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FUTURE TRENDS in the USE OF FERTILISERS

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FUTURE TRENDS IN THE USE OF FERTILISERS

(A lecture at the first meeting of the Fertiliser Association of Ireland)

by

G. W. Cooke

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I appreciate the honour of being asked to give the first lecture to your newly-formed Association. I have been associated with the Fertiliser Society in London since it was formed in 1947 and I know how important it is to have an organisation that brings together fertiliser manufacturers, agronomists and farmers. Exchanging information and opinions about fertilisers and their uses helps industry to make better fertilisers, and farmers to use them better.

You have advanced greatly in your use of fertilisers in Ireland in the last 20 years, largely because of enthusiastic and vigorous experimental work by the Agricultural Research Institute headed by Dr. T. Walsh. Both industry and farmers responded quickly to results showing how much yields could be raised by better manuring. The phenomenal increase in the fertilisers used in Ireland, which I shall discuss later, is proportionally greater than the increase in most countries. You also lead in other ways. Ireland is one of the very few countries which expresses fertiliser analyses in terms of the elements N, P and K instead of the archaic P_2O_5 and K_2O used in most countries, and which are relics of the chemistry of a century ago. I am sure that your Association will help greatly in extending and applying scientific work on crop nutrition in Ireland and I wish it every success.

faster. The Netherlands has the most stable and developed agriculture of these five countries; there much more N is now used, but less P and K are than in 1954. Changes in the USA and the UK have been very similar, large increases in N used, considerable increases in K and rather less increase

TABLE 4: Changes in proportions of fertilisers used between 1954 and 1964

1954 is taken as standard, = 1.0

	N	P	K
Ireland	3.5	2.7	3.2
Netherlands	1.8	1.0	0.8
UK	2.3	1.2	1.8
USA	2.3	1.5	1.5
New Zealand	2.0	1.8	7.5

in P. New Zealand agriculture is mainly based on grassland and in the warm wet climate clovers grow well and provide enough nitrogen for the animal farming systems used. Phosphate (and the sulphur supplied by single superphosphate) are the dominant nutrients needed in New Zealand when improving poor soils for grazing. Clovers also need a lot of potassium too. When much of the land in New Zealand was first farmed, the K in the soils plus that released by destroying natural vegetation was sufficient for productive pasture. In some areas the inevitable losses and redistribution of K involved in using herbage has exhausted the meagre supply and fertiliser-K is essential now. Potassium has been similarly exhausted in some poor soils in southern Australia that are used for intensive dairying.

Amounts of fertilisers used per hectare

The amounts of fertilisers used per hectare published by FAO (1) reflect type of farming, stage of agricultural development, density of population and the prosperity of individual countries. Some figures for 1963/4 are in Table 5. The Netherlands and Japan both of which need well-developed agriculture to feed their dense populations, used the largest dressings of fertilisers. Ireland and Spain are much more sparsely populated and use much less fertiliser. The difficulty of combining and interpreting fertiliser and population statistics is shown by these FAO figures. Fertiliser dressings are per hectare of agricultural land, numbers of people are per hectare of arable land. 'Arable' is usually land that is cultivated for crops, but different

TABLE 5: Average fertiliser used on agricultural land, and population density in 1964/5

	N	P	K	People per hectare of arable land
	Kilograms/hectare			
Ireland	6	10	16	2.3
Netherlands	130	22	51	12.5
Spain	10	4	2	1.5
UK	30	10	18	7.2
USA	9	3	5	1.0
India	3	0.4	0.3	2.9
Japan	104	32	69	16.1
New Zealand	0.6	12	6	3.2

countries return as 'agricultural' different proportions of their grassland and other areas of rougher grazing land. New Zealand also has very little arable. Japan has little or no grassland as we understand the term. India is included in Table 5; little fertiliser is used but the country is not densely populated and when agriculture is better developed there should be no difficulty in feeding the people.

Forms of fertilisers produced

While the total amounts of fertilisers produced have increased so much in the last 10-15 years, the proportions of the materials made have also changed.

Table 6 shows changes in the forms of nitrogen fertilisers produced in the world as a whole, published by FAO (1). In 11 years from 1954 ammonium nitrate displaced ammonium sulphate as the most important fertiliser. Calcium and sodium nitrates became less important and by 1965 urea provided over one-tenth of the world's nitrogen. Corresponding changes are thought to have taken place in UK but I have no recent figures. Replacing ammonium sulphate (21%) by ammonium nitrate (34% N) makes no problems, but possible increases in urea may do. Urea hydrolyses rapidly in soil and the ammonia released may damage germinating seedlings or be lost to the air when the fertiliser is on or near the soil surface. Urea used straight must be well buried to be efficient; one way of doing this may be to apply it in solutions that penetrate into the soil. One of the most striking features of Table 6 is the increase in the liquids ("solutions") that supply N. The total N used trebled between 1954 and 1965, and during this time the

TABLE 6: Changes in the forms of nitrogen fertilisers used in the world

	1954	1960	1965
	Percentage of total N used		
Ammonium sulphate	31	26	18
Ammonium nitrate	23	28	30
Calcium nitrate	6	5	3
Sodium nitrate	5	3	2
Cyanamide	6	3	2
Urea	-	6	10
Other forms			
Solids	8	11	15
Solutions	14	18	20

proportion applied liquid increased from one-seventh to one-fifth; this trend, best established in USA, is certain to spread to other countries.

Table 7 shows changes in the forms of phosphate made. During the 11 years after 1954, ordinary superphosphate became less important and concentrated (or triple) superphosphate more important. Basic slag supplies remained roughly constant. Other changes are not shown separately

TABLE 7: Changes in the forms of phosphorus fertilisers used in the world

	1954	1960	1965
	Percentage of total P used		
Superphosphate			
Single	62	51	45
Concentrated	9	14	15
Basic slag	13	16	13
Other products	14	19	27

by FAO, and no useful figures are published for UK. The proportion of nitrophosphate used has increased, (these fertilisers are made by treating rock phosphate with nitric instead of sulphuric acid, and they may become even more popular if sulphur prices continue to increase). The ammonium phosphate made has also increased greatly. Recent American developments have been with superphosphoric acid, from which condensed "polyphosphates" are made. If polyphosphates are used instead of orthophosphates, concentrations may increase still further but this change seems unlikely during the next 10 years. (Polyphosphates have to be hydrolysed to orthophosphates before they can be taken up by plants and they cannot be valued by the chemical tests now used.)

By contrast there has been little recent change in the forms of potassium fertilisers produced. Potassium chloride ("muriate of potash") supplies most of the world's K; some potassium sulphate is made for special crops and processes for making potassium nitrate more cheaply have recently been developed in Israel and in USA. Cruder potassium salts and minerals are also used, often to supply sodium for sugar beet and related crops, sometimes because they also supply magnesium.

Change in the forms of fertilisers farmers buy

Change in the forms of fertilisers used during the next 10 to 20 years is likely to be improved physical condition and increased concentration of materials we now know. Changes in the chemical nature of the fertilisers commonly used are more speculative. New "slow-release" fertilisers that fit nutrient supplies more closely to the needs of crops may be developed, but research of this kind already done has failed to find substances that are suitable fertilisers for ordinary agricultural crops.

CHANGE IN THE FERTILISERS USED IN BRITAIN

Most recent changes in the fertilisers sold have been made by manufacturers to supply products that are cheaper and have better physical properties and can be applied more efficiently; also to provide materials that are suited to individual crops, soils and farming conditions. I shall discuss these changes with the help of figures issued by the Fertiliser Manufacturers' Association (5).

Straight and compound fertilisers

Compound fertilisers ("mixed" fertilisers containing two or three nutrients) have always been important in UK and thirty years ago about half of the N, P and K was sold in this form. During the last fifteen years the amounts of "straight" fertilisers (containing only one nutrient) sold have diminished (Table 8); now only a third of the N is sold straight and a little of the K (5). Very few farmers now mix their own fertilisers, 30 years ago many did. No water-soluble phosphates are used as straight fertilisers, but three-quarters of all the water-insoluble phosphate is sold "straight" as basic slag (Table 9).

TABLE 8: Percentages of total plant nutrients sold in compound fertilisers in UK

	N	P (soluble)	P (insoluble)	K
1952/5	55	82	25	85
1959	63	91	23	85
1963	63	96	18	92
1967	64	98	23	92

TABLE 9: Basic slag used in UK

	Thousands of tons of P	Per cent of total P in all fertilisers
1958	44	26
1964	56	27
1967	40	20

Compound fertilisers have become more popular since most have been granulated (roughly 20 years); granules are easy to handle and spread (previously most straight fertilisers were damp powders that were difficult to handle). Compounds save labour and often are used to apply all the nutrients recommended for the crop in one operation.

It is difficult to foresee large changes in the proportions of straight and compound fertilisers used in solid forms in UK. More of the P and K fertilisers given to the better soils may be applied in winter, and more of the nitrogen may be used as straight top-dressing or placed beside crops grown in wide rows.

Changes in concentration

Twenty years ago some British fertilisers were granulated and were based on ammonium phosphate, but most were made from ammonium sulphate (21% N) ordinary superphosphate (8% P) and potassium chloride (42% K). Now much of the N and P is supplied by ammonium nitrate (33% N) and ammonium phosphate (11% N + 21% P); "triple" superphosphate (21% P), and some urea (46% N) are used. There are no recent statements of the amounts of different kinds of fertiliser materials made in UK and only these qualitative descriptions of trends can be made.

Changes in the forms of fertilisers used have increased the percentages of plant nutrients in compound fertilisers, as shown in Table 10, where I have retained the archaic expressions % P_2O_5 and % K_2O as these are still used in international statistics. By decreasing the bulk that has had to be handled, costs of handling and of bags have cheapened, and the farmer's work in spreading has diminished too.

TABLE 10: Changes in the concentrations of nutrients in compound fertilisers

	Percentage of				
	N	P_2O_5 (soluble)	P_2O_5 (insoluble)	K_2O	$N+P_2O_5+K_2O$
1952/5	6.7	8.6	1.8	10.6	27.7
1959	8.4	9.4	1.3	13.3	32.4
1963	11.3	10.1	1.0	13.5	35.9
1967	14.7	11.0	1.0	13.6	40.4

Many compound fertilisers are now nearly as concentrated as is possible from the materials used to make them, but the trend for average concentration to increase will, no doubt, continue. Less ammonium sulphate and more ammonium nitrate and urea will be made. Ammonium phosphates will replace more of the single and triple superphosphate still made.

Changes in types of compound fertilisers

Pre-war compound fertilisers were mostly rich in phosphate and poor in potassium and nitrogen. Experiments showed that much more nitrogen should be used; therefore during the War, and for some years after, the compositions of the mixed fertilisers that could be made were regulated, three types being important:

High K : 7% N, 3% P, 9% K

High N : 9% N, 3% P, 4% K

High P : 6% N, 5% P

After restrictions were stopped, in about 1950, many hundreds of compounds were made, but the most important were "high-K" types, which were intended for potatoes and sugar beet, but were used for many crops. This tendency continued until about 10 years ago when "High-N" mixed fertilisers became more important.

TABLE 11: Changes in types of compound fertilisers
Per cent of all compounds used

	1962	1965	1967
High-N	22	36	44
High-P	7	6	5
High-K	41	31	26
"1-1-1" type*	4	6	7
Low-N	11	13	10

*roughly equal percentages of N, P_2O_5 and K_2O

Table 11 shows the large changes in the kinds of mixed fertilisers produced. Five years ago, more than 40% of compounds were rich in K (about 12% N, 5% P, 15% K), whereas now more than 40% are rich in N (about 20% N, 4% P and 8% K). These changes have been made so that a single dressing of compound fertiliser can supply enough N for cereals, for grass, and for animal feed crops (like kale); they have been responsible for the amount of K used changing little in the last few years while the N used has increased greatly. There is little reason to expect further dramatic changes in the types of compounds used, but the total numbers offered to British farmers may diminish as manufacturers rationalise their production.

Liquid fertilisers

It is not easy to forecast how important liquid fertilisers will become in the UK; at present they possibly supply about 2 per cent of our total fertiliser. Table 6 shows how important liquid forms of nitrogen are, supplying one fifth of the world's N in 1965. Most early developments with liquids were in a few countries, principally USA, but

many countries are now testing them. The advantages of liquids are:

1) They are easily and cheaply moved by pumping.
2) They can be distributed more accurately than solids.
3) They can be placed where needed in the soil by being injected under pressure.
4) Some forms of liquid N fertilisers (principally anhydrous and aqueous ammonia) are much cheaper than equivalent solids.

Some liquid fertilisers supply N, P and K and in British experiments these have been as effective as equivalent solids. They are less concentrated than solid fertilisers and tend to be more expensive, so their use is not likely to increase rapidly. Increases in the use of liquids will depend on the factors I have listed and especially on the handling advantages to farmers who employ few workers but who can engage efficient contracters. Solid fertilisers are usually delivered by gravity with some mechanical assistance and are expected to flow like liquids through apertures and tubes; the most serious variations in delivery are because they do not behave as liquids. Liquids can be delivered much more accurately than solids because they can be pumped at intended rates and rarely block jets.

Practical difficulties in applying "High-pressure" liquids (such as anhydrous ammonia with 82% N) remain to be solved, for these must be injected below the soil surface to prevent nitrogen being lost to the air. "Low-pressure" solutions (such as solutions of ammonia in water, with 29% N) are satisfactory when injected a few cm deep; anhydrous ammonia must be injected at least 15 cm deep in arable land. Injecting liquids deeply needs strong and expensive applicators and a powerful tractor. Figures given by F. V. Widdowson (6), quoted in Table 12, show how the real cost of a fertiliser in the field is made of the cost of the material and the cost of applying it. The cheapest material to buy (in this example anhydrous ammonia) is made expensive when application is costly.

In our experiments with arable crops both aqueous and anhydrous ammonia were about as effective as ammonium nitrate, and little ammonia was lost. But anhydrous ammonia was less efficient than solid N fertilisers on grassland, presumably because ammonia escaped from the cuts made by the injection tines. We need much more straight nitrogen on grassland and liquid fertilisers could supply it; but new machines will have to be developed, or existing machines used in different ways, before the cheapness of anhydrous ammonia can become an advantage to the farmer.

TABLE 12: Approximate costs of applying 250 kg N/ha in December 1967

(after F. V. Widdowson (6))

	%N	Cost of fertiliser £	Cost of application per hectare £	Total cost £
"Nitro-Chalk"	21	19.4	1.8	21.2
"Nitram"	34	17.0	1.2	18.2
Aqueous ammonia	29	12.0	2.2	14.2
Anhydrous ammonia	82	11.8	4.3	16.1
Liquid N	24	19.8	2.3	22.1

CHANGES IN THE BASIS OF ADVICE ON FERTILISING

Field experiments that measure how fertiliser dressings affect crop yields show how much fertiliser is justified on the soils, and with the farming methods, used in the experiments. Laboratory research, and information about soils, show how the results of experiments on a few sites may be extended to other soils. Experiments that test the effects of fertilisers in different kinds of farming show how to allow for farming system in planning to use fertilisers. When all of these different kinds of information about fertiliser use are considered together with crop and fertiliser prices, "optimum" dressings for individual farmer's fields can be estimated. A recent N.A.A.S. publication (7) shows how to plan fertilising in this way and how the amounts of fertiliser that should be used can be calculated. Achieving these optima depends on economic conditions in agriculture, on how quickly information about fertilising spreads among farmers, and on the success of each farmer in solving the technical and management problems involved in buying and using more fertiliser and in dealing with the extra yields produced.

Arable crops

Until about 15 years ago most advice on using fertilisers in England was based on response curves derived by Crowther and Yates (8) from their summaries of the results of many field experiments done in Britain and other countries of

North-Western Europe before 1940. Table 13 summarises a few of their results for three root crops, which responded well to all three nutrients, and cereals which responded

TABLE 13: Responses per hectare to fertilisers in field experiments done in Great Britain before 1940

(mean effects on crops grown without farmyard manure)

	Swedes (tons)	Sugar beet (tons)	Potatoes (tons)	Wheat (kg)
31 kg N	5.5	2.3	2.8	427
28 kg P	11.0	1.0	2.0	38
52 kg K	5.8	1.0	3.0	289

most to N. When most farmers use much less than the recommended optima, the actual dressings used are not important. As the average dressings found in use on farms by surveys of the kind described by Yates and Boyd (9) approach the average optima, it becomes essential to vary manuring to allow for other manures, local climate, farming-system, and soil properties. Crowther's 1954 recommendations in Table 14 (the last to be based on pre-war field experiments (4)) were much more than Surveys of Fertiliser Practice showed farmers used on cereals and potatoes in the early 1950s. By 1966 average dressings used equalled or exceeded the 1954 recommendations for potatoes and sugar beet (10) and were not much less than the recommendations for cereals.

In most farming in Britain the supply of nitrogen limits yield of crops, responses to N-fertilisers are usual and estimating optimum dressings from response curves is satisfactory. Potatoes often respond to all three fertilisers; sugar beet usually responds to nitrogen and often to potassium and sodium, but less often to phosphorus. Enough modern experiments have been done on these crops for satisfactory recommendations to be based on response curves. But cereals and grass respond much less often than root crops to P and K fertilisers; few modern experiments have been done and there is no satisfactory basis from field experiments for justifying the three-quarters of the total P and K used in Britain that is given to these crops. Some other method must be developed for using these fertilisers rationally.

On most fields a fresh decision on the amount of nitrogen needed to regulate yields may be needed each year

TABLE 14: Optimum dressings for cereals and roots calculated by E. M. Crowther for 1954, compared with average dressings used by farmers in 1950-2 and in 1966

kg/ha of N, P and K

	Approximate optimum dressings for standard conditions in 1954			Fertilisers used by farmers*					
				In 1950-2			In 1966		
	N	P	K	N	P	K	N	P	K
Winter wheat	100	22	40	33	12	12	90	19	36
Spring barley	100	22	40	25	13	17	77	18	36
Potatoes	150	90	190	117	54	138	160	76	200
Sugar beet	110	55	100	113	50	115	160	50	157

* Average dressings are from Surveys of Fertiliser Practice for 1950-2 and for 1966; for cereals the data are for arable farming areas; for roots the dressings are averages for England and Wales.

because yield is lessened by using either too much or too little. Inorganic nitrogen is ephemeral in soil, for any surplus is liable to be lost by leaching, so dressings must be planned for "direct action". By contrast, there is not the same need to make annual decisions about phosphorus and potassium manuring, because surpluses are retained by soil and provide useful reserves. For any particular soil and farming system, a policy for PK manuring should be developed and then changed only slowly as periodical soil analyses show how the fertilising and cropping alter reserves.

I discussed the value of residues of P and K fertiliser in soils of long-term field experiments in an article last year (11). The development of our ideas on ways of giving advice on manuring was described in another article in the Journal of the Royal Agricultural Society of England (12). Soils rich in soluble P and K often yield more than poorer soils, however much fresh fertiliser is applied to the poorer soils. To avoid yields being limited by nutrient deficiencies, soluble P and K should be maintained at or above the amounts where large immediate responses to fertilisers are expected. This may seem to involve a waste of the fertilisers, but on a long-term it does not. All the evidence we have suggests that reserves of P and K in soils accumulated from fertiliser residues can eventually be useful to crops. In planning manuring, responses to P and K fertilisers measured in field experiments rarely provide sufficient guidance for modern conditions. Most decisions, except those for a few arable cash crops, must be based on soil analyses and on calculations of the effect of cropping and manuring on reserves of soil P and K.

The effect of farming system on available soil potassium

Crops take up several times as much K as P, and soluble potassium in soil may be altered quite quickly by drastic changes in farming system or manuring. To regulate potassium manuring by changes in soluble potassium in soil requires analyses to be done more often than for planning phosphate manuring, and this may be a serious burden on advisory laboratories. There are other complications. Many arable crops, potatoes and wheat are examples, respond much more than grasses to dressing of fresh K. Therefore, in ley farming, after the grass, extra potash may have to be given for any crops that give large responses to K.

A century ago advice was often based on a "balance sheet" of the nutrients needed by crops and the nutrients supplied. The method seems to have been abandoned in this century because it accepted that yields should be maintained whereas the few experiments done with increasing fertiliser dressings showed that crops could be increased by increasing the nutrients in circulation. For many years afterwards results of experiments alone were used to make manurial recommendations. Because our farming systems have changed, and much more produce is sold, nutrient balance calculations (aided where possible by soil analyses) are needed again to make sure that crops are not limited by too little of any nutrient.

The need to arrange for manuring to balance the nutrients removed by crops is least where roots that receive much fertiliser are grown often. It is most where crops are grown that are considered unresponsive (and so get little fertiliser) but, nevertheless, take up much nutrients. An example of this was a Rothamsted experiment where kale was followed by barley which was undersown with ryegrass; wheat was the fourth crop after ploughing the ryegrass.

TABLE 15: Gains and losses in 4 years of cropping with kale, barley, ryegrass and wheat

	N	P	K
		(kg/ha)	
Removed in 4 crops	437	58	348
Added by fertilisers			
20-4.4-8.3	359	81	151
10-4.4-8.3	364	157	303
By FYM*	56	34	168

(*25 tons/ha of manure of average composition)

Table 15 shows the amounts of nutrients that were removed by crops, together with the amounts supplied by fertilisers and by a possible dressing of FYM. The fertiliser rich in nitrogen would usually be recommended for these four crops, as all are reputed to respond little to P and K; it supplied about 200 kg/ha less K than the 4 crops removed. Using a fertiliser with less %N (10-4.4-8.3) to supply the same amount of nitrogen would have supplied nearly as much K as was removed (but much more P). A dressing of 25 tons/ha of farmyard manure to the kale would have replaced most of the K; had the kale and grass been eaten in the field, most of the K they contained would have returned to the field, avoiding the drain on reserves of soil K.

Grassland

Most early experiments on grassland were on swards cut for hay; from the results only modest amounts of N and P (and sometimes K also) were recommended. Very few experiments were made on grazed grass; the few that were, such as the famous work at Cockle Park, showed that phosphate was needed to make clover grow on soils poor in phosphorus, so providing more nitrogen for the sward. Most recommendations were for occasional large dressings of phosphate to be given to improve grazed grassland. In some pioneer work in Britain and in other European countries, much larger total amounts of nitrogen were tested, being divided and given as separate dressings before each cut or grazing. These established that total yield of grass could be much increased, and the time when it grew controlled, by giving nitrogen frequently. A very few farmers had applied these results more than 30 years ago. However, Surveys of Fertiliser Practice showed that, on average, very little N was used on grass in 1943-5, and the amounts were small even 10 years later.

The first summary of fertiliser experiments on grassland was made 14 years ago by D. A. Boyd and W. J. Lessels (13), who emphasised the importance of nitrogen for increasing yield and showed that phosphorus and potassium had less effect. Response was proportional to nitrogen used, but Boyd and Lessels did not recommend amounts; nor did they show how much P and K should be used to maintain yields from cut grassland. Many more experiments testing large nitrogen dressings on grass cut continuously, and some on grazed grass, done in the 1950s showed how nitrogen regulates yield in grassland farming. The respective merits of using clovers or fertilisers to supply nitrogen became clear. The fertiliser nitrogen justified for grassland depends on the yield required, on facilities for conserving, or on the kind of stock used for grazing; kind of soil has much less effect. In contrast, the phosphorus and potassium needed depend both on kind of soil and on how the grass is used. Grass taken from the field removes much P and K and this must be replaced to maintain fertility. Experiments have now given some basis for using P and K on grass that is cut continuously; the amounts needed on grazed grassland are much more difficult to estimate and more experiments are needed.

THE AMOUNTS OF FERTILISERS NOW USED ON UK CROPS AND CHANGES THAT ARE POSSIBLE

TABLE 16: Percentages of the total fertilisers used that were given to different types of crops in England and Wales in 1966

	Proportion of agricultural area %	N	P	K	Total
		Per cent of total fertilisers used			
Cereals	32	40	33	40	38
Other arable	10	17	21	27	21
Grass	58	43	46	33	41

Table 16 shows what proportions of the total fertilisers are used on different kinds of crops. Cereals occupy a third of the arable land in the UK and receive about a third of all fertilisers used, other arable crops (potatoes, sugar beet, vegetables and animal feeding crops) occupy only a tenth of the area but receive a fifth of the fertiliser. Grass occupies 60% of the land but receives only 40% of the fertiliser.

Current manuring of arable crops

TABLE 17: Average amounts of fertilisers used on important arable crops grown in England and Wales in 1965-1966

(The figures are averages actually used on treated fields)

	N	P	K
		kg/ha	
Winter wheat	88	25	43
Spring barley	69	18	38
Potatoes	164	79	206
Sugar beet	156	53	159

This general summary has been derived from Surveys of Fertiliser Practice for England and Wales of the kind described by Yates and Boyd (9). Table 17 shows the current manuring of some important arable crops. The average recommendations for potatoes and sugar beet, based on field experiments testing fertilisers, are slightly less than the amounts farmers now use. Table 18 shows how greatly the nitrogen used on cereals and grass changed between 1958 and 1966, but there was no corresponding increase in the phosphorus and potassium used. These changes were caused by farmers using more "High-N" fertilisers. Average nitrogen dressings are now much nearer to average optima, but it is unfortunate that there has been no increase in P and K used; in fact, for spring cereals there has been a slight decrease. The larger crops grown with more nitrogen will have certainly increased the P and K required.

TABLE 18: Changes in fertiliser use in England and Wales, 1958-1966

(Average rates actually used on fields where dressings were applied)

	N		P		K	
	1958	1966	1958	1966	1958	1966
			kg/ha			
Cereals						
Spring barley	36	69	21	18	42	38
Winter wheat	45	88	24	24	41	43
Grass						
Temporary	49	89	33	30	49	41
Permanent	41	68	41	29	45	36

Cereals

The average amounts of fertilisers now used on cereals (Table 17) are roughly correct. Some increase may be justified in future, perhaps of 20 to 30% in the average rates. There is an urgent need to adjust fertilising of all arable crops to suit soil and farming system.

Grassland

There have been similar changes in grassland manuring (Table 18). Between 1958 and 1966 the amounts of N used on

TABLE 19: Fertilisers used on grass in England and Wales in 1966 and future targets

	Approximate present use: Fields dressed %	Approximate present use: kg/ha used	Target, kg/ha: Cutting regime	Target, kg/ha: Grazing regime
Temporary grass				
N	75	88	350	250
P	66	30	40	20
K	59	40	250	80
Permanent grass				
N	46	68	350	250
P	43	29	50	25
K	36	36	250	80

grass increased by two-thirds whereas the P and K applied diminished everywhere. These trends are also certainly caused by farmers increasingly using High-N fertilisers; previously they used fertilisers richer in P and K and gave more dressings of straight nitrogen.

The yield from grassland in Britain is governed by nitrogen supply. Clover alone cannot fix enough nitrogen to give the large yields obtainable with N fertilisers. Under average conditions, where grass is cut regularly, at least 350 kg N/ha should be used in the season (divided into 4 to 6 individual dressings giving one for each cutting). When grass is grazed continuously some of the nitrogen is excreted and used more than once in a season. Usually, therefore, less nitrogen is needed for grazed than for cut grass; but 250 kg N/ha will be justified for grazing by dairy cows. The amounts of phosphorus and potassium needed also depend on how the grass is used and on the kind of soil. When grass is cut continuously all the P and K it contains is removed, and must be replaced to maintain soil fertility and yield. On rich soils some allowance may be made for the P and K the soil itself can supply, but reserves cannot supply what is needed indefinitely.

Table 19 compares the present average use of N, P and K in England and Wales with the amounts that it would be

reasonable to use. These "targets" in the table are very approximate, because correct optimum fertiliser dressings for grass cannot be stated unless the way the grass will be used is known. But the figures show that grass for both cutting and grazing should receive several times as much N as at present, and grass that is cut needs much more P and K.

FERTILISER EFFICIENCY

Using fertilisers inefficiently increases their real cost; better materials and methods of application may make manuring more efficient, and therefore cheaper. We used to worry about the small short-term efficiency of phosphate, of which rarely more than a quarter of a dressing is taken up by crops. The rest of the phosphate is precipitated in the soil; because it is slightly soluble it can be used slowly by later crops and experiments suggest that the whole of a dressing of P may ultimately be recovered. Potassium behaves similarly in medium and heavy soils, but large repeated dressings are leached from light soils and wasted. On average of the crops and soils where measurements have been made, only about half of the N applied has been recovered. This small uptake means the cost per kg of N that entered the plant (and made it grow) was double the cost per kg of N that was bought. As much of the surplus N is lost by leaching in our climate, inefficiency of this kind increases true costs of nitrogen manuring. The losses are serious from soils where N is easily leached, or where crops have small or diseased root systems that do not take up N efficiently. The large dressings of N now often recommended to help cereals overcome root disease such as take-all are used very inefficiently. If a larger proportion of a nitrogen dressing can be made to increase growth, less fertiliser will be needed for a given yield, and the savings may justify the extra costs of special application equipment, of repeated dressings of straight N fertilisers (perhaps by aircraft) or of slow-acting materials.

Fertilisers (and these must include lime, sulphur, magnesium and the trace elements, in addition to N, P and K) make it possible for us to control the nutritional side of soil fertility. During the last century the supply of plant nutrients on farms was maintained by control through leases of farming practices, and the sale of straw and the ploughing of pasture was often prohibited. Adequate fertilising makes such restrictions unnecessary, because the plant nutrients sold off the farm can be replaced simply and cheaply, so farmers can grow the most profitable crops that suit their soils and climate. Besides making good deficiencies of nutrients, fertilisers increase soil fertility by leaving residues in the soil. But this does not mean that we may need less fertiliser in future. The larger yields that come from supplying enough of one nutrient increase the need for other nutrients; because of these interactions between nutrients, experiments often show that optimum dressings are tending to increase rather than diminish, although soil fertility is being increased by the fertiliser and crop residues left in the soil.

Forestry

This paper has dealt with fertilisers for agricultural crops, but we should not forget that, in future, they may be much used in forestry. Fertilisers are already well-established for raising young trees in nurseries and the dressings needed are often large by agricultural standards. Trees often respond to doses of phosphate applied at planting, which avoids the "check" that may occur when planting on poor soils. Other experiments on older trees show that nitrogen manuring speeds growth. In a few other countries nitrogen manuring is being developed in practical forestry. But we still need the experimental results that will show whether gains from nitrogen manuring justify using it generally for shortening tree rotations, and producing the smaller trees that can be used economically in modern processes.

Labour

The people employed in agriculture in Britain continually become fewer and there are not half as many as twenty years ago. When labour is scarce and expensive there is always a risk that technical efficiency, and the application of scientific work, may be sacrificed to practical expediency. The need to save labour, to cheapen costs, and to use expensive machines fully in good weather, often makes it difficult to use fertiliser efficiently.

To rationalise spring work many farmers use only one compound fertiliser, which often means that either the extra dressings of phosphate and potash needed to balance losses or to improve poor soils are not given, or excessive dressings are given by using an unsuitable compound. Often the cheapest fertiliser, or the one a contractor is using, is bought, and not the form that is best for a special purpose. Fertiliser has most effect on young plants when placed near the seed or roots; for older crops it may be best to mix fertiliser deeply in soil. Careful timing of nitrogen dressings is essential to avoid leaching in a wet spring. Any special work, or special implements such as placement drills, that slow sowing often conflict with labour management. The remedy is likely to be that special operations of this kind may, in future, be done by contractors. With special equipment, and with the skill

from experience, good contracting services may do much to improve fertiliser efficiency; because they make it easy for farmers to use fertilisers, they should also increase the total amounts applied.

Economic conditions

Forecasts of developments in manuring must take account of the causes of changes in the distant and recent past, of technical developments in fertiliser manufacture and agriculture, and of the rate at which new information is applied by farmers. All changes in agriculture depend on costs and prices and I have assumed these will be stable; if the ratios of prices of fertilisers to values of farm produce change greatly this will alter fertiliser use. But fertilisers, properly used, are cheap. The amounts we use in Britain, which probably double our yields, cost only 9% of total farm expenses, less than the 11% that rent and interest on our farmland costs. Fertilisers lessen other farm costs, and diminish imports by producing extra food.

The acquisition and spread of technical information

Farmers have used much more fertilisers in the last ten years than previously and more experiments are needed to keep advice ahead of practice. Especially needed are long-term experiments that show how cropping and manuring alter soil fertility. The principles on which improved fertiliser practice must be based have been established in long-term rotation and crop-sequence experiments, but these have been done on very few farms and they need to be extended to many more soils and climates.

Farmers are keen to hear about and apply new materials and techniques that help to increase yields and cheapen costs. Your new Association can be invaluable if you provide a forum where farmers, fertiliser makers and agricultural scientists can meet. In your discussions you must avoid the breaks in communication that are caused by unenlightened economic self-interest, furtive commercial secrecy, or the 'ivory-tower' attitudes of some scientists. If you can establish mutual sympathy and confidence, you will do much to increase the agricultural prosperity of Ireland.

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