A Half Century of Fertiliser and Lime Use in Ireland

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The importance of a satisfactory supply of nutrient elements and lime, in soils, is now universally recognised as one of the major factors in crop production. When a crop, either tillage or pasture, is harvested from a field, a portion of the soil's nutrients is taken away, resulting in fertility depletion Another important source of loss is leaching. On soils naturally rich in nutrients the impact of this on productive capacity will of course be much less than on soils of low inherent nutrient supply. In the latter, crop and pasture yields are then directly related to the extent, to which losses are made good by the application of manures and fertilisers. It is of significance that in this country there are few, if any areas, where soils are naturally rich in nutrients.

In recent years, a number of reports have drawn attention to the relatively low, almost static level of crop and pasture production on an overall national basis With the need for raising agricultural production on an economic competitive basis so as to increase national income, the part which increased lime and fertiliser use can play, merits attention. This is especially so as a number of reports (2, 3, 4) have drawn attention to the very low levels of plant nutrients in our soils, while usage of fertilisers per acre is also very low

This paper represents an attempt, from an examination of agricultural systems and manurial practices over an extended period, to assess future needs of both fertilisers and lime, so that an appropriate level of output can be achieved, while at the same time protecting soil fertility.

Basis of Study

This study is presented in three parts as follows —

(1) An examination of the pattern of lime and fertiliser use from the beginning of the present century, with a brief assessment of the position in the previous century also.

(2) A consideration of the present nutrient and lime status in our soils, on the basis of survey and yield data.

(3) Based on the data derived under these two headings, together with a consideration of the results of modern field experiments designed to study the economic optimum use of fertilisers, an assessment is made of overall fertiliser and lime requirements

In this study, use is made of yield, crop, livestock and import-export statistics, soil analysis data, fertiliser survey information and results of field experiments.

PART I—THE LIME AND FERTILISER USE PATTERN.

The period 1800–1840

No detailed statistical records of the period 1800–1840 are available, so precise information on livestock numbers, crop acreage, or amounts of fertilisers applied, is not available It is known, however, that the provision of manures must have been an increasingly difficult problem for the Irish farmer of this period, owing to the enormous increase of nearly 3 million in the population between 1800 and 1841. It was, therefore, imperative to increase production from the land, especially of potatoes At this period, 45 per cent. of the holdings over one statute acre were less than five statute acres and 35 per cent. were from five to fifteen statute acres, so that it is doubtful whether increased production was entirely effected by expansion of the area tilled. Rather, it was brought about as much by increased yields per acre, as by increasing the tillage area. This meant that more and more manures had to be provided It is unlikely that this was reflected in an increase in the amount of farmyard manure from a greater number of livestock , these usually tend to diminish in numbers with increase in the area under cultivation

The average yield of potatoes in Ireland during this period (1812) is stated to have been five to six tons and the wheat yield was eleven to twelve cwts per statute acre Similar figures are given for the year 1832. These yields were stated to compare favourably with those obtained in Britain at the time and, indeed, this yield of potatoes was not exceeded during the following century The yield of wheat however, was low, much lower than that obtained from the 'seventies onward. This is a reflection of the manuring system followed All available manures were reserved for the potato crop, which was followed by wheat ; if two crops of potatoes were grown, a small amount of ashes was applied to the land for wheat

For all practical purposes, the manures used during the period consisted of dung, seaweed, turf mould, seasand and ashes Other manures used on a very limited scale were bones, rape meal, malt dust, liquid manures, oyster and other shells, furriers clippings and horn shavings.

An extraordinary and detrimental practice during the period was known as "Devonshiring" or burning the land, which consisted in collecting the top 5 in of soil, drying it, and burning it in heaps. The resultant ashes were then distributed and ploughed in Perhaps two crops of potatoes and several crops of corn were then grown in succession, after which the soil became derelict and completely unproductive for years. This practice was widespread in Ireland at the time and much of the land was burnt, not once, but several times over. Eventually in 1860, an Act was introduced to make burning illegal, without the previous written consent of the landlord.

There are many references to the high value placed on manures at the time. Turf mould was placed in every hole or puddle, where it could be trodden on by livestock , seaweed was carted immense distances and in the West was sold at fairs and markets, where its popularity often led to scenes of disorder, so great was the demand

Farmyard manure was also regarded as extremely valuable ; in fact, during this period the rent charged for manured conacre per statute acre was usually equivalent to a labourer's wages for a year (£7–£16) There can be little doubt that this very high value was due to its scarcity during the period, since the population was increasing out of all proportion to the numbers of livestock (there were less than two million cattle in Ireland in 1841—compared with 3 million in 1951).

Lime and seasand were also in great demand during this period ; farmers suffered great hardship travelling long journeys to the kilns or seashore, often using horseback for transport of perhaps a barrel of lime or sand at a time. The quantities used, judged by modern standards were excessive, often amounting to the equivalent of 10 tons ground limestone per statute acre : in the light of modern knowledge regarding the ill effects of overliming, it is obvious that crop production must frequently have been seriously impaired by this practice

In general, it can only be concluded that no nutrient build up in the soil occurred during the first half of the nineteenth century , rather, the reverse was the case since the only worthwhile intake of nutrients came from a very limited supply of farmyard manure and seaweed, whereas outgo was accentuated by the demands for more and more food crop acreage by the constantly increasing population There were no imports of fertilisers or feeding stuffs to augment the scanty supplies of organic home produced manures , so that in fact the drain on soil resources must have been far greater than is the case to-day, while, in addition, a considerable acreage of inherently very poor soil was being cultivated.

The Period 1841–1900.

During this period and thereafter, agricultural statistics were recorded, and a clearer picture of the impact of farming systems and practices on soil fertility is therefore available

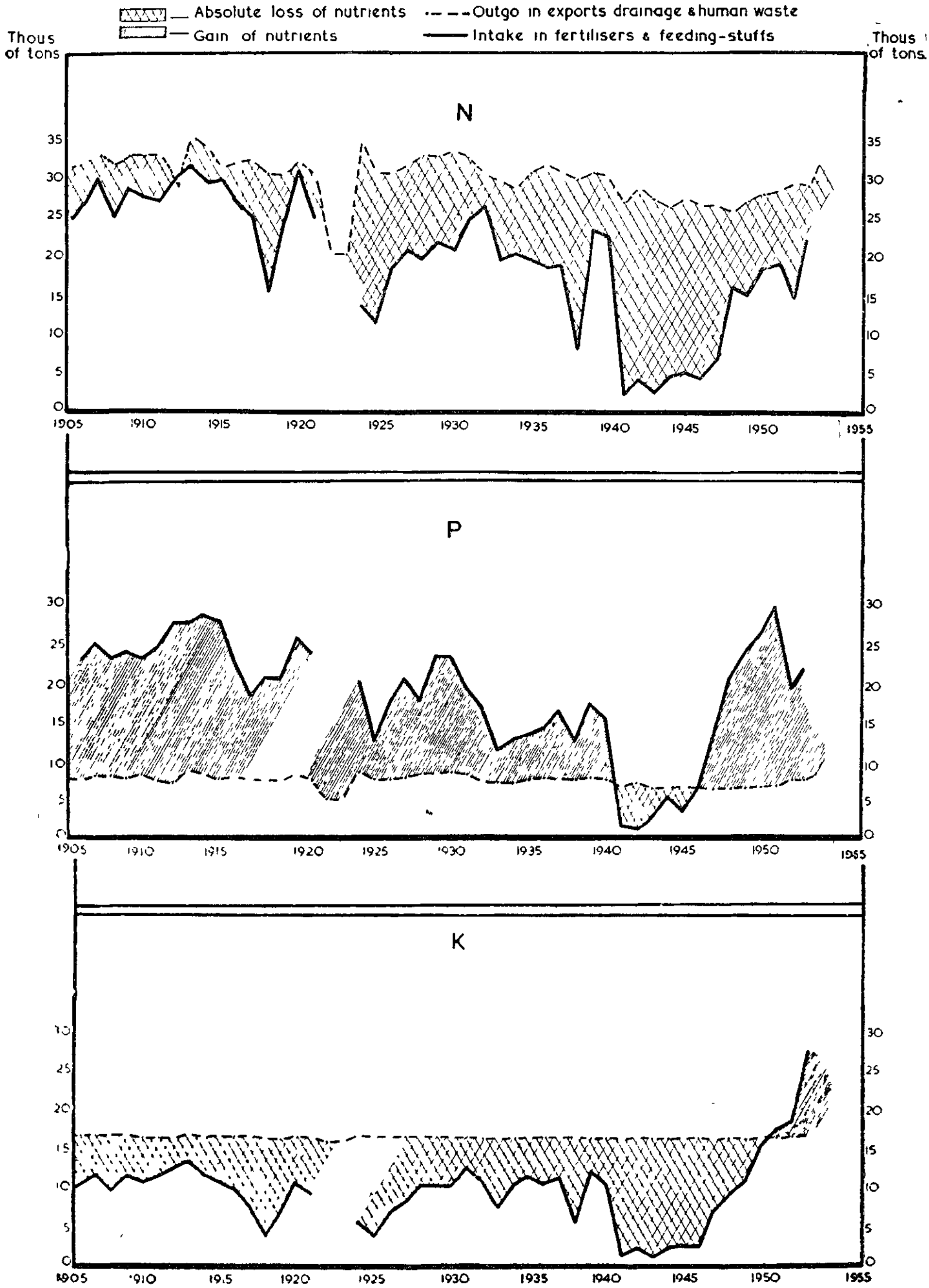
A study of the *yield figures* for the various cultivated crops for the period might be considered to afford some information on the nutrient supplying capacity of the soil All yields were comparatively high during the late 'forties and early 'fifties , this was followed by a decrease in yields during the 'sixties, after which yields increased (with occasional drops due to weather conditions in certain years, and during the two World War periods) right up to the present day.

Increase in crop yields was accompanied by a reduction in the area tilled, and expansion in the acreage of hay and pasture. This in turn was accompanied by a large increase in the numbers of livestock In fact, between 1851 and 1901 the total number of cattle trebled, pigs and horses doubled, and sheep increased fourfold in number per 1,000 acres of tillage.

With increasing numbers of livestock, the amount of farmyard manure naturally increased but in the absence of any considerable quantity of imported foodstuffs to boost its N P K. content, this extra farmyard manure did not represent an overall gain for our soils, it meant only more nutrients were in circulation in the cycle soil–crop–animal–farmyard–manure–soil. It is necessary therefore, to

Diagram I

ANNUAL OUTGO VERSUS INTAKE OF N, P, K. 1905 — 1953



consider whether these deficiencies were made good from the only other possible source, i.e. from fertiliser imports. The middle of the 19th century marked the beginning of the application of scientific principles to the manuring of crops For the first time, due to the efforts of Boussingault, Liebig and Lawes, the essentials of plant nuitrition were clarified This was followed by the foundation of the modern vast fertiliser industry in 1842 with the establishment by Lawes in England of the first superphosphate factory. Only limited information on the quantity of fertilisers used before 1903 is available ; it is known, however, that superphosphate was not used in any quantity in Ireland until the late 'fifties, but there were small amounts made on farms for some years previous to this, by dissolving bones in sulphuric acid. The main fertiliser applied during this early period was guano, used until the 'seventies, when the deposits were largely exhausted. Again no records of the amounts imported are available, but it is recorded that British imports in 1870 were 280,000 tons, and it is likely that Irish imports were only a fraction of this.

However, since the use of guano practically ceased after the middle 'seventies, and since the quantities used were small (a few cwt. per acre, on account of the high price, applied almost entirely for tillage crops) its effect on soil nutrient build up can be taken as negligible.

Potassic Fertilisers were first used in the early 'seventies, when experiments on the new manure were carried out at the Albert College, Glasnevin. There is no evidence that any worthwhile quantities were used in Ireland before the end of the nineteenth century, in fact even in 1904, the total amount of potassium (K) imported in fertilisers was only 469 tons.

Nitrogen Fertilisers.

Although nitrate of soda was first imported into Europe in 1830, it was not generally used until many years afterwards. In Ireland, it is doubtful whether any considerable quantity was used previous to 1904, since the amount imported in that year was only 6,825 tons, and much of this was used for making explosives. Regarding sulphate of ammonia, it is certain that very little of this was used by Irish farmers during the period under review, as is indicated by the import of only 678 tons in 1904.

The following table gives some indication of the extent of fertiliser use ; it records the quantities of superphosphate and compounds manufactured by the principal fertiliser firm in the country between 1861 and 1890.

That these quantities were comparatively trifling amounts will be evident from a comparison of the quantity manufactured in one year, e g. 1890 ; even if the fertilisers were used solely on tillage crops, the amount per st. acre (for 2,000,000 acres) would have been the negligible quantity of 32 lb In terms of soil nutrient build up, on a nationwide basis, this amount of fertiliser would have no measurable effect whatever, since its composition could certainly not have exceeded 99%P and 2% N.

Apart from the foregoing considerations, during this period, there were many adverse social factors operating, which completely dis-

TABLE 1.

Deliveries of Manufactured Manures from Irish Works

Season	Grand Total (tons)	Season	Grand Total (tons)
1861–62	859	1876–77	28,977
62–63	1,108	77–78	No records
63–64	1,487	78–79	available
64–65	2,495	79–80	24,681
65–66	3,892	80–81	24,882
66–67	5,272	81–82	22,022
67–68	7,139	82–83	22,635
68–69	8,961	83–84	20,158
69–70	12,334	84–85	18,828
70–71	15,912	85–86	19,673
72–73	16,538	86–87	20,063
73–74 .	No Records	87–88	20,586
74–75	available	88–89	25,122
75–76 .		89–90	25,454

couraged farmers raising the fertility of their land, the system of tenure was such, that any attempt at soil improvement was liable to be penalised by an increase in rent.

Taking the century as a whole then, it seems reasonable to conclude that, apart from liming, there was considerable depletion in nutrients. The one bright spot from the soil fertility aspect was the development of the permanent pastures in Meath, Westmeath, Longford and other areas following the reduction in tillage, but even in these, fertility build-up fell far below potential, because of inattention to nutrient replenishment. In this connection it is well known that properly managed and manured pasture is a vital factor in soil fertility build-up. The increasing yields of crops therefore was due to other reasons, the principal being the contraction in the area under tillage. It is well known that the best fields on the farm are retained for this purpose, and according as the grass and hay acreage increased, tillage receded from inferior fields to more productive fields.

Period 1900–1953.

Intake versus Outgo of Nutrients (*N.P. and K*)—The nutrient balance sheet pattern during this period is considered by making an estimate of the input versus outgo figure on an overall national basis. There are obviously many difficulties in the way of arriving at such an estimate. Table 2 provides an example of the method employed in this study This table shows two distinct main headings, i.e. input and outgo with a division again in terms of nutrients in circulation as distinct from those considered as representing possible absolute outgo, i.e. animal products, drainage losses based on lysimeter studies, human waste, etc. The quantity of farmyard manure has been estimated according to the method of Van Slyke (6).

Diagram 1 presents data obtained in this manner for the overall pattern of nutrient gains or losses. Reference to this diagram shows a consistent annual loss for nitrogen except for 1912. During the post-war period some downward trend in loss can be noted. In relation to this nutrient, it must be emphasised that there is one important input factor, i e the nitrogen fixed by clovers and other legumes which is not included. Its inclusion would naturally alter the situation where nitrogen is concerned

The relatively better situation shown during the pre-World War 1 period was due to imports of large quantities of concentrates (oil cakes, etc) for stock feeding , these contained high protein levels and therefore high nitrogen.

With the decline in stall feeding of cattle after the first World War, imports of concentrates decreased , this was reflected in the amount of nitrogen imported In 1953 the *total loss* of nitrogen was about 10,000 tons or the equivalent of about 50,000 tons of nitrogenous fertiliser

Phosphorus The diagram shows a relatively favourable situation where phosphorus is concerned , the intake of phosphorus in imports of fertilisers and feeding stuffs exceeded losses in exports, etc by a considerable margin, except during World War II period, when there was a total loss of about 5,000 tons annually The diagram shows a gradual deterioration in the phosphorus balance from the beginning of the century up to the end of World War II, when a rapid gain began and is continuing at present, due to increased imports of phosphorus in fertilisers

Potassium The diagram shows again, an unfavourable situation, throughout the period, in so far that there has been a consistent loss of potassium, which was accentuated during the War depression periods. However, the post-War period initiated a relatively more favourable position, and since 1950 there has been a gain of potassium , in 1953 this amounted to approximately 6,000 tons.

In interpreting these data, a few important considerations intervene. The quantities of nitrogen and potassium removed by crops in any one year were very much greater than those returned in farmyard manure or fertilisers Apart from the losses indicated in animal products, etc , it is obvious that there are also other sources of wastage. For both phosphorus and potassium, especially the former, in many soils there is serious loss of applied nutrient through fixation.

For phosphorus an average recovery of 40 per cent. must be considered in interpreting the overall picture.

Further, it may be pointed out that probably not more than 50 per cent of the nutrients imported in feeding stuffs find their way to the soil in farmyard manure This means that the nutrient balance picture would in actual fact be much more unfavourable than that shown in the diagram

The final pattern which therefore emerges is one of nutrient depletion, and is a continuation on a much less pronounced scale of a similar trend during the previous century A point of obvious interest is the significance of farmyard manure as an important source of nutrients on Irish farms, a consideration which is sometimes disregarded, in relating our fertiliser use to that obtaining in other countries.

Fertiliser Imports It is obvious from the foregoing considerations regarding nutrient " input " and " outgo " that adequate quantities of fertilisers must be used if production from our soils is to be increased or even maintained.

TABLE 2

Input and Outgo of Nutrients

"INPUT" OF NUTRIENTS, 1953

FERTILISERS	Nutrient content (tons)		
	Nitrogen	Phosphorus	Potassium
Nitrate of Soda	16		
Sulphate of Ammonia	10,295		
Compounds	55		
Other Nitrogenous Fertilisers	850		
Basic Slag		2,806	
Bone Manures		13	
Rock Phosphate		14,537	
Superphosphate		854	
Unclassified		321	
Muriate of Potash			24,777
Sulphate of Potash			180
Compounds			441
Total in Fertilisers .	11,216	18,531	25,398
FEEDING STUFFS			
Corn Offals	9,105	2,561	3,898
Oil cakes and meals	913	164	242
Other goods of vegetable origin	128	22	39
Fish Meal	511	206	51
Total in Feeding Stuffs	10,657	2,953	4,230
Total in Fertilisers and Feeding stuffs	**21,873**	**21,484**	**29,628**

"OUTGO" OF NUTRIENTS

EXPORTS	Nutrient content (tons)		
	Nitrogen	Phosphorus	Potassium
Cattle	4,955	1,348	346
Sheep	302	64	16
Goats .	5	1	—
Horses .	279	76	19
Pigs (Live)	1	—	—
Poultry (Live)	11	2	—
,, (Dead)	330	66	17
Beef	2,508	484	123
Pork, etc	915	274	70
Mutton	182	31	7
Other Meat	138	53	13
Rabbits	112	52	13
Total nutrients in Exports	11,422	2,450	624
Drainage Losses	5,000	500	15,000
Human Waste	15,000	4,500	1,000
Total Outgo of Nutrient	**31,422**	**7,450**	**16,624**

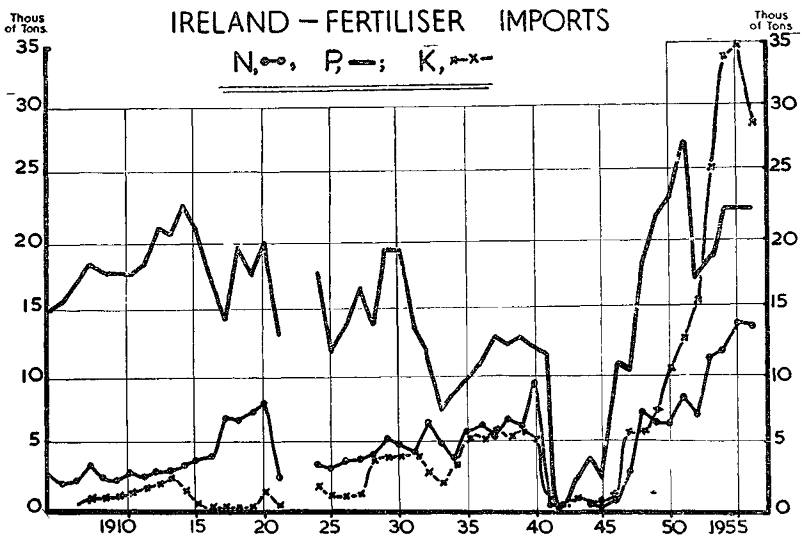
TABLE 2 —*continued*

	Nutrients in Circulation (tons) 1953		
	Nitrogen	Phosphorus	Potassium
Farmyard Manure .			
Solid 12,300,000	56,000	12,900	26,600
Liquid 4,800,000 .	47,700	2,800	52,300
Total	104,600	15,700	92,900
Assuming 50% *Return to the* Land .	52,300	7,850	41,450

	Nitrogen	Phosphorus	Potassium
Removed by Crops			
Cereals—Grain	18,478	3,465	4,619
—Straw	7,622	1,963	9,585
Potatoes	8,185	1,091	9,549
Turnips	3,164	506	3,586
Mangels	2,099	370	3,720
Sugar Beet —Roots	1,646	140	2,057
—Tops	13,990	247	2,057
Cabbage	417	60	476
Flax . ..	106	13	106
Hay	58,010	7,608	53,256
Total Removed in Crops	113,463	15,463	89,011
Milk (assuming 50% human consumption)	5,725	2,455	1,365
Total (Milk and Crops)	**119,442**	**17,918**	**90,376**

The annual imports of fertilisers 1904–1956 (in terms of total quantities of N.P.K.) are shown in Diagram 2.

Diagram 2



Considering phosphorus first, it will be noted that imports increased rapidly up to World War I by a total of about 50 per cent. ; there was a considerable reduction during this War, followed by a rise around 1920, after which imports fluctuated from 12,000 to 19,000 tons of phosphorous annually until 1930, when imports decreased from 19,000 to 7,000 tons in 1933 This was followed by a gradual rise until the outbreak of World War II when imports were completely cut off in 1941 until 1945. The post-war period, up to 1956, shows a relatively steep increase (with decreases in certain years) to a total of approximately 22,000 tons of phosphorus. In general there has not been a spectacular increase in imports of phosphatic fertilisers, e.g 18,000 tons of phosphorus was imported in 1907 and approximately 22,000 tons in 1914 (a figure not greatly exceeded to-day).

Nitrogen imports show completely different trends to those of phosphorus , they range from 2,500 tons of nitrogen in 1904 to over 12,000 tons in 1956 , there was a continual increase except for wartime depressions, the last of which (World War II) was followed by a considerable increase. In fact the imports of nitrogen doubled between 1952 and 1956.

Imports of *Potassium* in fertilisers were at a very low level from 1904 until 1927, when imports increased from 1,000 tons to 4,000 tons in 1931, followed by a sharp decrease in 1933 to 2,000 tons. Imports again rose to 5,500 tons in 1935 and remained around this figure until the war years, when supplies almost vanished. The post-war period saw a spectacular rise in potassium imports to a peak figure of nearly 35,000 tons in 1955, followed by a drop to 28,500 tons in 1956.

Generally the diagram shows that phosphorus was the predominant nutrient imported until after the recent War, when increase in imports of nitrogen and particularly potassium showed much greater upward trends than phosphorus imports As already discussed, this has resulted in a decrease in the ratios of phosphorus and potassium to nitrogen.

Fertiliser use in Ireland compared to other countries.

Comparison of fertiliser derived nutrients used in Ireland with other countries is shown by Table 3 after O E.E.C , 1955 (the figures are in terms of nutrients per hectare of arable land applied in 1954–1955, and in the table phosphatic and potassic fertilisers are expressed in terms of P_2O_5 and K_2O respectively) Diagram 3 gives a graphic illustration of the position

TABLE 3.

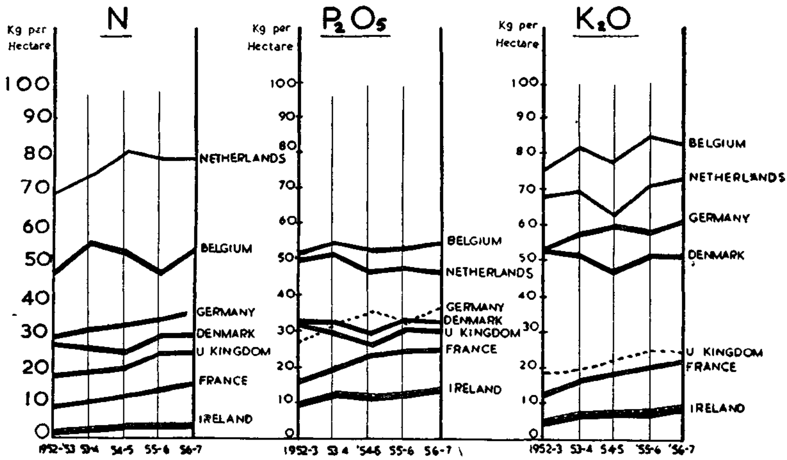
Fertiliser derived Nutrients used in Ireland and other Countries

Country	N	P_2O_5	K_2O	Total	Total Agr. Area 1,000 (hectares)
Netherlands	77 1	50 7	72 4	200 2	2,308
Belgium	59 0	53 7	78 8	191 2	1,751
Denmark	24 8	29 7	48 7	103 2	3,066
France	11 2	22 5	17 4	51 1	28,663
Germany	31 7	33 8	59 9	125·4	14,197
United Kingdom	19 9	32 3	21 0	73 2	12,570
Ireland	2 7	13 0	8 4	24 1	4,688
Average for 17 O E E C Countries	14 9	20 8	18 4	53 9	

This table shows that our use of ferilisers is much below that of any other European country. Even compared with the United Kingdom, where climate and conditions generally approach ours, the latter uses 7 times more nitrogen, 2½ times more phosphorus, and 3 times more potassium per statute acre than is used here

Diagram 3

CONSUMPTION OF FERTILISERS



It is also of interest to examine the relative proportions of the different nutrients used here, and in other countries (O E E C , 1955).

TABLE 4

Ratio of P_2O_5 and K_2O to N, when N=1

COUNTRY	1949-50		1950-51		1951 52		1952-53		1953-54		1954-55	
	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
Netherlands	0 9	1 1	0 7	0 9	0 6	1 0	0 7	1 0	0 7	0 9	0 7	0 9
Belgium	1 2	1 3	1 0	2 0	1 1	1 7	1 1	1 6	0 9	1 4	0 9	1 3
Denmark	1 4	1 5	1 2	1 4	1 2	1 8	1 2	2 0	1 2	2 0	1 2	2 0
France	1 7	1 5	1 3	1 7	1 7	1 6	1 8	1 4	2 0	1 6	2 0	1 6
Germany	1 0	1 8	1 2	1 8	1 2	1 9	0 9	1 8	1 0	1 9	1 1	1 9
United Kingdom	2 0	1 1	2 0	1 1	1 5	0 9	1 7	1 0	1 6	1 0	1 6	1 1
Ireland	7 5	1 7	7 5	2 6	5 4	2 9	5 1	2 6	4 9	3 0	4 8	3 1

It is apparent that we use much more phosphorus and potassium relative to nitrogen, than other countries, in none of which the ratio is greater than 2 to 1 This is a reflection of the grassland type of farming practised here, involving more relative use of phosphorus than in countries where farming systems are mostly on a cash crop basis

While there is no doubt that the narrowing of the N P_2O_5 K_2O ratio in recent years is a favourable trend and that further progress in this direction is desirable it must be pointed out that a direct comparison with other European countries can be misleading This is because we have soils and climate different to theirs with a much greater potential for building nutrient rich organic matter especially through the agency of clovers and favourable soil, physical conditions, with also, of course, a much higher acreage of good land per head of population.

Fertiliser Use practice

While the overall use of fertiliser is important, an equally important consideration is the way in which this fertiliser is used, i e. what crops receive attention, and the basis on which this fertiliser is applied together with methods of application This can be seen from a consideration of fertiliser use practice.

For the greater part of the period under review, because of the absence of specific fertiliser use data, it is possible only to speculate. However, it can be taken as reasonably certain that apart from a few limited areas, practically all the farmyard manure and fertilisers available were applied to tillage crops, with root crops receiving the major portion of the farmyard manure.

A more specific picture of the pattern of fertiliser use has been possible from an analysis of data submitted by advisers in connection with soil analysis during the spring of the present year (1957). This data is presented in Table 5, classified on a " Farming System " basis

The most striking feature of the Survey is the invariable use of manures, either F Y.M. and—or fertilisers on root crops , cereals too are usually manured, especially in tillage counties It was noted however, that much of the cereal manuring comprised the application of phosphorus only, and in few cases was sufficient nitrogen applied.

It is noteworthy that the lowest rate of manuring of cereals occurred in the dairying districts of N Kerry, Limerick, Cavan and E. Galway, a predominantly sheep farming area In connection with cereal manuring it is of interest that in a number of areas the practice of drilling seed and fertiliser together is general, resulting in a considerable economy in fertiliser and more consistently higher yields.

Little more than half the 1956 hay crops and only 36 per cent. of permanent pasture received any fertiliser ; the worst areas in the latter respect being Offaly 12 per cent. and E.Galway 4 per cent.

The largest proportion of pasture fields which were manured in 1956 were in Counties Carlow 55 per cent and E Cork 65 per cent.

In interpreting these latter figures, it must be remembered, however, that the usual soil analysis upwards bias probably applied, namely that the fields surveyed were on the more progressive farms. Therefore, the general position for grassland is probably, in fact, much worse than is shown by the figures, so that the average figure of 36

TABLE 5

Fertiliser Use Survey—1956.

County	Farming System	Percentage of Fields under each crop to which Manure was applied in 1956			
		Roots	Cereals	Hay	Pasture
		%	%	%	%
Cavan	Mixed, mainly dairying	100	76	26	20
Limerick	Mixed, mainly dairying	100	70	56	35
W Waterford	Mixed, mainly dairying	100	94	53	23
N. Kerry .	Mixed, mainly dairying	100	62	46	43
Clare .	Mixed, mainly dairying	100	70	70	48
Wexford	Mixed, mainly tillage	100	100	90	10
Carlow	Mixed, mainly tillage	100	100	60	55
Kildare	Mixed, mainly tillage	100	100	50	16
E Cork ..	Mixed, mainly tillage	100	92	50	65
W Cork ..	Mixed .. .	100	95	94	51
Offaly .	Mixed .	100	88	70	12
Dublin	Mixed and Dairying	100	90	25	50
Meath	Beef Production and Milk ..	100	92	50	23
Wicklow .	Sheep Production and Tillage .	100	98	57	30
E Galway .	Sheep	100	67	90	4
	Mean	100	86	59	36

per cent for manured pastures is almost certainly too high In general, however, the survey emphasises the neglect of our grassland where fertilisers are concerned, an extremely serious matter in view of the fact that three-quarters of our arable land is under permanent pasture, and that moreover, this is the main source of soil fertility building

Use of Lime Under Irish conditions, an adequate liming programme is of special importance in soil fertility maintenance and crop production Because of climatic conditions resulting in excess of rainfall over evaporation, there is loss through drainage for a considerable portion of the year This loss is accentuated by reason of the medium and light loam texture of a great portion of our soils, and the level of organic matter, giving a high release of carbon dioxide and hence a greater leaching capacity to drainage water Moreover, the major areas of soils are derived from lime-poor parent materials. As already indicated, lime was intensively used, and probably over used in this country up to the 'seventies of the last century. Its use then declined due to the introduction of fertilisers such as guano and superphosphate, which gave quicker and more spectacular results social and economic reasons were also contributory factors restricting the amount of lime used By the beginning of the present century the practice of liming had declined to only a fraction of what it had been It is difficult to give an accurate estimate of the position, because no statistics covering this matter are available The practice of burning lime continued on a limited scale however, while the traditional collection and distribution of lime-containing sea and coral sand continued in many coastal areas. Data available from the Lime Subsidy Scheme operated by the Department of Agriculture from 1934–1951 shows that, beginning with 25,000 tons of burnt lime in 1934–35, application under this scheme reached a peak point of 78,000 tons in 1940–41, declining in 1949–50 to 49,360 tons. The average for the 17 year period was 46,550 tons per year. In addition to this, an estimated annual average amount of sugar factory waste lime of the order of 50,000 tons was also applied. These two sources of lime represented at the outside, not more than the equivalent of 100,000 tons of ground limestone annually. With the introduction of the new Ground Limestone Scheme in 1951, the position changed completely, as is

TABLE 6

Ground Limestone and Sugar Factory Lime delivered each year

Year	Ground Limestone (tons)	Sugar Factory Lime (tons)	Equivalent Total of Gr Limestone (tons)
1951/52	278,000	53,000	304,500
52/53	502,000	89,000	546,500
53/54	649,000	90,000	694,000
54/55	806,000	66,000	839,000
55/56	1,103,000	50,000	1,128,000
56/57 . .	*969,000	*40,000	970,000

*estimated

seen in Table 6 which shows the amounts of ground limestone and sugar factory lime, delivered each year under the Ground Limestone Transport Subsidy Scheme

Up to 1951, the amount of lime applied represented less than 1 per cent of overall requirement, since then, as figures given later show there has been a spectacular increase in lime use However, comparison with estimated requirement shows that the latest figures are still less than 10 per cent of the optimum level required in fact the amount of lime applied is lower than that lost annually in drainage.

PART II—THE NUTRIENT AND LIME STATUS OF IRISH SOILS

From a consideration of the data in Part I, it is obvious that at no time within the past century, at least, was there an opportunity for any appreciable build-up of nutrients in Irish soils; on the contrary, there was a considerable degree of extraction. There was, moreover, at least half a century of serious lime depletion It is also of significance that we have no large areas of naturally rich soils, as under the forest type of vegetation which records show, once largely covered the country, a considerable degree of soil weathering took place Moreover, our climatic conditions are conducive to such weathering proceeding at a fairly rapid rate On the other hand, however, these climatic conditions are also conducive to the rapid build up of organic matter in soils under grass, and in this organic matter under good management conditions, reserves of nitrogen and other nutrients accumulate This is shown by the data of McDonnell and Walsh (2) from work on phosphorous levels in Irish soils in relation to farming systems

The present nutrient and lime status of our soils must also be examined against a background of a very wide variety of soil types, each having its own production potential From preliminary soil classification studies, it has been found that within the mineral division of soils above, there may be some 30 major groups, each of which can be further subdivided locally into probably some 50 types on the basis of the classification system being used

We can now proceed to a consideration of the nutrient and lime status data This is mainly available from the results of the analysis of over half a million soil samples examined in connection with advisory work It must be noted, that these results probably show a distinct upward bias, the samples generally being from the land of the more progressive farmers In addition, specific surveys have been carried out on a detailed field to field basis in some confined areas in —Bansha, Co Tipperary; Ballyduff, Co Waterford and Cooley, Co Louth

General Surveys

Walsh *et al* (3) in 1950 from a consideration of general analytical results, found over 90 per cent of the samples either very or moderately deficient in phosphorus, over 50 per cent deficient in potassium, and less than 50 per cent. satisfactory for lime. Again, an examination on a county basis, of the analytical data for some 12,000 samples tested in January, 1957, shows the results presented in Table 7.

TABLE 7.

pH and Nutrient Levels of Soil Samples tested in January, 1957

County	*pH*			Calcium			Phosphorus			Potassium		
	A	B	C	A	B	C	A	B	C	A	B	C
	%	%	%	%	%	%	%	%	%	%	%	%
Carlow	17	36	47	27	35	38	44	46	10	36	28	36
Cavan	40	45	15	38	36	26	31	56	13	5	12	83
Clare	23	49	28	42	38	20	67	18	15	37	12	51
Cork	24	38	38	22	47	31	52	38	10	27	24	24
Donegal	44	38	18	47	38	15	59	21	20	41	26	33
Dublin	14	36	50	40	34	62	34	42	24	35	25	40
Galway	7	23	70	13	27	60	31	39	30	34	21	45
Kerry	15	48	37	19	43	38	49	37	14	35	19	46
Kildare	7	38	55	6	28	66	50	36	14	56	18	26
Kilkenny	10	41	49	6	39	55	55	29	16	35	24	41
Leitrim	37	44	19	34	38	28	58	36	6	34	22	44
Limerick	3	40	55	5	26	69	37	48	15	21	21	58
Longford	38	35	27	21	36	43	60	14	26	17	19	64
Laois	13	27	60	6	46	48	33	44	23	38	26	36
Louth	17	47	36	15	55	30	40	51	9	22	15	63
Mayo	22	45	33	16	40	44	52	37	11	36	22	42
Meath	29	34	37	11	30	59	52	35	13	41	21	38
Monaghan	38	46	16	18	55	27	36	50	14	7	10	83
Offaly	8	21	71	8	28	64	49	29	22	53	22	25
Roscommon	11	43	46	12	35	52	50	33	17	30	22	48
Sligo	16	55	29	25	51	24	51	35	14	22	23	55
Tipperary	18	42	40	12	48	40	48	38	14	36	23	41
Waterford	26	34	40	30	42	28	57	31	12	28	22	50
Westmeath	9	43	48	8	38	54	46	33	21	33	26	41
Wexford	30	50	20	42	38	20	76	21	3	31	28	41
Wicklow	44	40	16	47	41	12	66	30	4	40	20	40
Overall Average	22	40	38	21	39	40	49	36	15	32	21	47

A= Very unsatisfactory. B= Unsatisfactory. C= Moderately Satisfactory

Taking pH levels, which considered in conjunction with those of calcium, afford a reasonably accurate picture of lime status, examination of the figures presented for the various counties, shows, as might be expected, a correlation with soil parent material Thus, the lowest proportions of moderately satisfactory levels (i e over pH 6 0) occur in counties Cavan (15 per cent), Monaghan (16 per cent.), Wicklow (16 per cent.), Donegal (18 per cent.), Leitrim (19 per cent), Wexford (12 per cent), Longford (27 per cent) and Clare (28 per cent), where the soils are mainly derived from non-limestone materials On the other hand, in counties where limestone parent materials predominate, the proportion in the moderately satisfactory category are much higher ; these include Counties Limerick (69 per cent.), Kildare (66 per cent.), Offaly (64 per cent.), Dublin (62 per cent.), Galway (60 per cent), Meath (59 per cent.), Westmeath (54 per cent), Roscommon (52 per cent)

It is obvious from these figures, that lime status is at an extremely critical level in the non limestone-derived soils and even on soils where limestone parent materials predominate, the position is far from satisfactory. This is rather contrary to common belief, but is logical enough in view of the continual downward movement of lime occasioned by leaching due to rain.

With an overall picture of some 60 per cent of our soils still lime deficient, there remains obviously quite a lot of leeway to be made up.

Phosphorus It is seen that the phosphorus position, in practically every county, is very critical and the overall average figure for the country shows that only 10 per cent. of our soils can be regarded as satisfactory. The most deficient counties are those where soil acidity is also a problem, which is logical, in view of the fixation of applied phosphorus associated with acid soils Counties with the highest proportions of "very unsatisfactory" levels, include Wexford (76 per cent), Clare (67 per cent.), Wicklow (66 per cent.). Longford (60 per cent), and Donegal (59 per cent.).

It has been the general experience that adequate phosphorus status as shown by soil analysis is found almost exclusively in samples representing intensively manured tillage areas, especially coastal regions, or land where heavily manured root crops have been grown the previous year

Potassium Reference to Table 7 shows that the highest percentage of satisfactory potassium levels occur in Counties Cavan (83 per cent), Monaghan (83 per cent), Longford (64 per cent), Louth (63 per cent), Limerick (58 per cent), Sligo (55 per cent) This is due to the predominance of rather heavy textured, poorly drained soils in these counties, and may also be related to the type of clay mineral occurring in such soils It is of interest to note that counties with the lowest proportion of satisfactory potassium levels include Kildare, Offaly and Meath, where the soils contain high calcium levels

Counties Donegal and Wicklow also contain high proportions (41 per cent and 40 per cent respectively) of deficient soils, despite the fact that considerable areas of soils in these counties are derived from granitic parent materials, which of course contain appreciable amounts of potassium The relatively coarse texture and resultant high leaching properties of these soils predispose to considerable loss of potassium in drainage.

In general, it may be stated that low soil potassium levels are associated with soils of low clay content, e g. very sandy soils, high lime content and peaty soils. Much of our old pastures show exceptionally low levels of available potassium, a fact which is often responsible for the widespread lack of clover growth in pastures ; clover has a relatively high demand for potassium, much higher than grasses, which can sustain normal growth, even where the potassium status is quite low The result is in turn reflected in low nitrogen levels, and inferior output.

Considering potassium levels on a national basis, the overall average indicates that approximately 50 per cent. of our soils are deficient in potassium ; increased use of potassium especially on pastures therefore is necessary for any programme of soil fertility improvement.

Local Surveys.

The results of a survey, on a field to field basis of Bansha Parish, Co Tipperary, which was carried out in 1949 to 1952, included a thorough examination of nutrient levels, in relation to soil types and farming systems, have been reported by Walsh *et al* (4)

The total arable area of the parish was approximately 15,000 acres, with a permanent pasture area of over 11,000 acres The agriculture of the parish was mainly livestock farming, concentrated mainly on milk and store cattle production, coupled with a limited amount of sheep farming on the hills surrounding the parish. Data showing soil nutrient levels in Bansha are presented in Table 8

TABLE 8

Soil Nutrient levels in Bansha, Co Tipperary

Category	Lime	Phosphorus	Potassium
	%	%	%
A .. .	18 1	79 7	48 0
B	41 3	11 4	30 5
C	30 6	8 9	21 5

These figures are similar to those obtained from the general survey and when it is remembered that this is predominantly a dairying area, the position is seen to be very critical. Moreover, in this survey it was also found from the analysis of herbage samples for phosphorus, that in only 29·4 per cent. of the samples was the level satisfactory for high producing cows. A similar survey in the parish of Ballyduff, Co Waterford gave the result shown in Table 9, where A—very deficient, B—moderately deficient, and C—satisfactory. In this instance, a high degree of both phosphorus and potassium deficiency is shown.

TABLE 9

Soil Nutrient levels in Ballyduff Parish, Co Waterford

Category	Lime	Phosphorus	Potassium
	%	%	%
A ..	15	83	57
B .	46	12	31
C .. .	39	5	12

A rather different situation regarding lime and nutrient status is shown by results from a survey carried out in the highly farmed area of Cooley, Co. Louth. This area was divided into three sections, on a farming type basis as follows Area No. 1 (Cooley peninsula—Greenore, Ballyagan, Whitestown, where farming is at a high level with good manuring). Area No 2 (Carlingford—Grange, Bush, Rathcow, where farming is at a moderate-high level) and Area No 3

(Castletowncooley hill area where little fertiliser is used). The results of this survey are shown below, with classification on the same basis as for Ballyduff.

TABLE 10.

Percentage of Samples in each Nutrient Category, Cooley, Co Louth

Area No	Lime			Phosphorus			Potassium		
	A	B	C	A	B	C	A	B	C
	%	%	%	%	%	%	%	%	%
1 .	—	23	77	7	31	62	8	8	84
2 .	16	21	63	26	53	21	5	63	32
3 .	35	40	25	60	40	—	15	30	55

In this instance, Area No. 1 can be regarded as representative of a few limited coastal areas under intensive farming, while area 2 is well above the national average in level of farming and output, with an above average level of fertiliser use. There is further ample verification of the present critical nutrient and lime status of our soils, from data recorded from experimental sites where no fertiliser was used, and also a comparison of the national average yields with those which may be obtained by the use of optimum fertiliser. This point is referred to again in Part III. The position then is that the overall average output is low which is understandable in view of the very low usage of fertiliser on nutrient depleted soils. If a satisfactory level of output is to be achieved this position must be changed with however, due attention to attaining the economic optimum yield, so that production can be on a competitive basis, with a reasonable return to the farmer. In considering this matter, it may be added, that while our soils are nutrient, and in many instances lime depleted, they are by and large in good physical condition, with the exception of the extensive Drumlin belt and coal measure shale areas, and well supplied with organic matter.

Against this background we can now proceed to a consideration of overall nutrient (N, P, and K) and lime requirement, on an economic optimum application basis.

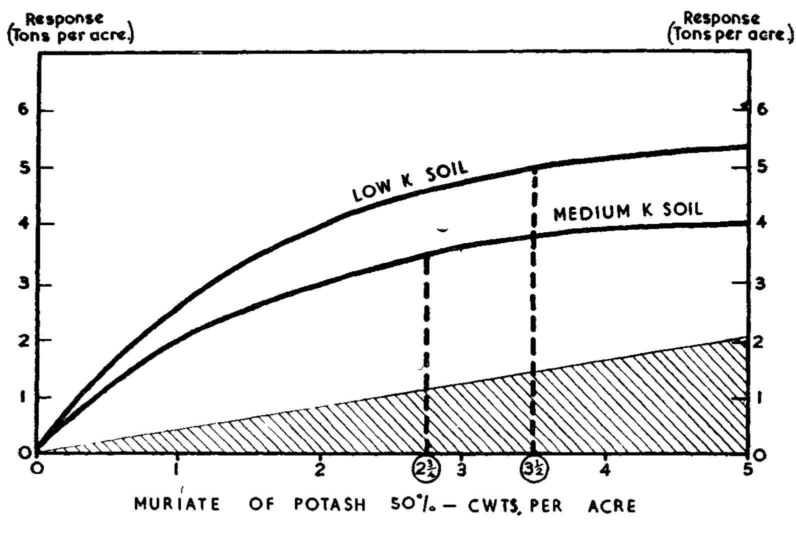
PART III—NUTRIENT AND LIME REQUIREMENT

Taking the data provided in Parts I and II as a basis, there are obviously several ways in which the assessment of our total N, P, K, and lime requirements can be approached We can consider the problem on the basis of maximum yields plus a substantial build up in the lime and nutrient status of the soils, or on the basis of optimum economic yields as defined later. From both the technical and economic stand points, there is much to recommend the latter procedure.

The objective then must be to obtain optimum response at minimum cost, an approach which among other things from the technical aspect requires the application of techniques such as fertiliser placement and control by soil analysis. The former for instance in the case of cereals, can reduce the quantity of phosphorus and potassium applied by half, while the significance of the latter can be realised from Diagram 4. In this diagram the response to muriate of potash is compared with the cost of the manure on the basis that the crop is valued at 50/- per ton while the gross cost of fertiliser applied is 21/- per cwt Here it is shown that the most profitable dressing of potassium varies according to soil potassium level. If soil potassium were at the high level, no potassium would be necessary In the absence of soil test information, the average most profitable dressing of muriate of potash, i e. about 3 cwts, would be recommended, entailing of course inefficient use from the economic standpoint.

Diagram 4

RESPONSE OF FODDER BEET TO K



In assessing overall requirements ; for tillage crops an estimate is made on the basis of economic optimum applications, derived from the results of field experiments ; for pastures information of a less specific character is utilised as dicsussed later.

Response to Fertilisers.

A. Tillage Crops.

This will be considered under two headings for each crop :

(1) The effect of manure versus no manure.

(2) The most profitable amount of fertiliser (without farmyard manure).

The latter has been calculated by using the method of Crowther (1) from the results of incremental fertiliser experiments carried out in recent years The diagrams which follow show the response curves for potatoes and wheat to increasing increments of nitrogen, phosphorus, and potassium, in conjunction with the most profitable dressing of each nutrient shown by the vertical broken line *This latter may be defined as the point where the value of crop response to an increment of fertiliser becomes equivalent to the cost of that increment* It depends mainly on the value of the crop compared with the cost of the fertiliser, so that changes in these factors will cause changes in the most profitable dressing of fertiliser. However, examination of the diagrams will show that little change in the response (or profit) will be caused by small variations from the most profitable dressing of fertiliser. Thus, unless considerable changes occur in the cost of fertiliser or value of the crop, recommendations for the most profitable dressing need not be changed appreciably

It should be realised tnat these dressings are for average conditions, so that adjustments would naturally have to be made for individual farms due to fertility and soil type variation, but in general, considered from the overall national aspect, the values shown are considered to give a reasonably accurate estimate of the amounts of fertiliser required for maximum profit on an acre basis. Where levels of nutrient are below average, response per unit of fertiliser will of course be greater as has already been seen in Diagram 4.

The hatched area of the diagrams shows the cost of the fertiliser increments in terms of crop units. The cost taken for fertiliser includes an estimate of the cost of application and of harvesting the extra crop, etc. The values assigned to the crop are prevailing market values at the moment (early 1957).

In the field experiments the results of which are summarised below sulphate of ammonia was used as a source of nitrogen. Consequently the optimum economic dressings are given in terms of this fertiliser. Other types of nitrogenous fertilisers, such as those based on ammonium nitrate, can be used with equal efficiency for most of the crops listed.

Potatoes. A comprehensive series of experiments on the manuring of potatoes was carried out during the early years of the century, by the Department of Agriculture in every county. These showed that best results were obtained from a dressing of:

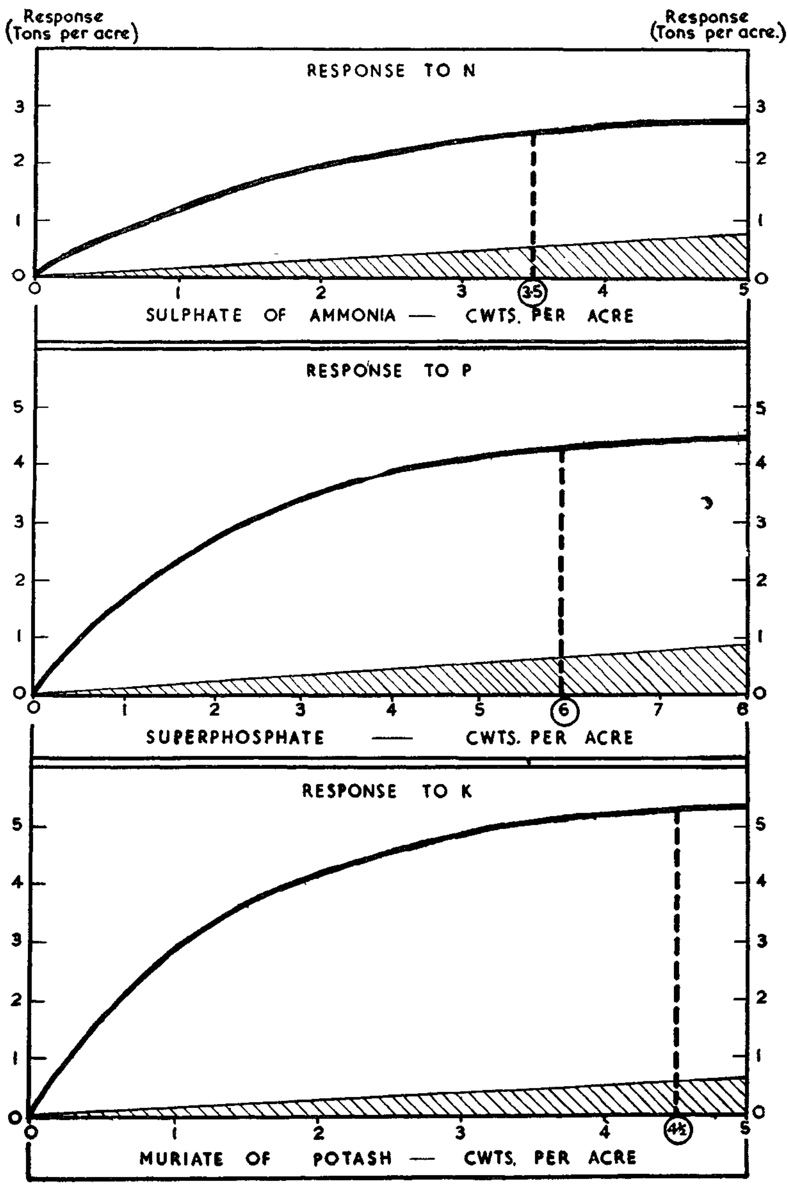
15 ton farmyard manure.
1 cwt. sulphate of ammonia.
4 ,, superphosphate. 35%.
1 ,, muriate of potash.

The average yield without manure was 5 ton 3 cwt. and with the above manuring 12 ton 9 cwt.—representing an increase of 7 ton 4 cwt. of potatoes.

A further series of experiments on a nation wide basis was carried out in 1950, and repeated in 1951 in co-operation with the Agricultural Instructors. These experiments on potatoes included incremental applications of nitrogen, phosphorus, and potassium as sulphate of ammonia, superphosphate and muriate of potash respectively, so that it is possible to construct response curves and work out the most profitable amounts of nitrogen, phosphorus and potassium

Diagram 5

RESPONSE OF POTATOES TO FERTILISERS



required. In Diagram 5 the value of the response in extra yield of potatoes is taken at £8 per ton in relation to the following gross costs of fertiliser applied · sulphate of ammonia, 26/- per cwt ; superphosphate, 17/- per cwt. ; muriate of potash, 21/- per cwt.

The most profitable fertiliser applications (in the absence of course of F.Y M) for potatoes under present price conditions is shown to be :

3½ cwt. sulphate of ammonia.
6 ,, superphosphate (35%).
4½ ,, muriate of potash (50%).

This gives a total yield of about 12½ tons, representing an increase of about 7½ tons of potatoes, a highly economic return, as will be shown later.

Mangels. Similar experiments to those on potatoes were carried out for 15 years subsequent to the establishment of the Department of Agriculture These showed that the most suitable manuring for mangels was

20 tons farmyard manure.
2 cwt. sulphate of ammonia.
4 ,, superphosphate.
4 ,, salt.

The average yield from the unmanured was 9 ton 9 cwt , compared to 33 ton 19 cwt. from the completely manured treatment, representing an increase of 24 ton 10 cwt from manuring.

The most profitable amount of potassium is equivalent to 2½ cwt. of muriate of potash per statute acre. Incremental data on most profitable levels of nitrogen and phosphorus for mangels is not available, but there is much experimental evidence to indicate that the optimum for these nutrients is in the region of —

2 cwt. sulphate of ammonia } per statute acre
6 ,, superphosphate (35%) }

The complete dressing would produce a yield of about 30 ton per statute acre.

Swedes. Manurial trials with swedes carried out over a period of eleven years before World War I showed that an application of :—

1 cwt. sulphate of ammonia }
4 ,, superphosphate (35%) } per statute acre
1 ,, muriate of potash (50%) }

increased the non-manured plot yield of 4 ton 17 cwt. to 22 tons, representing an increase of 17 ton 3 cwt.

Experiments were carried out in every county in 1951 by Agricultural Instructors with phosphorus and potassium on an incremental basis.

Precise data on response of swedes to nitrogen is lacking but it is reasonably certain that not more than 2 cwt. of sulphate of ammonia per statute acre would be justified

The complete most profitable amount of fertiliser for swedes is therefore .—

2 cwt. sulphate of ammonia }
6 ,, superphosphate (35%) } per statute acre.
2½ ,, muriate of potash }

The overall yield to be expected from this dressing would approximate to 27·5 tons.

Cereals.

Oats Very thorough and comprehensive experiments were carried out on oats by the Department of Agriculture during 11 successive years in the pre-World War I period

The best results were given by —

1	cwt	sulphate of ammonia	per statute acre
3	,,	superphosphate	
1	,,	muriate of potash	

This gave a total yield of 22 cwt. 2 qr, an increase of 6 cwt 3 qr. over the non-manured plots which produced only 15 cwt. 3 qr Considerably better yields than these have been obtained from average fertiliser dressings in recent years. Mean results from 108 experiments over 2 years showed that 1 cwt. sulphate of ammonia, 4 cwt. superphosphate (35%) and 1 cwt. muriate of potash produced an average yield of 27·67 cwt of grain

These experiments were designed to test the effect of four increments of both phosphorus and potassium on the response of oats. A basal dressing of the two nutrients not under test was applied to all four plots

Using the data derived from these experiments the most profitable levels of phosphatic and potassic fertilisers for oats have been determined Incremental data on the response to nitrogen of oats was not available, but there is reason to believe that the amount would be somewhat lower than for wheat because of the lower value of oats. It is likely that the quantity would be about 2 cwt. of sulphate of ammonia per statute acre

The most profitable dressing for oats is therefore :—

2	cwt.	sulphate of ammonia	per statute acre.
3½	,,	superphosphate (35%)	
1	,,	muriate of potash	

This gives an average yield of approximately 27 cwt. per statute acre or an increase of 7 cwt. of grain. This dressing for oats, as also the dressings recommended below for wheat and barley refer to broadcasting. Where combine drilling is practised the dressing of phosphorus and that of potassium in many instances can be reduced by 5%.

Wheat Various experiments on the manuring of wheat have been carried out, extending over several years. The results generally have been similar to those obtained with oats.

An application of :

1	cwt.	of sulphate of ammonia	per statute acre.
3	,,	superphosphate (35%)	
1	,,	muriate of potash	

increased the yield from 17 cwt. 2qur. to 23 cwt., an increase of 5 cwt. 2 qrs

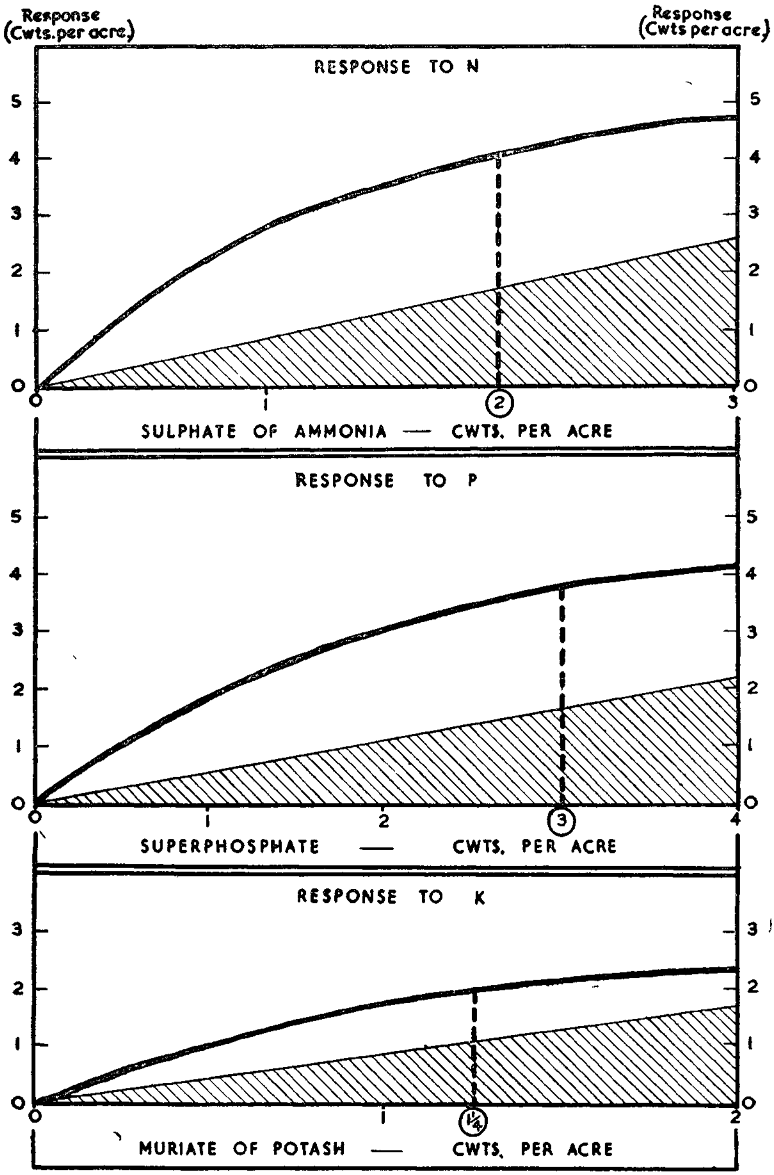
As in the case of oats, modern experiments during the past five years gave average results much higher than those shown above. Total average yield given by :

1	cwt.	sulphate of ammonia	per statute acre.
4	,,	superphosphate (35%)	
1	,,	muriate of potash	

was 25·12 cwt. of wheat.

Diagram 6

RESPONSE OF WHEAT TO FERTILISERS



Using data from these experiments which tested phosphorus and potassium on an incremental basis, and using nitrogen response data obtained from nitrogen top-dressing experiments recently carried out at Johnstown Castle and the Department's stations, it has been possible to develop curves and to calculate the most profitable dressing of nitrogen, phosphorus, and potassium for wheat See diagram 6 where the value of response in extra yield of wheat is taken at 30/- per cwt in relation to the following gross costs of fertiliers applied; sulphate of ammonia, 26/- per cwt , superphosphate, 17/- per cwt , mutriate of potash, 21/- per cwt

These show that the most profitable fertiliser application for wheat at the present time is ·

2	cwt	sulphate of ammonia	per statute acre
3	,,	superphosphate (35%)	
$1\frac{1}{4}$	,,	muriate of potash (50%)	

This will produce an average yield of about 27 cwt. of grain.

Barley. Pre-war experiments on barley established that a similar fertiliser dressing to that recommended for wheat and oats gave best results, i e

1	cwt	sulphate of ammonia	per statute acre.
3	,,	superphosphate	
1		muriate of potash	

increased the non-manured plot yields from 17 cwt to 21 cwt. 1 qr., an increase of 4 cwt 1 qr per statute acre.

Recent experimental work has shown that yields from fertiliser are now much higher, with the advent of the stiff strawed high yielding varieties The average yield, obtained in a large number of "county" experiments in 1956 was 33 cwt. per statute acre, from a dressing of

1	cwt.	sulphate of ammonia
4	,,	superphosphate
1	,,	muriate of potash

Information on response of barley to increasing increments of nutrients is not available at present, but general experimental results indicate that the most profitable amount of fertiliser under present conditions would approximate to

2	cwt.	sulphate of ammonia	per statute acre.
4	,,	superphosphate 35%	
$1\frac{1}{2}$	,,	muriate of potash	

The average yield to be expected from this would be in the region of 36 cwt. of barley per statute acre.

B. *Pasture and Hay.*

While the assessment of optimum economic use of fertiliser on grass intended for hay is reasonably straightforward the position with regard to pasture is much more complex. It involves not alone the question of the most satisfactory yardstick of output measurement, but also the nature and composition of the sward, and the role of fertiliser as ecologic factor in affecting sward type changes In addittion to the quantity factor, the quality factor also comes into the picture.

So far, no modern experiments have been undertaken here, to determine the optimum use of fertil'ser for different grass swards, but following the survey of pasture output now under way, it is proposed to undertake such a series However, from data available from this pasture survey, and from a considerable volume of experimental work it is possible to make some estimates. From figures published by O.E.E C. (5) it has been shown that output from our pastures at the present time is about 14 cwt. Starch equivalent (S E.) per acre. In the survey of pasture output undertaken in 1956, by the Department figures varying from as low as 4 cwt. S E to 37 cwt S E. were found. Without fertiliser, output from the major acreage of our old pasture lies in the region of 10–12 cwt S E. per acre. From manurial experiments carried out at Johnstown Castle and elsewhere, it can be estimated that for old pastures properly managed, a yield of some 22 cwt. S E can be reached on the basis of an annual application of some 2 cwt superphosphate and ½ cwt. muriate of potash, with about 2 cwt superphosphate as an initial dressing, together with about 1 cwt. of nitrogenous fertiliser. Considered in terms of butter fat output it can be taken that the average for creamery districts is now in the 60–70 lb per acre region. With manures and management this figure can be doubled on a country basis; figures in excess of three times this output are now being obtained by many farmers. Again, much depends on the nutrient status of the sward; where the phosphorus and potassium status is very low, higher initial dressings are necessary

The same application can, under average conditions, maintain satisfactory nutritional conditions for new pastures with however, somewhat higher applications in the initial two years after laying down. With new leys the response to fertiliser, in terms of yield output is higher, and in new swards, an output figure of 30 cwt. (S E.) acre is reasonable

These figures refer to normal in-season production alone When we come to consider out-of-season production, in order to lengthen the grazing season, higher levels (about 50%) of phosphorus and potassium together with 1½–2 cwt. per statute acre of nitrogenous fertiliser are necessary. When viewed from the standpoint that in this way a considerable expansion in the grazing season is possible with consequent decrease in feeding and housing overheads, these applications are quite economic.

Hay. Trials carried out by the Department of Agriculture for 13 years at 217 centres showed that a dressing of 1 cwt. of nitrogenous fertiliser, 2 cwt. superphosphate (35%) and the equivalent of about ½ cwt. of muriate of potash increased yield from 33 cwt./ac. to 51·5 cwt. More recent experiments have shown that still higher increases in yield can be obtained from an application of an extra 1 cwt. of nitrogenous and extra potassic fertiliser, the yield expectancy from 1½–2cwt. of nitrogenous fertiliser plus 3 cwt of superphosphate plus ¾–1 cwt. of muriate of potash being approximately 60 cwt./ac. of hay.

Response from Lime.

The problem of evaluating the effect of lime when applied to acid soils is a very difficult one Again, as with pasture response to manuring, there are a number of factors involved apart from the straightforward one of immediate yield increase. This arises mainly from the fact that a satisfactory lime status has a favourable influence on the effect of practically all the other plant nutrients, in addition to constituting a most important ecological factor. In addition, its effects are long term. That its use can be a highly profitable investment has been shown by numerous experiments in recent years.

Table 11 portrays average results obtained from a nationwide series of field experiments on tillage crops carried out by the Agricultural Instructors in recent years, and Table 12 shows results from a long term rotation experiment still proceeding at Johnstown Castle. In all cases, only normal applications of fertilisers were used, similar amounts of course being applied to both unlimed and limed treatments.

TABLE 11

Crop responses to liming (various counties 1953–56)

Crop	No Lime	2 tons ground limestone per acre	4 tons ground limestone per acre	Number of Centres
Barley	16 8 cwts	27 6 cwts	30 3 cwts	13
Wheat	3 7 ,,	24 0 ,,	28 0 ,,	1
Mangels	21 9 tons	26·7 tons	28·2 tons	5
F. Beet .	9·4 ,,	15 2 ,,	17·2 ,,	5
S Beet ..	7 3 ,,	12 2 ,,	14 5 ,,	2
Swedes .	14 6 ,,	21 8 ,,	24 9 ,,	3

TABLE 12.

Results from liming at Johnstown Castle (1947-1955) (*lime applied in* 1947 *only*).

Year	Crop	No Lime	55 cwts ground limestone/ac	Response
1947 ..	Barley	6·7 cwts	16·4 cwts	9·7 cwts
1948	Mangels	20·6 tons	36·4 tons	15·8 tons
1949	Wheat	20 1 cwts	38 9 cwts	18 8 cwts
1950	Silage mixture .	41·1 cwts. D M.	50·2 cwts D M	9·1 cwts. D,M,
1951	,, ,, .	63 0 ,,	92·0 ,,	29·0 ,,
1952	,, ,,	64·1 ,,	77 3 ,,	13·2 ,,
1953	,, ,,	74·1 ,,	81 9 ,,	7 8 ,,
1954 .	Wheat ..	12·0 cwts	22·4 cwts	10·4 cwts.
1955	(1) Mangels	No crop	19·9 tons	19·9 tons
	(2) S Beet	No crop	6 3 tons	6·3 ,,

It is apparent from these results that highly economic and sometimes spectacular responses can be obtained from the liming of acid soils, provided of course that adequate amounts of manures are also used. It may be added that the " no lime " plots in the above experiments received the same level of manuring as the " limed " plots.

It will be noted from Table 11 that Sugar and Fodder Beet are very responsive to liming , in fact yields were uneconomic without liming ; swedes are next in order of response

Both barley and wheat also proved highly responsive to lime application when grown on acid soils The low yields produced by the "no lime" treatment which received the same manures as the limed plots emphasise the loss in value from using fertilisers on acid soils for most farm crops.

Contrary to general belief, oats has also shown a response to lime The following data extracted from a nationwide series of experiments on the response of oats to superphosphate demonstrate this

TABLE 13.

Response of Oats.

Number of Centres	pH range	Increased yield from 4 cwts Super (cwts per st/ac)
29	4 8—5·5	8 7
15	5 6—6 2	15 4
6	6 3—8 0	8 9

The position with regard to optimum fertiliser dressings and responses due to these dressings can be summarised as in Tables 14 and 15. The optimum fertiliser dressings are "without F.Y M." and for broadcast applications on cereals. In addition, these tables show the value of responses at current prices In interpreting the figures for response to fertiliser it may be added that, on the basis of the present national yield figures, the per cent. increase due to fertilisers is as follows :

TABLE 14

Percentage increase in yield due to fertilisers

	Potatoes Tons/ac	Mangels Tons/ac	Swedes Tons/ac	Wheat cwts /ac.	Oats cwts./ac	Barley cwts /ac	Grass S E cwts ac
No Fertiliser	5 2	9 5	4 8	15 2	17 1	17 0	12 0
National Yield	8 8	18 7	16 9	23 2	19 9	23 9	14 0
Optimum Yield	12 5	27 0	27 5	27 0	27 0	36 0	22 0
% increase in Yield now due to Fertiliser	69	97	252	53	16	41	17
% increase in Yield desirable for optimum economic return	240	184	473	78	58	112	83

TABLE 15

Tillage crops—Optimum fertiliser dressings

Crop	Sulphate of Ammonia	Super 35%	Muriate of Potash 50%	Cost
				£ s d
Potatoes	3½	6	4½	14 7 6
Mangels	2	6	3½	11 7 6
Swedes	2	6	2½	10 6 6
Oats	2	3½	1	6 12 6
Wheat	2	3	1¼	6 9 3
Barley	2	4	1½	7 11 6
Pasture*	—	2	½	2 5 6
Hay	1½	3	¾	5 6 0

*For maintenance, after initial dressing at twice this level plus 1½ cwt /ac of nitrogenous fertiliser

TABLE 16

Crop responses to Optimum fertilisers

Crop	Control (Yield)	Optimum Fertiliser (Yield)	Increase in Yield	Value of Increase	Cost o Fertiliser	Profit from Fertiliser
				£ s d	£ s d	£ s d
Potatoes	5 2 (tons)	12 5 (tons)	7 3 (tons)	58 8 0	14 7 6	44 0 6
Mangels	9 5 (tons)	27 0 (tons)	17 5 (tons)	26 5 0	11 7 6	14 7 6
Swedes	4 8 (tons)	27 5 (tons)	22 7 (tons)	34 0 0	10 6 6	23 13 6
Wheat	15 2 (cwts.)	27 0 (cwts)	11 8 (cwts)	17 14 0	6 12 6	11 1 6
Oats	17·1 (cwts)	27 0 (cwts)	10 9 (cwts)	12 0 0	6 9 3	5 10 9
Barley	17 0 (cwts)	36 0 (cwts)	19 0 (cwts)	21 17 0	7 11 6	13 5 6
Pasture	12 cwts S E	22 cwts S E	10 cwts S E or 1¾ cwts Beef or 186 gallons milk	15 10 0	2 5 6	13 4 6
Hay	31 cwts	60 cwts	29 cwts	14 10 0	5 6 0	8 4 0

The data in these tables show clearly the profit in fertiliser use at present price levels. They also emphasise the total overall increase in output which can be achieved. Considered on a national basis, in terms of overall fertiliser and lime requirements, the position as shown in Table 17 emerges. These calculations are based on the present acreages devoted to the different crops. With the appropriate increases in yield, there is no doubt however, that in order to have the maximum effect on the national economy, and in order to conform with appropriate farming standards, a shift in acreage for certain crops at least would be necessary.

TABLE 17

Fertiliser and lime requirement.

Crop	Nitrogen (N) (tons)	Phosphorus (P) (tons)	Potassium (K) (tons)
Potatoes . ..	10,730	6,130	27,320
Swedes . ..	2,530	2,530	6,250
Mangels . . .	1,350	1,350	4,690
Oats	11,190	6,530	11,090
Wheat . . .	10,210	5,110	12,650
Barley .	3,420	2,280	5,070
Pasture (1)	40,000	26,000	83,000
Pasture (2) .	14,400	20,200	30,000
Hay ..	28,500	20,000	29,500
Total . . .	122,330	120,130	209,570
Minus nutrients in F Y M. .	52,300	7,850	41,450
Total needed from fertilisers	70,030	112,280	168,120
Now used (1956) . .	14,900	25,235	30,959

In interpreting the above data the following points may be noted ·

(1) If phosphorus and potassium are combine drilled for cereals the amounts indicated above can be reduced by 50 per cent.

(2) Pasture (1) refers to the quantities of phosphorus and potassium required for maintenance, the nitrogen under this heading being for out-of-season grazing Pasture (2) provides for initial improvement applications of N, P, and K at rate of 1 cwt./ac. of nitrogenous fertiliser (205%N.) 4 cwt /ac. of superphosphate and 1 cwt./ac. muriate of potash; N and P are calculated ont he basis of 90% of pasture area and K on 60% with a programme to cover 20% of the area every year for 5 years.

(3) In estimating nutrients supplied by F.Y.M. an allowance of 50 per cent. is made for availability of nitrogen. This is based on experimental data.

(4) It will be observed that no allowance has been made for sugar beet, fruit crops, peas, cabbages and other market garden crops.

Total Lime Requirements.

In estimating overall requirement of lime in terms of ground limestone, (taking requirement on a county basis in terms of acreage requiring (*a*) 1½ tons per acre and (*b*) 3 tons per acre) we arrive at a final figure of 17,000,000 tons. In addition, taking the acreage of soils in each county which can be easily depleted of calcium in relation to rainfall, a figure of some 1½ million tons for annual loss is arrived at. This figure is an annual maintenance one, and exceeds the total quantity now applied to make good total deficit and annual loss.

Finally, in relation to both lime and fertilisers, the estimated totals make no provision for the 3 million acres of waste land, out of a total of just 15½ million acres, which could with very considerable national benefit, especially for sheep farming, be substantially improved through the application of scientific techniques

General Remarks

While recognising the difficulties inherent in attempting to translate the data presented here into practice in terms of increased output, the high potentiality of fertilisers and lime can be recognised The growth response curves show increments per unit of fertiliser higher than that obtained by any other European country The implications of this in terms of possible competitive efficiency are obvious, even though now this response level is a reflection of the very low level of nutrients in our soils By adopting the appropriate application technique this feature of our soils can in fact be turned to good account. At present, however, the percentage of overall production from our pastures which can be attributed to fertiliser, as seen in Table 14, is more representative of subsistence type pastoral farming than an agricultural system which should essentially be operated at a high level of competitive efficiency If such a high level is to be reached then the use of the quantities of fertiliser and lime indicated is necessary It may be argued that the desirable levels represent too high an increase over those now being used, and that the cost would be too great However, it must be clearly understood that in order to make full and economic use of such levels as those recommended, appropriate changes in production, land use planning, organisation and marketing would need to be effected It must finally be stressed that the desirable use levels indicated are essentially conservative, the level of production which our soils can give, if required, being at a considerable higher point than that which is considered here to be economic optimum

Some Conclusions

1. From the data presented in Part I it can be concluded that our soils have been subject to a moderate degree of nutrient depletion over a long period. At times due to the intervention of emergency conditions depletion was accelerated In recent years a more favourable balance has been reached While in terms of absolute outgo-input figures a favourable balance was found for phosphorus, this must be related to the loss entailed through the transfer of applied phosphorus into unavailable form in soils. For nitrogen on the other hand, the distinctly unfavourable balance must be matched against nitrogen additions from clovers and other legumes. In the early years of the century much more nutrients were imported in feedingstuffs than in fertilisers. An important feature of the overall pattern of fertiliser use was the almost complete neglect of pastures.

2 Severe lime depletion proceeded throughout the first half of the present century with the amount applied annually comprising less than 10 per cent. of requirements.

3 Depletion of both lime and plant nutrients is now reflected in the high proportion of soils found, by both soil analysis and crop response, to be deficient in phosphorus, potassium and lime.

4. As a basis for estimating the levels of fertilisers and lime required an approach has been made in terms of optimum economic response assessed from modern field experiments on crop response to fertilisers and lime. The data provided show that for all crops and pastures the use of optimum fertiliser dressings would result in a good profit level, while giving an average increase of about 100 per cent. in output For pastures, especially, the present level of output due to fertilisers is very much below the economic optimum

5 On a national scale, the rationalisation of fertiliser and lime use, on the basis of economic optimum dressings would require an approximately 470 per cent. increase in the use of nitrogen, 440 per cent in the use of phosphorus and 540 per cent. in the use of potassium It is considered that if agricultural production is to reach the required degree of competitive efficiency this level of fertiliser and lime use is necessary

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DISCUSSION

Mr. F. E. Dixon suggested that the "Balance Sheet" of soil nutrients should include the contribution of substances deposited in rain· Scandinavian measurements had found that rain contributes appreciable quantities of nitrogen to the soil.

In reply, *Dr. Walsh* agreed that the rain contribution could be important and disclosed that measurements have been commenced in Ireland with the co-operation of the Meteorological Service.