise	Percentage
Wheat	14.1
Barley	14.2
Potatoes	16.2
Creamery milk	5.5
Cattle	9.3

This table reflects, to some extent, the fertiliser-use policy of farmers as a whole. It is apparent that producers consider fertilisers a more useful input or have a much clearer view of the impact of fertilisers in efficient production of tillage crops than of grassland and grazing livestock.

This attitude towards fertilisers is also very evident from recent fertiliser-use surveys carried out at farm level in this country. Some of the results are shown in Table 4.

Table 4 : Percentage of crop area fertilised 1964 and 1967

Crop	1964	1967
Wheat	98.7	97.5
Feeding barley	94.8	98.3
Malting barley	99.7	99.1
Oats	83.4	86.2
Potatoes	76.2	93.2
Sugar beet	97.7	100.0
Feed roots	-	96.2
Hay	50.0	66.1
Silage	52.9	87.4
Pasture	37.6	35.1

Source : Fertiliser-Use Survey, 1967

Whilst the Fertiliser-Use Survey showed that the quantities of fertiliser applied to the majority of crops shown in Table 4 was less than recommended levels, the figures mean that on the whole most concern must be shown in regard to fertiliser-use policy for grassland. There was no worthwhile change in fertiliser use on pasture and, since this represents by far the

major proportion of the agricultural area of the country, there is a greater scope for improvement in this area.

The representation of the average national situation obviously conceals trends and developments which illustrate the background to fertiliser use at individual farm level. Since the desirable direct effect of fertiliser application is the raising of land productivity, one would expect ample evidence of substitution of fertiliser for land especially in situations where the land resource is a barrier to expansion of farm output. Again this problem would be expected to be most critical where average farm size was low. It is interesting to note therefore that no real evidence of this is apparent from the Farm Management Survey being carried out by the Agricultural Institute. For example, in 1968/69 the average expenditure on fertilisers per acre for various farm size groups was as follows : 15-30 acre group, £1.26; 30-50 acre group, £1.44; 50-100 acre group, £1.87; and the 100-200 acre group, £2.04. Since this trend is the opposite to what one would expect, it can only be explained by accepting that land is not, in fact, the really limiting and critical resource. Our work has shown indeed that farm size is, in general, inversely linked with capital availability and educational status. The lack of capital and managerial ability to exploit the productivity potential of fertilisers is therefore a significant barrier to the effective use of fertilisers under our conditions. For this reason, and this is an aspect which I will return to later, it may seem inappropriate to propose fertiliser-use policies, where the fertiliser input is treated in isolation and unlinked with the other package of inputs which, of necessity, go into the production process on every farm.

Apart from the direct increase in output from effective use of fertilisers, or rather due to it, the obvious objective for such use must be the achievement of higher net returns. There is ample evidence of the association between fertiliser expenditure and gross margin, i.e., the difference between output and variable costs of production. In the Farm Management Survey already referred to, we can cite the example of two farming systems based on grassland utilisation, viz., manufacturing milk production and drystock farming. The average gross margins received from milk production in 1968/69 was £30 per acre, whilst that from drystock production (mainly cattle) was £11.30. The respective fertiliser expenditure per acre was £1.40 and £0.90, i.e., increased use of the order of 55% where the net returns justified such application rates. It should also be pointed out that, when a substantial tillage enterprise was added to each of those farming systems, fertiliser use increased substantially, from £1.40 to £3.00 in the case of milk farms and from £0.90 to £2.20 in the case of cattle farms. This trend emphasises the link between fertiliser use and returns because, in general, the margins from tillage crops were higher than from milk or cattle production. As well as this it shows once again the importance of taking capital into account, since less capital is required to take advantage of the fertiliser-based additional output from arable crops than from livestock enterprises.

This latter observation on the situation at farm level has major implications for national fertiliser use in Ireland where almost 90% of the land is under grass. Since the realisation through higher margins of the fertiliser-induced productivity of grassland requires substantial amounts of capital, the over-riding influence of this input in any programme for the effective

use of fertilisers becomes easily apparent.

The examination of economic optimum use of fertiliser, or any input for that matter, is an extremely complex issue when related to grassland. In the normal course of events the economic optimum is reached when the return from the last unit of input, in our case fertiliser, is exactly equal to the cost of that unit of fertiliser. In the early stages of fertiliser use one would expect the return to exceed, by a considerable amount, the cost of the last unit used. As more and more fertiliser is applied a stage is reached where the return from each successive unit begins to fall off - the area of diminishing returns. Nevertheless, even though the return is getting less it is still more than the cost involved so that it is still profitable to continue. Eventually the return falls to the point where the return from the last unit just pays the cost involved. This is the economic optimum point as it would not pay to go any further.

There is an important qualification to the actual doing of things in order to calculate the returns from varying applications of fertiliser for the purpose of determining the economic optimum and that is that other things must be held constant. This implies an environmental situation normally only found under experimental conditions. But in livestock trials on grassland other inputs cannot be held constant. Additional capital has to be invested in the extra livestock for the higher stocking rates required in order to stock each treatment in proportion to the amount of herbage produced. Additional machinery and labour would be involved in more intensive treatments; finally, the implied management levels would vary as between treatments. All these factors have to be taken into account when applying

the results from experimental work at farm level.

There is also the assumption underlying the calculation of an economic optimum that sufficient capital is available to exploit all the profitable investment opportunities open to it. In practice, the normal farming siutation is not one of adequate capital availability, owing to the imperfections in the supply of capital to farmers, or in some cases their willingness to invest all the money for which economic opportunities exist on the farm.

It is important to stress that, in determining the optimum economic use of fertilisers at farm level, the limited capital farm situation is not the exception but is the one which normally prevails, and this must be taken into account when developing fertiliser-use programmes designed for inclusion i . the typical planning situation in farming.

A major source of data on relationships between fertiliser use and standards of performance at farm level are farm management surveys. They do not avoid problems associated with varying management levels or various resource levels but they do give a representative picture of achievements from a wider range of circumstances and environments than can be obtained from other sources.

It is useful, therefore, to examine the results of some farm management studies which we have carried out in the Agricultural Institute and which document the achievements under actual commercial farming conditions where a wide range of fertiliser usage is available for examination.

In a small sample of 70 farms producing creamery milk the results outlined in Table 5 were achieved.

Table 5 : Fertiliser usage, income and working capital

Average fertilisers per acre (£)	Acres per L. U.*	Net income per acre (£)	Costs per acre (£)	Working capital per acre (£)
1.85	Under 1.6	22.8	18.2	48.0
1.48	1.6 - 2.0	16.5	13.7	32.7
1.20	2.0 - 2.4	14.1	9.9	33.0
0.80	Over 2.4	9.7	7.2	25.0

*L. U. = livestock unit

It can be seen clearly that increased use of fertilisers was accompanied by higher returns. The amount spent on fertilisers was not particularly high in any of the classes shown. Nevertheless, the farms with the higher fertiliser use achieved the highest stocking rates and returns over twice as great as those farms with lowest fertiliser usage. It is also worth noting that as fertiliser usage increased farm costs increased by much more than fertiliser costs alone. In fact, costs on the farms using highest rates of fertiliser were over twice as high as on those with low usage. The important point here is that these costs were justified and higher incomes resulted. It can also be seen that a greater investment in working capital, i.e., livestock, machinery, etc., was necessary to benefit from the higher rates of fertiliser application. These aspects bear out the point made earlier that it is not sufficient to look at the costs of the extra fertiliser only in an economic evaluation of the merits of such a policy.

More recently the opportunity arose to make an examination of a larger sample of dairy farms and thus to increase the number of fertiliser-use categories. The results obtained from a sample of 154 creamery milk farms are set out in Table 6.

Table 6 : Fertiliser usage, stocking rates and gross margins (G.M.)

Fertilisers per acre (£)	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-3.0	> 3
Average G.M. per acre (£)	20.3	22.9	27.3	28.5	30.6	36.9
Acres per cow	2.6	2.3	2.2	1.9	1.8	1.6

Source : Farm Research News, May-June 1968

Again we can see the clear relationship between fertiliser use and the gross margin achieved. Table 6 also shows the role played by increased fertiliser usage in the achievement of higher stocking rates, which is the factor directly responsible for the higher returns.

In the case of cattle the relationship between fertiliser expenditure and gross and net margins is much less strong. The results from a study on this aspect of cattle production are shown in Table 7. It can be seen that even though output increased as fertiliser expenditure increased, the improvements were barely, if at all, sufficient to cover the extra costs involved.

Table 7 : Cattle : Fertiliser use, returns, costs and investment per acre

Fertiliser on grassland (£)	Output (£)	Total costs (£)	Gross margin (£)	Net margin (£)	No. of L.U.'s	Cattle investment (£)
0-0.5	12.20	8.25	9.85	3.95	0.44	26.50
0.5-1.0	14.96	10.31	11.42	4.65	0.49	29.25
1.0-1.5	18.47	12.78	13.25	5.69	0.59	38.40
1.5-2.0	19.76	15.26	12.39	4.50	0.61	35.39
2.0 & over	22.92	17.79	13.45	5.13	0.66	42.47

This again shows how other costs rise as fertiliser use increases. The gross margin of about £10 per acre on the farms with low use of fertiliser increased to only £13 per acre on the more intensive fertiliser-using farms, and even then, the increase was not consistent. Similarly the relationship between fertiliser use and net margin is only slight since overhead costs appear to be higher on the more intensive farms.

These results highlight the fact that, in cattle production, fertiliser use is not of itself a critical factor in the overall level of profitability, and only insofar as higher fertiliser use is an integral part of a more intensive stocking system is it economically justified. There is a relationship between fertiliser use and stocking rate, but the evidence seems to indicate that it is of the utmost importance to use improved stocking rates as the route to higher profitability in cattle production, and to adopt higher fertiliser use and the other management policies in relation to this objective of improved stocking rate. There is evidence from our surveys that this aspect of fertiliser use is not adequately realised.

Another factor retarding fertiliser use from reaching its full potential is the relative inflexibility of the input itself in a farm programme. It is less flexible than concentrate feed because its effect is not so apparent but more particularly there is, due to the nature of the natural biological processes, a lag in response between application and realisation of the return. This lag in response is especially important in that it demands a greater degree of forward planning both for expected response and for capital requirements than does feeding of concentrates. For these reasons concentrate feeding is much more widespread in

Ireland than fertiliser use. In 1968, farmers spent over two and a half times as much on purchased feed as they did on fertilisers. Indeed, it is only this year that expenditure on fertilisers reached the 1953 figure for purchased feed. Not only does this highlight the opportunity which exists for increased fertiliser use, it also emphasises the changes which must come about in terms of a policy for effective use of fertilisers.

In considering such a policy we must differentiate between the approach which may be taken at the micro or farm level and the macro or national level. At macro level it was acceptable, because there was no alternative, to treat fertilisers in isolation from other inputs. The justification for not treating fertilisers as merely part of the package of inputs necessary in the production process is that it is neither possible to control exactly the national input of fertilisers nor the exact level of use of the other production factors. National policy, therefore, can only influence fertiliser use and this influence has been most conveniently operated by treating it in isolation. This, however, cannot ensure effective use.

At micro level this approach is, I think, a serious mistake and maybe the greatest single cause of deficiencies in effective fertiliser use. Treating fertilisers in isolation at farm level fails to recognise the complex nature of the production process which in most instances requires a package of inputs to produce a mix of commodities. Furthermore, it fails to recognise the growing need for "service type" inputs, especially capital, if a producer is to take advantage of the increased productivity generated by additional fertiliser use. This becomes critically important where the direct effect of fertilisers is to produce

forage for livestock production. There is little point in applying extra fertiliser to produce extra forage unless additional livestock are available to utilise it. This is where the additional capital requirement becomes crucial.

All this means that in the dissemination of recommendations for application at farm level regard must be had for the extremely close inter-relationships that exist between all the inputs used in the production process. We can no longer expect effective and efficient use of any of these inputs if recommendations are based on the productivity of or response to incremental use of one input while other inputs are held constant. Other inputs cannot be held constant if we are to have efficient and expanding production. The mix of inputs must, therefore, be emphasised because this is how actual farm practice operates. In future we must concentrate on this mix aspect and present recommendations to farmers by tying up in a package, as it were, the various levels of all the controllable inputs to be used in a production system for each commodity. In each proposal for an intensive production system we must set out the details of the quantity and type of commodity to be produced per unit of land together with the package of inputs, including fertilisers, but especially service inputs, such as capital, labour, and management, necessary to make this system both technically and economically efficient.

In line with EEC policy, we will also need to restructure and reorganise our national policy with regard to effective fertiliser use. Policies which rely on direct input subsidies will no longer be possible, especially where the actual production of fertilisers rests outside direct government control. I believe that increased and effective national use of fertilisers will in any

event require programmes and policies which are much wider in scope than what can be achieved by direct government intervention on fertiliser prices. The only real long-term national policy for increased fertiliser use must be one which is based on the attainment of growth in agriculture. We have much evidence of this from trends in the development and growth of our own economy. An overall expansion of agricultural production will lead to increased capital formation. This will remain a prerequisite for expansion of fertiliser use, which when coupled with provision of research results in the appropriate form to farm producers, will generate further expansion in the agricultural sector. It is in this way that long-term and sustained growth in fertiliser use can be maintained.