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CHANGING PATTERNS in FERTILISER USE

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(Paper presented at the sixth meeting of the Fertiliser Association of Ireland)

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1. INTRODUCTION

This paper attempts to discuss the agronomic implications of recent trends in fertiliser technology and the changing patterns in fertiliser use. Recent research in Ireland and elsewhere, into new and conventional fertilisers and their methods of application, is evaluated. Finally, the agronomic implications of various research projects, at present underway, on fertiliser use for specific soil associations, regions and crops are discussed.

2. FERTILISERS AS AN INPUT IN IRISH AGRICULTURE

Profitable farming normally involves a considerable investment in fertiliser use as an input factor in crop and livestock production. While the proportion of input costs attributed to fertiliser vary according to the individual farming or national circumstances, it is usually of such magnitude as to justify critical evaluation. The costs of fertiliser inputs relative to total costs are much lower for Ireland than for most other countries and are shown together with output data for a number of farm enterprises in Table 1; they are taken from the comprehensive report on the factors which influence optimum economic use of fertilisers by Walsh and McDonnell to the 1966 F.A.O. International Symposium on the Economic Aspects of the Use of Fertilisers, Geneva, 1966 (1).

Table 1 : Total costs, fertiliser costs and output per acre for different enterprises on Irish farms

Enterprise	Total costs/ acre (£)	Fertiliser costs/acre (£)	Fertiliser cost as % total	Output/ acre (£)
Wheat	18.4	2.6	14.1	34.5
Barley	16.2	2.3	14.2	33.0
Potatoes	76.4	12.4	16.2	107.0
Creamery milk	18.2	1.0	5.5	31.5
Cattle	10.8	1.0	9.3	15.3

The particularly low cost figures for creamery milk and cattle enterprises are really a reflection of the low fertilising of pasture and of the fertiliser-use policy of farmers as a whole (1, 2).

The total national expenditure in 1968 on fertilisers and lime was £18.76 m, an increase of 127% over 1960. Allowing for price increases of between 14 and 15%, the quantity of fertiliser and lime used has gone up by 98%, i.e., a doubling in 8 years. The national expenditure per acre on crops and pasture increased from about 15 shillings in 1960 to 32 shillings in 1968. In 1960, fertilisers accounted for less than 10% of total costs in agriculture, whereas in 1968 they accounted for almost 14%. In 1960, fertilisers were the fourth largest input, in terms of costs, in Irish agriculture. By 1968 they were joint third with wages, are now rapidly catching up on machinery and by the early 1970's may be second only to animal feed in importance (2).

It is obvious that fertiliser use is increasing quite rapidly and will likely assume even greater significance in the years

ahead. Long-run growth of fertiliser use will only be successful if accompanied by efficient use. Gross agricultural output increased by 50% in value between 1960 and 1968 and there seems to be no doubt that fertiliser use has played a major part in achieving this by substituting for land and labour. The ratio of agricultural output to fertiliser expenditure changed from 23.3 in 1960 to 16.1 in 1968, due to the law of diminishing returns. The ratio of 16.1 is still quite high and shows that we are moving towards the point of economic optimum use. As Heavey also points out (2), this decreasing ratio means that greater emphasis must be placed on efficiency in fertiliser use.

3. RECENT DEVELOPMENTS IN INFORMATION ABOUT FERTILISERS

Within the past few years, there have been significant developments relating to publications, information and communications generally, which make discussions of fertilisers and their use in Ireland easier :

(i) The foundation of the Fertiliser Association of Ireland, which has presented papers (2, 3, 4, 5, 6, 7, 8), all relevant to Irish conditions.

(ii) The availability of statistics and information from the Department of Agriculture and Fisheries on the forms and quantities of fertiliser used. This enlightened approach is to be commended as the withholding of information in some regions has inhibited rational discussion of the subject - a point that emerged at the recent symposium on the economic and agronomic aspects of new and conventional forms of fertilisers in Geneva, December, 1970 (9).

(iii) The recent publication of a 'Fertiliser Manual' for the guidance of agricultural advisers (10).

(iv) The summary in an extensive paper, of 20 years of Irish research in developing a basis for fertiliser use (11) and the recent publication of two papers summarising soil and agronomic research in this country since 1941 (12, 13). These papers provide a basis for evaluating the progress made in the past decade in fertiliser use and technology since the first comprehensive study on lime and fertiliser use was made in 1957 (14).

(v) The publication of bulletins on the economic aspects of fertiliser use at farm level by the fertiliser manufacturing interests and the dissemination of information on fertilisers at field days and seminars organised by the Fertiliser Association of Ireland, the Department of Agriculture and Fisheries, the advisory services, An Foras Talúntais and other bodies.

(vi) Increased publication, by the fertiliser industry itself, of research activities and by the other bodies concerned, such as Johnstown Castle and other centres of An Foras Talúntais.

(vii) Research into farmers' adoption of such practices as nitrogen application for early grass, soil testing and silage making has also informed the fertiliser industry on dissemination processes (15).

(viii) Finally, and perhaps of most importance, have been the publications in 1966 (16) and 1969 (17) on national fertiliser-use surveys with detailed information on fertiliser and lime rates, the percentage of each crop receiving fertilisers, the distribution of national fertiliser consumption between

crops, fertiliser sources used, regional differences in fertilisation and the relationship between livestock carrying capacity and fertiliser use.

4. CHANGES IN ATTITUDES AFFECTING FERTILISER USE

Quite rapid changes are occurring which are affecting fertiliser use (18). These include :

4.1 Farmers

(a) They are not satisfied with present yield and profit.

(b) More are anxious to remove limiting factors.

(c) They are looking for new ideas and methods to improve their standard of living.

4.2 Fertiliser industries

(a) They are more competitive and service oriented.

(b) They are keener to introduce year-round fertilisation, especially autumn and winter fertilising, using special off-season discounts.

(c) As fertilising rates increase, bulk application becomes more feasible.

4.3 New technology

(a) New technology in fertilisers is continually being developed by fertiliser companies, national fertiliser development centres (such as T.V.A.), universities, research institutes, etc.

(b) The additive effects of good technology from the other areas of agricultural research such as increases in silage making, the introduction of better and new crop varieties, better soil management and agronomic practices, all tend to hasten changes in fertiliser use.

Advances in the theory of agronomy and crop production will undoubtedly enlarge the scope for fertilisers. Recent examples include that of Mengel (19), who pointed out at a recent symposium in Israel that the genetic potential of crop production is only realised to the extent of 50 to 60%. At the same symposium, Warren Wilson (20) concluded from a theoretical analysis that is was possible to achieve maximum yields about 30% greater than the highest now obtained by careful application of agronomic techniques. Considerable expansion in fertiliser use was also foreseen by Brogan (6) in his study based on applying present standard fertiliser rates, increasing livestock numbers in accordance with potential stock carrying capacity and increasing fodder conservation. At a recent symposium on "Beef in the Seventies", Conway (21) forecast a growth in fertiliser consumption of 150,000 tons of nitrogen, 100,000 tons of phosphorus and 75,000 tons of potassium to meet the increasing fodder requirements of the national cattle population in the seventies.

4.4 Economics

(a) In some cases, crop and livestock prices are becoming favourable and hence the aim is for higher yields.

(b) There is a better realisation of the large capital investments in land, machinery and other inputs in modern agriculture. This leads to more incentives to innovate in fertiliser inputs, such as new fertiliser forms and application methods.

4.5 World food demand

Although there are surpluses of certain food commodities,

there is no reason to believe that, with the world population increasing, this will continue. Food surpluses are a relatively minor embarrassment, as in many cases they represent less than a year's demand. Military planners stockpile enormous quantities of metals, chemicals, petroleum and other commodities, equivalent to the demands for 5 years or more in some cases. As production runs in agriculture are mostly on an annual basis, a modern world food strategy will increasingly demand stockpiling, to overcome localised short-falls in bad seasons. In regions of low agricultural productivity, it is becoming clearer that food deficits can, to a certain extent, be equated with fertiliser-use deficits.

To sum up, the increasing tendency towards intensification in agriculture and towards making the maximum use of land resources will make fertiliser use more important, if food marketing problems are overcome.

5. FACTORS AFFECTING FERTILISER USE

Walsh and McDonnell (1) have outlined the main factors, variations in which may be expected to affect the economic optimum use of fertilisers (Table 2). These factors extend from the environmental, through husbandry and economic to personal. There is an obvious progression from the physical factors (which, whether variable or fixed, should be quantifiable with the advance of the new science of agronomy) to the most intangible though equally important personal factors of the farm operator which determine his individual ability to manage input alternatives to the best economic advantage. These factors can be grouped into 'variable' and 'fixed' categories, i.e., the first indicates the choice range

Table 2 : Factors, variations in which affect economic optimum use of fertiliser

	Factor group	Variable		Fixed	
	(1) Climate	water supply) temperature) light intensity)	greenhouse conditions	rainfall) temperature) light intensity)	field conditions
	(2) Location			aspect, altitude, slope, accessibility to transport, convenience to roadways	
Environment	(3) Soil type			inherent soil physical conditions, effective root feeding depth, inherent major and trace elements supplying power, inherent soil biological state	
	(4) General	drainage, previous manuring (major and trace nutrients), crop rotation, use of inoculation organisms			
	(5) Specific	date of sowing, planting pattern and rate of seeding, rate and method of fertiliser* application, yield and quality potential of crop (species or variety), weed, disease and pest control		crop tolerance of nutrient deficiency or imbalance	

*Other than fertiliser whose optimum is to be determined

(or combination) open to the farmer or more specifically within his control, while the latter group involves factors which the farmer cannot normally change or easily control.

The environmental factors affecting fertiliser use - climate, location and soil type - are being studied at Johnstown Castle and other research centres of An Foras Talúntais. It is generally acknowledged that an adequate supply of soil moisture is one of the more, if not the most, important factor in relation to optimum crop production. The Irish climate, ensuring adequate supplies of moisture (sometimes in excess) is thus particularly conducive to fertiliser response. This advantage of the Irish environment is not fully exploited as far as fertiliser use is concerned. The advantage strikes one forcibly if one traverses any of the large sub-humid areas of Central North America, where fertiliser use on excellent soils is restricted by inadequate soil moisture. In addition, the problem of high osmotic pressure in the soil solution following fertiliser application, which damages young seedlings, is almost non-existent with fertiliser use in Ireland.

6. CONVENTIONAL AND NEW FERTILISER FORMS

Defining new and conventional fertilisers is difficult. Date of first application is not appropriate as a criterion, as aqueous ammonia was being used before Liebig, but would not be called a conventional fertiliser today. On the other hand, calcium ammonium nitrate, first produced after World War I, and hence used for the first time 80 years after aqueous ammonia, is justly called a conventional fertiliser.

6.1 Nitrogen sources

It is more reasonable to consider the evolving share of the market as a criterion for conventional and new fertilisers, with conventional fertilisers defined as having a stagnating or declining share of the market. This criterion was used to produce Table 3 for Irish conditions, after Saalbach (22). Cooke has gone further and refers to conventional fertilisers with less than 25% N as obsolete (23).

Table 3 : A classification of new and conventional fertilisers

Conventional	New
Nitrogen	
Ammonium sulphate	Urea
Ammonium nitrate	Anhydrous ammonia, aqua ammonia, slow-release fertilisers
Sodium nitrate	Liquid fertilisers
Calcium nitrate	High concentration compounds
Calcium ammonium nitrate	
Calcium cyanamide	
Phosphorus	
Superphosphate, 8% P, 16% P	Metaphosphates
Basic slag	Triple superphosphate, 20% P
Ground rock phosphate	Superphosphoric acid
Dicalcium phosphate	Polyphosphates
	Ammonium phosphates
	Elemental phosphorus
Potassium	
Potassium chloride	Potassium nitrate
Potassium sulphate	

The world situation for relative use of nitrogen fertiliser forms is shown in Fig. 1 (22, 24). Urea and liquid fertilisers

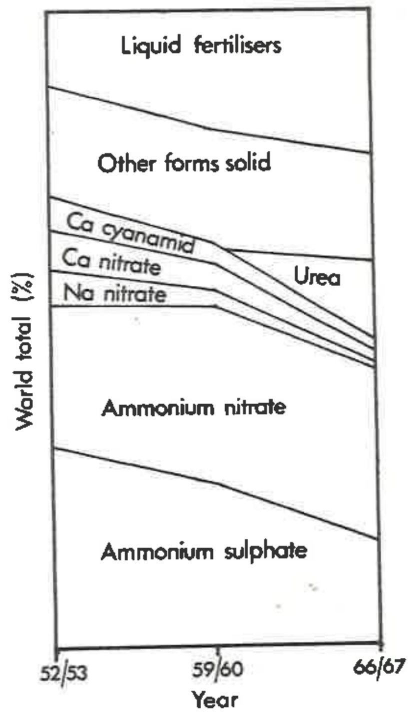


Fig. 1: Changes in forms of nitrogen fertilisers produced in percentages of world total (Cooke)

are expanding their share of the market quite rapidly, whereas ammonium sulphate, ammonium nitrate, other nitrates and cyanamide are in relative decline, particularly in recent years. A somewhat similar analysis of the world situation for nitrogen fertilisers is shown in Fig. 2, but with projections to 1975 (25). Urea's share of the world nitrogen fertiliser market has risen from less than 5% in 1955 to 16% in 1969 and is expected to increase to about 26% by 1975. These figures are for solid urea only and do not include urea used in solution. By 1975, it is expected that nearly 40% of the world's fertiliser nitrogen capacity will be in the form of urea (including solutions and urea content of complex fertilisers).

6.2 Phosphorus sources

World trends in phosphatic fertiliser materials are shown in Fig. 3 with projections to 1975 (25). Normal superphosphate is in rapid decline, with a projected 22% of the world's phosphate fertiliser market in 1975. Concentrated superphosphate will remain at about 16%. The biggest increase will be in ammonium phosphates, complex fertilisers and others - reaching 56% by 1975. Basic slag, in 1969, supplied about 10% of the world's phosphatic fertiliser, but this is expected to decline to about 6% by 1975. Basic slag, in Europe, is an exception to the general rule that concentrated granular compounds increase at the expense of powdery and less concentrated compounds. Basic slag consumption in Ireland increased from 122, 000 tons in 1966/67 to 156, 000 tons in 1970/71. In Britain over 700, 000 tons of basic slag are used annually and 25% of all phosphate used in Britain is applied in the form of basic slag, especially on grassland.

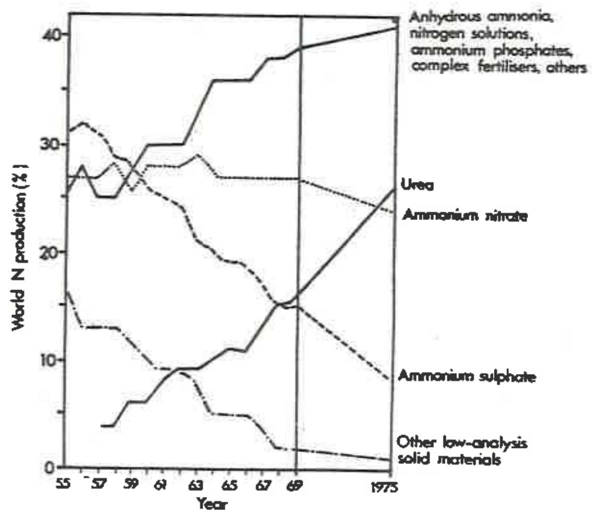


Fig. 2: World trends in types of nitrogenous fertiliser materials

7. TRENDS IN FERTILISER TECHNOLOGY

Table 4 shows the trends in fertiliser technology which have been well summarised by Hignett and co-workers of the National Fertiliser Development Centre, U. S. A. (25, 26).

7.1 Higher nutrient concentrations

A substantial proportion (often half or more) of the total cost of getting fertiliser nutrients on to farms is due to costs of transport, storage and handling. To reduce these costs, progress towards higher nutrient concentration has been substantial, and this trend is likely to continue. The trends for Ireland, the United Kingdom and United States from 1957 onwards are shown in Table 5 and Fig. 4 (25, 26, 27, 28). Ireland, since 1967, leads the world with the highest nutrient content ($N + P_2O_5 + K_2O$) in compound fertilisers. A concentration of 47.5% was reached in 1969-70, which is

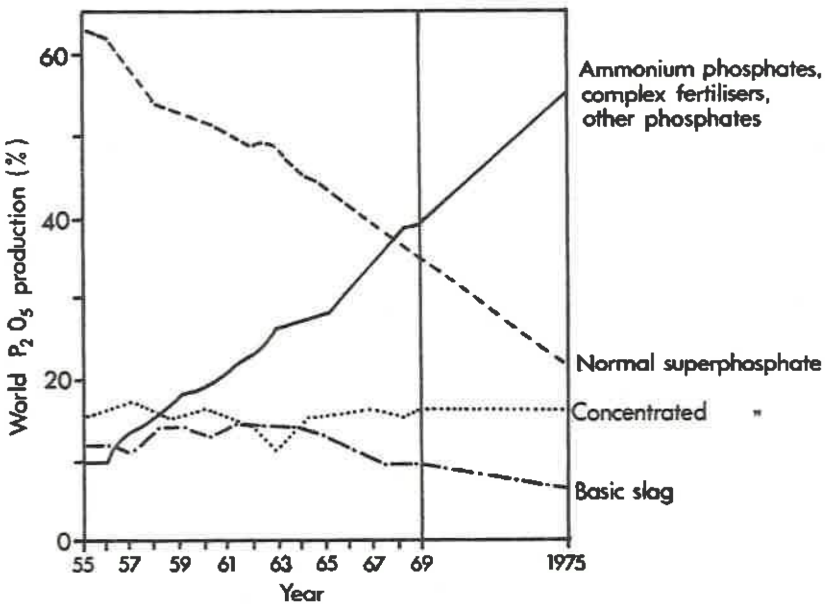


Fig. 3: World trends in types of phosphatic fertiliser materials

Table 4 : Foreseeable trends in fertiliser technology

1.	Higher nutrient concentrations
2.	Granulation
3.	Liquid fertilisers
4.	Suspension fertilisers
5.	Controlled release sources
6.	New nitrogen sources
7.	New phosphorus sources
8.	Bulk shipment, handling, blending
9.	Foliar applications
10.	Larger manufacturing plants
11.	Shipment of intermediate products
12.	Pollution

Table 5 : Trends in nutrient concentration ($N + P_2O_5 + K_2O$) of compound fertilisers

	Year	Conc. (%)	Year	Conc. (%)	Rate of conc. increase (%/year)
U.K.	1957-58	31.1	1966-67	40.0	1.03
Japan	1960-61	27.0	1967-68	37.0	1.43
France	1957-58	27.2	1966-67	35.3	0.67
U.S.A.	1957-58	30.2	1967-68	38.1	0.79
Ireland	1957-58		1969-70	47.5	1.37

about 7% higher than in the United Kingdom. The increase in nutrient concentration has been dramatic since 1964, when it was 27.3%. A linear increase of 20% occurred between 1964 and 1968. Over the 12-year period 1957-58 to 1969-70, the increase in Ireland has averaged 1.37% annually. The only comparative increase has been that

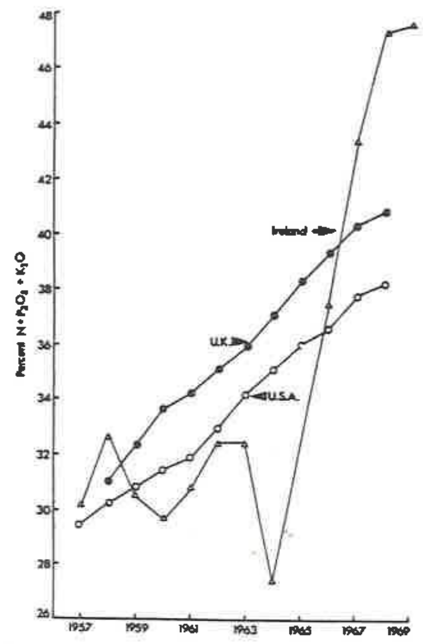


Fig. 4: Trends in nutrient concentration of compound fertilisers

of Japan, where nutrient contents increased by 1.43% annually from 1961-62 to reach a concentration of 37.0% in 1967-68.

World-wide plans are weighed heavily towards such high analysis materials as urea and diammonium phosphate, so continued progress in this direction is assured. Research workers view with enthusiasm prospective new fertilisers with equivalent nutrient contents exceeding 100%. The ultimate in concentration of phosphate fertilisers may, as Cooke (29) has pointed out, be elemental phosphorus (100% P or 229% P_2O_5), based on work in New Zealand by Rothbaum (30).

Despite these increases in concentration there has been very little change in the nutrient ratios of Irish compound fertilisers since 1957 (Table 6). As nutrient ratios depend on a host of factors and is a large and separate subject in itself, it is outside the scope of this paper.

The increasing tendency towards higher concentrations in compound fertilisers is shown for the period 1957 to 1970 in Table 7 (27).

Table 6 : Nutrient ratio ($N:P_2O_5:K_2O$) compound fertilisers, Ireland and United Kingdom

Year	Ireland	United Kingdom
1957/1958	1.0:3.0:3.3	1.0:1.4:1.6
1966/1967	1.0:3.03:3.5	1.0:0.8:0.9

Table 7 : Average nutrient concentration of fertiliser compounds in Ireland 1957-1970

Year	Tons P_2O_5	% P_2O_5 in compounds	Tons K_2O	% K_2O in compounds	%N+ P_2O_5+ K_2O	% N in compounds
1957/58	29,668	12.8	32,331	14.0	31.1	4.3
1958/59	30,699	14.2	31,560	14.6	32.9	4.1
1959/60	31,753	12.4	35,174	13.8	30.5	4.3
1960/61	37,595	12.5	39,246	13.0	29.7	4 2
1961/62	40,642	12,3	46,955	14.2	30.7	4.2
1962/63	44,044	12.2	56,375	15.7	32.5	4.6
1963/64	44,904	12.5	55,653	15.5	32.5	4.5
1964/65	46,736	11.8	45,377	11.4	27.3	4.1
1965/66	51,364	12.7	62,061	15.3	32.5	4.5
1966/67	68,137	15.0	78,732	17.4	37.4	5.0
1967/68	89,349	18.1	96,970	19.7	43.3	5.0
1968/69	100,574	19.7	108,173	21.2	47.2	6.3
1969/70	107,219	19.8	116,485	21.5	47.5	6.2

7.2 Granulation

It is expected that the trend towards granulation of all solid products will continue. No revolutionary new and superior processes for granulation are predicted for the foreseeable future. In the future there will be increased emphasis on closely sized, dust-free, hard granular materials that can be stored and handled in bulk, with an increasing tendency to incorporate larger proportions of urea. As granulating plants are relatively expensive and complicated, they need a fairly large output to be economical.

There has been a dramatic increase in the amounts of fertiliser granulated in Ireland - Fig. 5 and Tables 8 and 9 (27). Up to 1964-65 powdered compounds exceeded

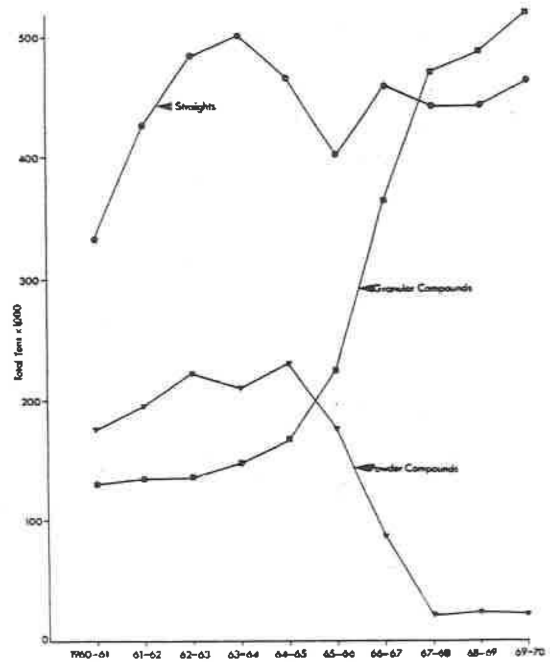


Fig. 5: Consumption of fertilisers in Ireland, as straights and compounds (powder and granulated)

Table 8 : Fertiliser consumption (tons) as straights and compounds in powder and granulated forms, Ireland 1957-1970

Year	Straights	Compounds		
		Total	Powder	Granulated
1957/58	237, 227	230, 983	no data	no data
1958/59	343, 320	216, 292	no data	no data
1959/60	362, 198	255, 588	no data	no data
1960/61	335, 726	301, 277	175, 500	125, 777
1961/62	420, 861	328, 809	194, 809	135, 000
1962/63	483, 266	359, 776	223, 697	136, 079
1963/64	507, 184	358, 691	211, 531	148, 160
1964/65	467, 478	397, 676	230, 017	167, 659
1965/66	401, 026	404, 689	177, 836	226, 853
1966/67	460, 041	453, 027	87, 458	365, 569
1967/68	444, 627	492, 875	20, 692(a)	472, 183
1968/69	443, 138	509, 487	20, 936(b)	488, 551
1969/70	462, 282	542, 686	20, 805(c)	521, 881

(a) Includes 9, 600 tons potassic basic slag
(b) Includes 17, 000 tons potassic basic slag
(c) Consisted entirely of potassic basic slag

granular compounds. Since then, output of granular compounds has increased about three-fold to 522, 000 tons and powdered compounds has declined by 90% to 21, 000 tons. This is another illustration of the considerable technological advances made by the Irish fertiliser industry in the late sixties.

7.3 Liquid fertilisers

The world's first commercial production of liquid mixed chemical fertiliser was by Sir James Murray and associates in Ireland in 1841 (31). It is also of interest that Murray had priority, by a short interval, over Lawes in pioneering the first commercial manufacture of superphosphate.

Table 9 : Fertiliser consumption (tons elemental basis) as straights and compounds, Ireland, 1957-1970.

Year	Straights			Compounds		
	N	P	K	N	P	K
1957/58	8, 150	14, 055	16, 660	9, 850	12, 950	26, 840
1958/59	11, 680	20, 000	17, 500	8, 920	13, 400	26, 200
1959/60	10, 640	22, 140	19, 140	11, 060	13, 860	29, 200
1960/61	12, 030	18, 690	22, 020	12, 570	16, 140	32, 580
1961/62	15, 310	23, 060	27, 020	13, 690	17, 740	38, 980
1962/63	13, 820	29, 475	27, 400	16, 680	19, 225	46, 800
1963/64	18, 000	31, 000	29, 400	16, 200	19, 600	46, 200
1964/65	12, 670	28, 400	37, 430	16, 430	20, 400	37, 670
1965/66	13, 360	20, 780	17, 480	18, 040	22, 420	51, 520
1966/67	24, 400	25, 460	26, 240	32, 600	29, 740	65, 360
1967/68	25, 800	24, 600	22, 000	27, 200	39, 000	80, 500
1968/69	31, 000	24, 500	20, 000	32, 000	43, 900	89, 800
1969/70	36, 300	25, 800	29, 000	33, 900	46, 800	96, 700

Liquid fertilisers have had a remarkable growth in the United States, but have been slow to catch on in Europe. They have considerable advantages :

(i) Ease of handling - the main advantage.

(ii) Ease of uniform application at the desired depth.

(iii) Adaptability.

(iv) Incorporation of micronutrients, pesticides.

(v) Good agronomic results.

(vi) Capital requirements are low.

Liquid fertilisers have been classified into three categories based on the pressure they exert on the inner walls of a container - Table 10 (22).

Methods and equipment for manufacturing liquids are simple and inexpensive. Unlike granulation processes, a large-scale operation is not necessary for economic success. Whereas the economic minimum scale for manufacture of a

Table 10 : Classification of liquid fertilisers

I.	High pressure (up to 20 atm)
	Anhydrous ammonia
II.	Medium to low pressure (up to 8 atm)
	1. Amines (ammonia, ammonium nitrate, urea solutions)
	2. Aqua ammonia
III.	Pressure-free solutions and suspensions
	1. N-solutions based on ammonium nitrate and/or urea
	2. NP and NPK solutions
	3. Suspensions and slurries

granular compound may be 100,000 tons annually, a liquid blend can be economically produced at one-tenth that capacity. The manufacture of liquid fertilisers involves little or no problem of air and water pollution. Material losses are almost non-existent and control of composition is easier. In the United States, they are mainly compounded from ammonium polyphosphates, urea-ammonium nitrate and potassium. In general, there is usually no difference in agronomic results between solids and liquids when the two forms contain the same chemical compounds and placement is the same. Liquid nitrogen fertilisers are particularly popular in Denmark and are also gaining in France, Great Britain and U.S.S.R. - Table 11. The spectacular development of anhydrous ammonia as a nitrogen fertiliser in Denmark has been associated with a strong co-operative system.

British experiences with liquid fertilisers have been

Table 11 : Consumption of liquid fertilisers as percentage of total N consumption in 1967/1968

	NH_3	Solutions
Denmark	32.5	-
France	1.4	3.6
Great Britain	0.8	2.9
The Netherlands	0.3	-
Spain	-	1.1

summarised by Thirkell (32). Typical formulations in the U.K. are 14 : 6 : 8, 9 : 9 : 9 and 7 : 7 :11. A general disadvantage of liquid mixed fertilisers is the comparatively low analysis, particularly in those grades containing a high proportion of potassium. One method of overcoming this is to use suspension fertilisers.

7.4 Suspension fertilisers

These are liquids containing 1 to 3% of a gelling-type clay to minimise settling. The nutrient content can reach a level comparable to that of solid fertilisers - and about twice the level of liquids (33). The average analysis of liquid mixed fertiliser in the U.S. in 1967 was 7 : 5 - 16 : 2 - 6.1 compared to 8 : 6 - 16 : 6 - 12.7 for all mixed fertiliser ($N:P_2O_5:K_2O$). There is considerable flexibility in formulation as it is not necessary that raw materials be water-soluble. Handling and application are more difficult than with liquids.

There is a considerable amount of research already underway in the United States on suspension fertilisers. In Ireland, a limited amount of work has been reported (34) on evaluating a

T. V. A. formulation made by cold mixing T. V. A. liquid base suspension 12 : 40 : 0 with urea-ammonium nitrate solution and potassium chloride. The results of a pot experiment, using mustard as a test crop, are shown in Table 12. Uptake of nutrients was at least as effective from the suspension material as from the equivalent amount of straight fertilisers. In field experiments on grassland at the Drumlin Soils Research Centre, Ballinamore, there were no significant differences between suspensions and conventional fertilisers in 1967 and 1968.

Table 12 : Yield and uptake of N, P and K from suspension and conventional fertilisers (mg per pot)

	Suspension fertilisers	Conventional fertiliser
Dry matter yield	148.0	113.0
N uptake	7.1	5.1
P uptake	0.50	0.34
K uptake	5.4	3.9

7.5 Controlled release fertilisers

These have attracted considerable attention, particularly the nitrogen sources. As Cooke (35) and others have pointed out, inorganic nitrogen in soil is ephemeral; growing crops take it up quickly and any not used by plants is likely to be leached or denitrified. The considerable losses of soil and fertiliser nitrogen in modern crop production are a serious economic problem and a threat to the environment. Agronomists are looking for alternative methods of applying fertiliser nitrogen, and obsolete sources such as ammonium sulphate and cynamide are in rapid decline. Controlled release fertilisers would

appear to have a bright future provided an accurate control of release can be achieved and the price is competitive. Although the first U.S. patent for a coating process to produce a slow-release fertiliser was granted in 1907, it is only within the past decade that a major interest was developed. Recent developments were reviewed by Hamamoto (36) and Powell (37).

The advantages and disadvantages of controlled-release fertilisers are summarised in Table 13. The first two - increased efficiency in uptake and reduced losses by leaching and decomposition - could be of enormous importance in Ireland, and experiments have been laid down in spring 1971 to test three controlled-release sources : urea-formaldehyde (UF), isobutylidene diurea (IBDU) and sulphur coated (SCU) urea in pot culture and small-scale field experiments, at Johnstown Castle, with grass and cereals (38).

Table 13 : Slow release fertilisers - advantages and disadvantages

Advantages :

1. Improved efficiency in uptake by plants
2. Reduced losses by leaching and decomposition
3. Reduced fertiliser application costs
4. Less scorching and damage to seedlings.

Disadvantages

1. High cost

With the present level of fertilisation, it is in general impossible to cover fully the nutrient requirements of cultivated plants for the whole vegetation period by a single fertiliser application in spring. The reasons for this are summarised in Table 14.

Table 14 : Disadvantages of a single fertiliser application in spring

1.	High osmotic pressure values in soil solution can damage plants
2.	Luxury consumption of nutrients early in vegetative phase can lead to cereals lodging and to deficiency later
3.	Leaching losses

In the past, farmers used to split heavy nitrogen dressings to overcome these problems. Researchers have investigated a considerable number of sources of controlled-release fertilisers and some of these are listed in Table 15. The only commercially available materials (other than natural organics) are the urea-formaldehyde (UF) compounds and crotonylidene-diurea (CDU) in Germany; urea-formaldehyde reaction products (ureaform) (UF) in the United States and isobutylidene diurea (IBDU) in Japan (25). They have a place in specialised uses, e.g., home gardens and golf courses. They are too expensive, as yet, for general farm use. Their success is not due primarily to more efficient utilisation of nitrogen; in fact, rarely is a slow-release nitrogen fertiliser found more effective than a properly applied soluble material. Their safety, even in unexperienced hands, and their property of providing more uniform growth throughout a season are probably responsible for their success.

A development of possible considerable significance to agronomists in Ireland is sulphur coated urea (SCU), developed by T.V.A. (39, 40). The urea granules are sprayed with molten sulphur in a rotating drum to form a coating,

Table 15 : Slow release nitrogen sources

A.	Nitrogen carriers	
	1.	Urea condensation products
	2.	Oxamide
	3.	Ammonium humates
	4.	Calcium cyanamide materials
	5.	Lignin sulphonic acids
B.	Coated fertilisers	
	1.	Inorganic coating
	2.	Organic coating
C.	Nitrification inhibitors	
	Bactericides	

which is then further coated with a 3% coating of wax. A small amount of microbiocide is incorporated in the wax to prevent soil microbe attack on the coating. By using this process, nitrogen products that release 1% or less of their nitrogen per day, when immersed in water, have been produced. The coating process can be varied to give products with a range of release capabilities. Recent estimates indicate that the cost of nitrogen in SCU will probably be about 25 to 50% more than for the uncoated material (41).

A very full account of SCU is reported in the Sulphur Institute Journal (40), with outlines of process details, estimates of production costs and agronomic effectiveness. A recent report on the effectiveness of this material for grassland is also encouraging (42).

The sulphur in SCU could also be of considerable agronomic benefit where sulphur levels in soils are deficient, and this has been confirmed in the field in Muscle Shoals, Alabama (42).

Controlling the nitrogen supply to cereals under Irish conditions is a major agronomic problem. Considerable losses can occur with an over-supply and farmers, in many cases, ensure against this by using too little nitrogen. Low yields of cereals have been mainly ascribed to the use of too little nitrogen (10). Although the most recent fertiliser recommendations (10) suggest a reduction of one-third in nitrogen applied to cereals on certain heavy limestone soils, the problem of nitrogen nutrition of cereals, to obtain optimum yield and quality, is difficult. Perhaps some of these problems can be solved with controlled-release, nitrogen sources.

A study into the potential demand for slow-release fertilisers within Europe is at present underway in the Battelle Institute, Geneva, and a preliminary report has been given by Martley (43).

At this point, it is appropriate to quote two varying view-points on controlled-release fertilisers :

"The ultimate goal is the production of a fertiliser material that will release nutrients at a rate equal to the demands of the growing plant. This goal may never be reached, but considerable progress has already been made. Slow-release fertilisers may be at least a partial answer" (36).

Another authority - Cooke (23) is, by contrast, quite pessimistic in his approach : "It seems a hopeless task to design materials that will release nitrate by one biological mechanism at a rate that matches need for nitrate of another

biological system (the crop). I suggest such research will continue to be unrewarding and should be abandoned. Current work with simpler compounds that are sparingly soluble, and with nitrification inhibitors is undoubtedly worthwhile".

A considerable amount of research into nitrogenous slow-release sources, specially IBDU, is underway in Japan (36). By the end of 1964, a 40,000 tons per year plant for IBDU containing high analysis granular compound fertiliser was completed. The compounds produced were 15 : 15 : 15 and 16 : 10 : 14 for vegetables and crops, 18 : 11 : 11 for fruit trees and 10 : 10 : 10 for paddy.

High nitrogen recovery and increased yields were reported in tests with IBDU on Italian ryegrass and orchard grass. The Japanese approach to controlling nitrogen release from these materials has been to control the rate of hydrolysis by altering the granule size. Tomlinson (44) has also confirmed that nitrogen is efficiently recovered by Italian ryegrass from IBDU, particularly on acid soils. The cost to farmers of IBDU is over twice that of conventional fertilisers per unit of nitrogen. When IBDU is used for making compounds, the cost was about 20% above that of fertilisers.

The conventional approach to controlling nitrogen release from urea-formaldehyde sources is to vary the degree of condensation in polymerisation of the urea and formaldehyde. The free urea in the product is immediately available whereas the highly condensed polymer is quite slowly available.

Saalbach (22) concluded that all three condensation products (UF, CDU, IBDU) were successful in fertilising lawns and ornamental plants.

Slow-release micronutrient sources have attracted considerable attention in The Netherlands, Germany and U. S. A. (45). These are listed in Table 16. The slags are sources of copper, cobalt and zinc and are considered superior to copper sulphate as copper sources (46). Oxides are used as sources of manganese, zinc and copper, especially for vegetables and field crops in Michigan. In the United Kingdom, two grades of manganous oxide are available - Fertiliser Manganese 40 and 58, containing 40 and 58% manganese respectively. Frits are available in The Netherlands and elsewhere as micronutrient sources, especially molybdenum, and show greater residual effects than the simple salts. Fusions of micronutrients with sulphur have shown varying degrees of success in the United States and are being further tried as sources of manganese, zinc and copper. Encapsulation in polyethylene has also shown promise. Frits were evaluated as boron and cobalt sources at Johnstown Castle during 1970 and oxides and slags are being tested in 1971 (46).

7. 6 New nitrogen sources

Saalbach (22) has pointed out the difficulties in distinguishing between new and conventional fertilisers, with date of first application being inappropriate as a criterion. In Table 3 fertilisers which are considered conventional and new, under Irish conditions, are outlined, based on Saalbach's criterion of the share of the market occupied. Conventional fertilisers are thus defined as having a stagnating or declining share of the market. Cooke (29) has gone further and refers to conventional fertilisers with less than 25% N as obsolete. In

Table 16 : Slow-release trace element fertiliser sources

1.	Slags
2.	Oxides
3.	Frits
4.	Sulphur fusions
5.	Plastic coatings

Ireland, as elsewhere, urea is increasing its share of the nitrogen market quite rapidly. Anhydrous ammonia, aqua ammonia and slow-release fertilisers are still at the developmental stage in Ireland and sales are low, apart from such specialised outlets as horticulture.

7. 6. 1 Urea

Urea has three considerable advantages :

(i) ease of manufacture

(ii) relative ease of handling

(iii) high nitrogen content (theoretical 46. 6% N compared with 20 to 26% N for calcium ammonium nitrate).

The agronomic aspects have been comprehensively treated by Tomlinson (44) and experiences in the United Kingdom are somewhat similar to those in Ireland. In general, urea is not placed close to germinating seeds, but is more widely used for top-dressing pastures.

There are two aspects of urea placement that concern Irish agronomists - simple osmotic effects and effects on the soil buffer capacity. The extent to which these occur affects the performance of urea and explains the numerous and apparently contradictory results obtained when comparing urea with other nitrogen sources. In combine drilling of cereals, the use of too much urea must be avoided because urea hydrolysis can lead to alkaline microsites which damage young seedlings - directly by ammonia toxicity or indirectly by nitrite toxicity. A summary, showing the relative effectiveness of urea, in 180 experiments around the world since 1960, is shown in Table 17 (44). In general, urea is about 90% as effective as other nitrogen sources. Experiences in Ireland, as pointed out by Murphy in the discussion on Tomlinson's paper (44), are that very little differences, if any, occur in grassland responses, particularly as one moves north and west in these islands.

It would appear that the only factor likely to militate against urea in arable farming are uncertainty regarding response rather than cost. Widespread field experiments with urea are at present underway in Ireland and the position will hopefully be clarified during the 1971 season.

Table 17 : Comparison of urea with other nitrogen fertilisers

Crop	Number of comparisons	Cases where urea was Sig. better	Cases where urea was Sig. worse	Efficiency of urea compared with other forms in all trials (%)
Grassland	73	0	13	89
Winter wheat	17	2	3	96
Spring barley	25	0	5	89
Sugar beet	19	0	2	88
Potatoes	44	2	4	88

7.6.2 Anhydrous ammonia

Research on anhydrous ammonia in Ireland did not start until autumn, 1965. Initial experiments with sugar beet and barley showed that anhydrous ammonia was comparable with sulphate of ammonia, but that applications were not as effective in autumn as in spring (47). These results are very similar to findings in Britain, Denmark, Germany, France, The Netherlands, Norway and Sweden during 1953-1968. In 183 experiments with cereals, spring-applied anhydrous ammonia was superior by about 2% as shown in Tables 18 and 19 (48, 49).

Table 18 : Effect of spring-injected NH_3 on the yield of spring-sown crops expressed as a percentage of the yield obtained with solid nitrogen

Country	Cereals	Potatoes	Sugar and fodder beet
Britain	102	99	98
Denmark	102	99	101
Germany	102	99	102
France	-	107	101
The Netherlands	103	103	101
Norway	99	101	-
Sweden	102	-	98
Mean	102	100	100

In general, the main conclusions from Irish research on anhydrous ammonia are :

(i) application in winter is inefficient

(ii) splitting the dressing over the growing season is superior to a single application

(iii) there is little difference between calcium ammonium

Table 19 : Effect of autumn-injected NH_3 on the yield of spring-sown crops expressed as a percentage of the yield with spring-injected NH_3

Country	Cereals	Potatoes	Sugar and fodder beet
Britain	91	-	85
Germany	96	-	96
Denmark	-	88	93
The Netherlands	94	91	90
Norway	80	-	-
Sweden	93	-	95
Mean	94	89	95

nitrate applied in bulk and anhydrous ammonia applied in spring.

(iv) autumn injection of ammonia is too hazardous because of the mild wet winters in Ireland.

The application of anhydrous ammonia to grassland is difficult. It is almost impossible to avoid mechanical damage to the sward and little information is available on the ideal spacing between tines and the ideal depth of injection. It would appear that solid nitrogen fertilisers will continue to dominate the Irish market.

7.7 New phosphorus sources

Evaluating the relative agronomic efficiency of phosphorus sources is hindered by the different criteria used in different countries. In Ireland and Britain, water solubility is used; in continental Europe, solubility in alkaline ammonium citrate is used, whereas in the United States, neutral ammonium citrate is the standard.

7.7.1 Ammonium phosphates

Ammonium phosphates are rapidly becoming the dominant fertiliser phosphorus source on a world scale, and in Ireland they are by far the most important phosphorus ingredient in the high-analysis granular compounds described earlier. Ammonium phosphates are particularly favoured in Ireland because of the importance attached to high solubility.

Ammonium phosphate is the culmination of a long trend towards the removal of calcium from phosphate fertilisers, with triple superphosphate representing an intermediate stage, with all of the sulphate and two-thirds of the calcium removed. Superphosphate is in rapid decline as a phosphorus source. The continual trend to calcium removal increases concentration and solubility.

7.7.2 Potassium phosphates

Potassium dihydrogen phosphate has attracted considerable attention recently in Ireland because of the success of Thompson and Somers (50) of Goulding Fertilisers Ltd, in producing this material, which they call Marina Salt. The five major agronomic advantages ascribed to this source are :

(i) high concentration - 46% P_2O_5, 30% K_2O

(ii) high solubility

(iii) absence of chloride

(iv) safety in handling

(v) compatability with other materials, for compound and liquid fertilisers, prilled and granulated.

Agronomic trials are presently underway with this material.

Another potassium metaphosphate has also been evaluated in the United Kingdom by Harris (51). In general, metaphosphates appear to be at least as good, agronomically, as a mixture of superphosphate and potassium chloride. The outlook for potassium phosphates in Ireland will be strongly affected by fertiliser subsidies, which are based on water-soluble phosphorus and on the potential outlet for the by-product hydrochloric acid.

7.7.3 Improved basic slags

Basic slag is an important phosphorus fertiliser for grassland in Ireland. Dust problems have made application inconvenient. These problems are being overcome and phosphorus content increased as a result of recent research (52).

The physical quality of basic slag is being improved by additives, granulation and mini-granulation and by proofing, and the phosphorus content is being increased by magnetic beneficiation. It is expected that basic slag will continue to hold its share of the phosphorus market in Ireland, provided iron-ores of sufficient phosphorus content continue to be processed.

7.7.4 Elemental phosphorus and phosphine

The ultimate in concentration of phosphatic fertilisers may be elemental phosphorus (100% P or 229% P_2O_5). Earlier work by Rothbaum (30, 53) in New Zealand has been followed by pot culture trials with red phosphorus in Irish soils. In general elemental phosphorus is not so effective soon after application. It is only when oxidation is well-advanced that the material becomes agronomically effective. There is a distinct possibility that elemental phosphorus will play an important part in the fertiliser industry as the 'running-in' difficulties of the large elemental phosphorus plants in

Newfoundland are overcome.

Phosphine, the phosphorus analogue of ammonia, was investigated by Thornton (54). The material is difficult to transport, store, distribute and apply (53), in comparison with ammonia. Considerable technical difficulties must be overcome before it becomes a significant phosphorus fertiliser.

7.8 Bulk blending, handling and shipment

Bulk blending and handling of fertilisers has been largely associated with the United States (55, 56). Three advantages of the system are attracting increasing attention in Ireland :

(i) lower handling and distribution costs than for the bagged product

(ii) the possibility of associating custom application service with bulk blending

(iii) bulk blenders, because of closer contacts with farmers, could provide a more direct technical advisory service on fertiliser use to farmers.

It would appear that a major obstacle to bulk blending in Ireland is the considerable investment already incurred by the fertiliser companies in recent years in granulation plants at the five major fertiliser manufacturing centres which are well dispersed throughout the country.

7.9 Foliar application

Foliar sprays have been used in Ireland mainly for glasshouse and horticultural crops and for trace-element deficiencies in field crops. Present research is concentrated on foliar application of phosphorus to hasten maturation in high value crops such as early potatoes. Two applications of dilute phosphoric acid with urea as a carrier, a detergent and a sugar have been successful in increasing the phosphorus contents of tubers and also dry matter contents in pot culture. Further work is in progress to extend the results to field conditions.

8. SOME PROBLEMS IN FUTURE FERTILISER USE

Future advances in fertiliser use will depend on progress in other directions. Under Irish condtions, these might include :

8.1 Soil association approach

During 1969 a general soil map of the country was published, based on the major soil associations and as part of a National Soil Survey. This map is becoming the basis for fertiliser recommendations on a regional level and differences in inherent soil fertility between soil associations are becoming clear. This approach has been to identify the major national soil associations and on the basis of these to develop quantitative response data for the main crops including grass. This is an extension of the pedological approach which was used very successfully during the previous two decades to diagnose nutritional problems based on soil-parent material, e.g., soil acidity, cobalt deficiency etc.

Nitrogen recommendations for cereals have already been altered because of findings based on soil association differences. Nitrogen recommendations for limestone heavy textured soils in the Midlands have been reduced by one-third. Another example of the value of soil survey in fertiliser use is concerned with the sulphur status of south-eastern soils, Fig. 6 (57). Five of the thirty-one soil associations in the country have been diagnosed as potentially sulphur deficient, Fig. 7 (57).

Significant differences also occur in the total phosphorus

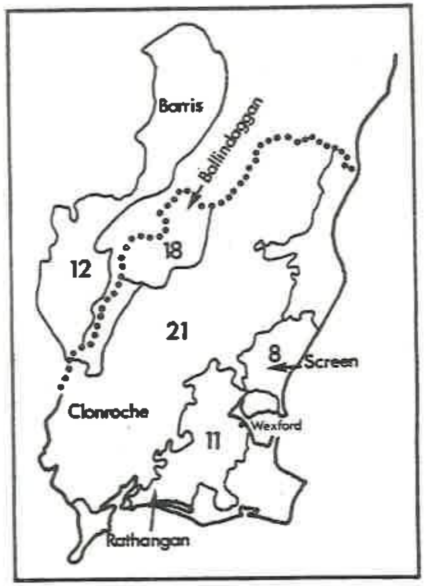


Fig. 6: Available sulphur (ppm) in some South Eastern Irish Soil Associations

contents of the major Irish soil associations - Fig. 8 and Table 20 (58). The following broad conclusions on total phosphorus can be drawn :

(i) Relatively high status

(a) The north-east : Monaghan, S. Cavan, Louth and the east drumlin belt.

(b) The mid-west : Limerick, N. Kerry, W. Clare.

(ii) Intermediate or variable status :

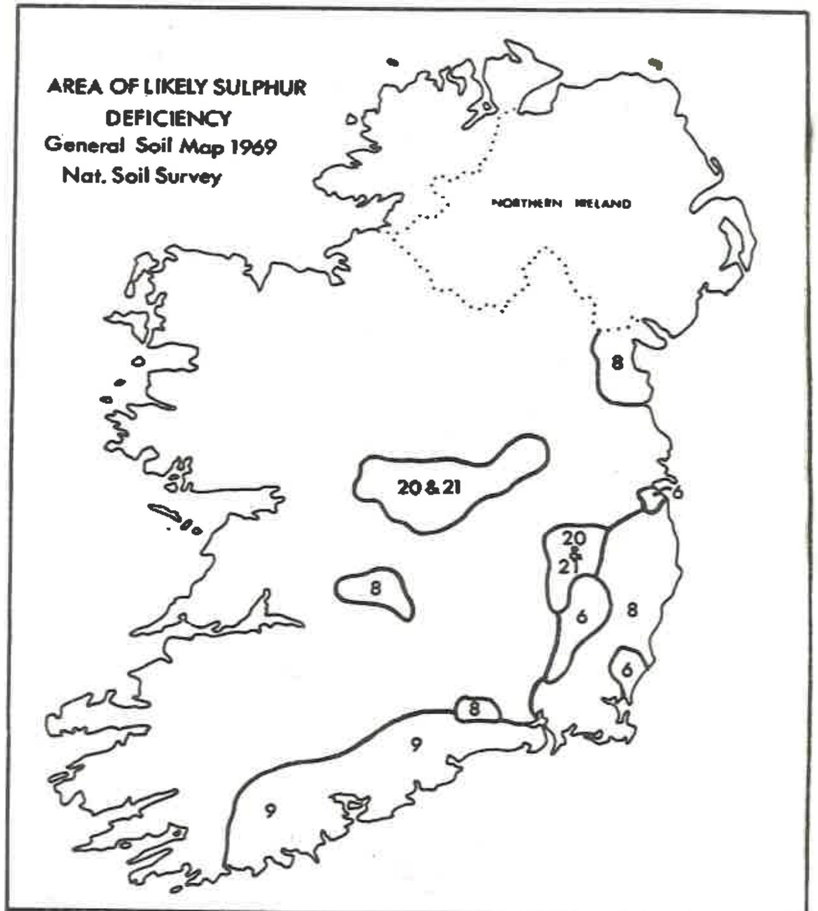
(a) Central Plain. There is considerable variation, possibly due to the phosphorus and other impurities in the parent limestones of Upper, Middle and Lower Carboniferous ages.

(iii) Relatively low status :

(a) South-east : Wexford, Carlow, S. Kilkenny, Wicklow.

(b) North-west : Mayo, Sligo, N.E. Galway, S. Donegal, Leitrim and the west drumlin belt.

(c) Peatlands.



Soil No.	Parent Materials	Total area%
6	Morainic and blown Sands, Granite, Sandstone Drift.	1·3
8	Ordovician, Silurian Shales	8·1
9	Old Red Sandstone	6·6
20 & 21	Morainic Gravels, Sands, Gravelly Drift.	8·2

Fig. 7: Areas of likely sulphur deficiency in Ireland

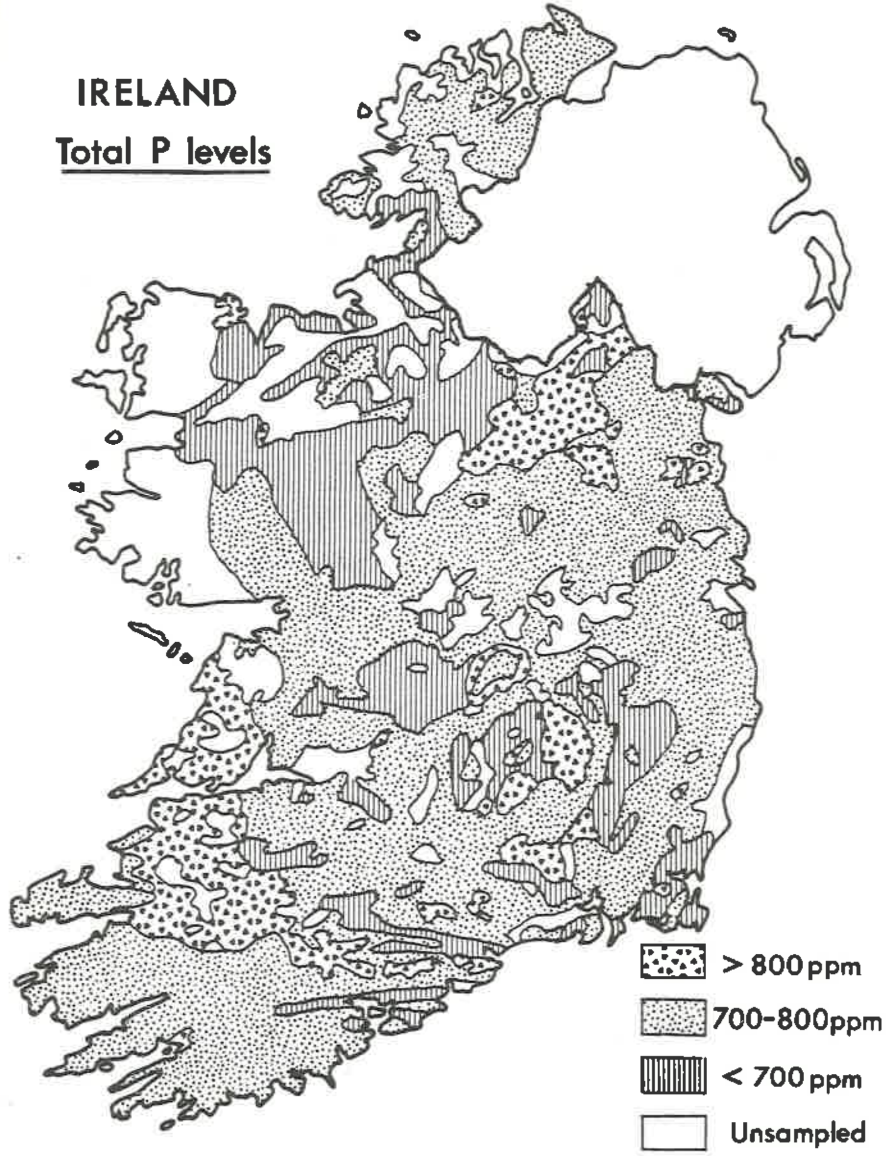


Fig. 8: Total phosphorus in Irish soils

Table 20 : Relationship between soil associations and soil phosphorus values

Soil association no.		County	Total phosphorus (ppm)	No. of samples
15	Drumlin Gleys	Cavan, Monaghan	936	17
4	Reclaimed Podzols (O. R. S.)	Cork	877	16
13	Gleys-Coal Measure shales	N. Kerry, W. Clare, N. Kilkenny	817	37
19	Acid-Brown Earth-Drumlin	S. Monaghan	774	17
24	Grey Brown Podzolics Limestones	Limerick, S. Tipperary, Laois, N. Kildare, Dublin, Meath, Westmeath, Longford, E. Offaly	774	109
8	Acid Brown Earth-shales	Wexford, Wicklow, Louth	763	31
18	Grey Brown Podzolics Drumlin	S. Mayo, E. Clare, Sligo	751	13
23	Shallow Brown Earths Limestone	Galway, Mid-Roscommon, N. Westmeath	729	33
1	Peaty Podzols	S. Kerry, W. Cork, Wicklow, Donegal	719	19
20	Grey Brown Podzolics - Limestone gravel	S. E. Galway, S. Westmeath	716	26
9	Brown Podzolics (O. R. S.)	Cork, Waterford	711	63
25	Gleys-Limestone Shales	N. E. Galway, Roscommon	662	20
7	Acid Brown Earths-O. R. S.	Cork, Waterford	659	25
17	Drumlin-Gleys-Shales	Leitrim	656	25
6	Light textured Acid Brown Earths	Carlow, Wicklow, Wexford	656	8
21	G. B. P. -Gravelly Limestone	N. Tipperary, N. Carlow, S. Kildare	612	25
22	Degraded G. B. P.	N. E. Galway, S. Mayo, N. W. Roscommon	493	17
	Weighted mean		733	

It is noteworthy that Soil Association No. 22, degraded Grey Brown Podzolics, covering large areas in N. E. Galway, S. Mayo and N. W. Roscommon is particularly low in total phosphorus (493 ppm, compared to the national average of 733 ppm) and in available phosphorus (Morgan value of 2.5 ppm). This suggests that such anomalous soil series need particular investigation and shows how useful a soil survey is in delineating soil fertility differences.

8.2 Secondary and minor nutrients

As yields increase and major element usage increases, the demands on the soil reserves of secondary and minor nutrients also increase. We are particularly fortunate in Ireland that 20 years of research have already delineated many of the problem areas. This approach is being further intensified by a systematic national geochemical survey (59). This basic information on the variable composition of soils is already very useful and will become more so as yields increase and fertilisers become purer. A practical outcome of this research was the recent decision to raise boron levels in sugar beet fertiliser compounds from 0.22% to 0.33%. It is hoped that fundamental information on the minor element content of the soil associations will make it easier to decide whether to apply minor elements in general to fertilisers. Irish experiences to date have tended to treat each soil association separately and to avoid deliberate inclusion of minor elements in all fertilisers in a blanket approach.

Secondary elements have been relatively neglected in fertiliser studies in Ireland up to recently. Active research programmes on magnesium and sulphur were started in 1968-69. The major meteorological, soil, crop and fertiliser factors likely to lead to deficiencies of these elements have been described. The major effort has been in diagnosing deficiencies, with soil and plant analyses being particularly useful. Quick and reliable soil tests are now available and it is hoped that these will be used more extensively for diagnostic purposes.

8.3 Soil acidity

The efficiency of any fertiliser programme depends on a satisfactory lime status. No method of fertiliser application is efficient if soil acidity has not been corrected beforehand. Despite intensive research, development and advisory efforts on liming over the past 20 years, soil acidity is still an important obstacle to efficient fertiliser use. It is particularly distressing from a soil management viewpoint, that the soils which are most acid, and lowest in native fertility, receive little or no lime.

8.4 Residual or carry-over effects

A problem of increasing importance for future fertiliser use and application methodology is to define the residual value of previous fertilising programmes. Most of the fertiliser research in Ireland until recently was concerned with raising fertility levels efficiently, and little, if any, attention was given to residual effects. Many intensive arable areas of the east and south are now accumulating nutrients. To date, very little is known of the value of these residues in the various soil associations. A nation-wide series of field experiments to estimate systematically residual values under different cropping systems will start during 1971.

8.5 Fertiliser-use anomalies - crops and regions

Reports on fertiliser-use surveys issued in 1966 and 1969 (16, 17) have highlighted some serious anomalies in fertiliser use and application methods. Some crops such as early potatoes and sugar beet are in general over-fertilised, whereas other crops, particularly hay and permanent pasture are inadequately fertilised. There are also considerable geographical anomalies with the percentage of hay fertilised varying from 28 to 93 and of pasture from 14 to 70, depending on region.

An overall national fertiliser policy demands that these anomalies be investigated and remedies taken.

8.6 Application methods

Distributing fertilisers in the field has been made much easier in the past 20 years by the granulation of most fertiliser compounds.

The quality and uniformity of granules are likely to be further improved. Basic slag, which posed distribution problems under windy conditions, has recently been produced in small granules, which are easy to spread and are said not to diminish the availability of phosphorus to plants conferred by fine grinding.

Fortune (60) has stated that the three main types of fertiliser distributor available in Ireland are :

(i) Full-width machines, e.g., plate and flicker or reciprocating plate types.

(ii) Oscillating spout.

(iii) Spinning disc.

The numerous technological and economic factors affecting the choice and use of these distributors, such as initial cost, spreading width, rate of working, ease of applying granulated, powder or lumpy material, east of maintenance and setting, evenness of spreading, and levels of operator skill required to operate satisfactorily, have been evaluated and published in the numerous machinery test reports issued by the various national testing stations such as Oakpark in Ireland and Silsoe in the United Kingdom.

Irregular delivery characteristics are inherent in many distributors and such machines perform badly, especially when operated by unskilled workers. Holmes (61), in a discussion on the agronomic requirements of fertiliser application, has suggested that variations of much more than ±10% should not be tolerated.

There can be significant yield and hence financial losses due to uneven spreading as recent work has shown (60, 61), Tables 21 (60) and 22 and 23 (61). The losses are particularly noteworthy at the very responsive portion of the response curve.

The theoretical aspects of uneven distribution have been

Table 21 : Values of coefficient of variation obtained with various broadcasters

Machine	Type	Width of spread (ft)	Coefficient of variation (%)		
			At optimum spreading width	At optimum + 3 ft	At optimum - 3 ft
Amazone 1	Twin disc	18	4.4	5.8	6.8
Amazone 2	"	19	5.0	11.4	15.6
Harder	"	18	7.0	11.5	8.8
Kromag	"	16	5.4	13.7	12.2
Lister	Single disc	15	10.2	18.5	5.0
Lely	"				
Bogballe	"				
Vicon	Spout	21	7.7	11.4	8.9

Fertiliser used : Granular compound (10:10:20)

Table 22 : Loss (£ per acre) due to uneven application of compound fertiliser on potatoes under very responsive conditions

Fertiliser rate (% of rate reqd for max yield)	Unevenness of application (coefficient of variation %)			
	10	15	25	50
100	1.49	3.29	9.27	37.36
90	1.18	2.66	7.54	30.16
80	1.00	2.15	6.01	23.89
50	0.33	0.89	2.34	9.23
25	0.06	0.19	0.58	2.33

dealt with by Holmes (61) and Dickins (62), in the United Kingdom. The yield losses result essentially from the curvilinear nature of the yield response to fertiliser. Taking a very simple case : if part of the area receives a higher than intended rate of application and another part a correspondingly lower rate, the extra rate (Y-X) in the first area will be less than the loss of yield (X-Z) in the second area. This means that the