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FUTURE DEVELOPMENTS

IN TECHNOLOGY AND MARKETING OF FERTILIZERS--1970-80

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Forecasting future developments in any field is subject to many uncertainties. If the forecaster lacks the gift of clairvoyance, he must rely on extrapolation of past trends, analysis of present plans, and assessment of future needs. All of these methods are uncertain; past trends seldom continue unaltered, present plans may prove unwise or inadequate, and future needs may be incorrectly assessed or inadequately provided for. The only certainty is that many changes will take place. It is appropriate that we do our best to foresee them so we can make plans accordingly.

Increased Use of Fertilizer

Fertilizer use has increased sharply in recent years. Figure 1 shows that the world consumption of $N + P_2O_5 + K_2O$ reached 59.5 million metric tons in 1969 and has approximately doubled in just 8 years, and tripled in 14 years. In other words, more fertilizer tonnage has been added in the last 8 years than in all previous history, a trend that obviously cannot continue indefinitely. Nitrogen use has increased more rapidly than that of the other elements; it has doubled in the last 6 years and quadrupled in the last 14.

(Figure 1)

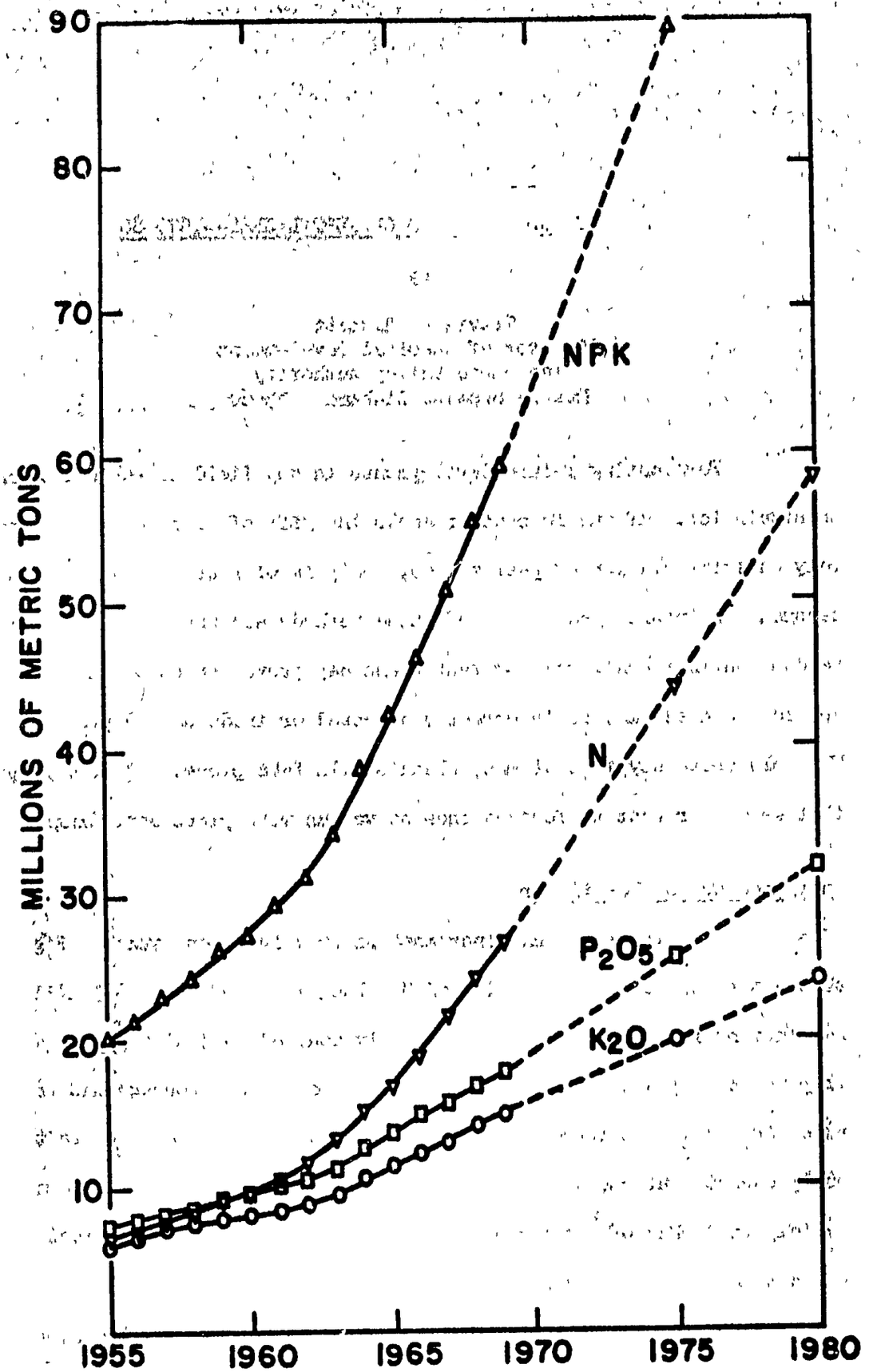

FIGURE I
WORLD COMSUMPTION OF FERTILIZER

Projections of present trends at declining percentage growth rates indicate that, by 1980, total consumption of the three major nutrients will reach 115 million tons, which is close to the requirement estimated in 1966 based on world food needs (1).

The largest tonnage increases have been in the developed regions of Europe and North America, but the percentage increases have been greatest in the less developed regions of Asia, Africa, and Latin America.

The principal reason for the increased use of fertilizer is the need for more and better food for the world's growing population. It is possible to maintain a low to medium level of crop production with little or no fertilizer by utilizing the native fertility of the soil, returning crop residues and wastes, and utilizing the small amount of nitrogen brought down with rainfall or fixed by legumes. But this level of crop production is no longer adequate to feed the growing population of the world.

A second reason is economics; in contrast to the rising cost of labor and machinery, fertilizer costs have declined. Even in countries that have a surplus of food crops, a farmer cannot afford to neglect a substantial fertilizer application. In the past, many farmers have relied on growing legumes in a crop rotation to supply nitrogen, a sound practice when chemical nitrogen fertilizers were expensive and labor was cheap. Now the practice has become uneconomical in many areas.

In addition to the need for more food, there is a need for a more balanced diet in many countries. The principal means for improving diets is inclusion of more animal protein. And as people become more affluent, they demand more protein-rich animal foods. Production of animal protein requires several times as much crop production per food calorie as direct use of cereals, so improvement of diets puts an additional stress on farm production.

It seems certain that the greatest increases in fertilizer use will take place in countries where fertilizer use is now low, where food needs are great, and where population growth is rapid. In some countries such as Japan, Belgium, and The Netherlands (to name a few), fertilizer use probably is now fully adequate for present cropping systems. However, scientists continue to devise means for increasing crop yields through improved varieties, higher plant population, and many other devices. Each of these practices increases fertilizer requirements. To mention an extreme example, yields in glasshouses are substantially higher per acre than for field crops. While the increased yield is properly attributed to control of the crop's environment, it is common practice to apply more than a ton per acre of fertilizer nutrients ($N + P_2O_5 + K_2O$), a level five to ten times higher than for field crops (2).

Another example is the use of hybrid or improved varieties of seed. Some writers have implied that increased crop production which can be attained by better seed will lessen the need for fertilizer. I think the opposite is more likely; farmers who buy expensive seed are more likely to fertilize adequately, and the improved varities are more likely to respond to increased level of fertilization. In my opinion, it is meaningless to try to estimate how much of an increased crop yield is due to improved seed and how much to fertilizer. Any practice that increases yields removes more mineral nutrients from the soil and hence increases fertilizer needs.

Concentration

One important trend in fertilizer technology is increase in concentration of N, P_2O_5, and K_2O. Figure 2 shows this trend for four countries where the concentration of compound fertilizers has increased at rates ranging from 0.67 to 1.43% per year during the last decade. The United Kingdom has attained the highest average concentration, 40.4%, while Japan shows the greatest rate of increase. The reason for this trend lies in economics; bagging, storage, handling, and transportation often account for more than half of the cost of fertilizer delivered to the farmer. So increasing the concentration can markedly decrease the cost per unit of nutrient content at the farm.

(Figure 2)

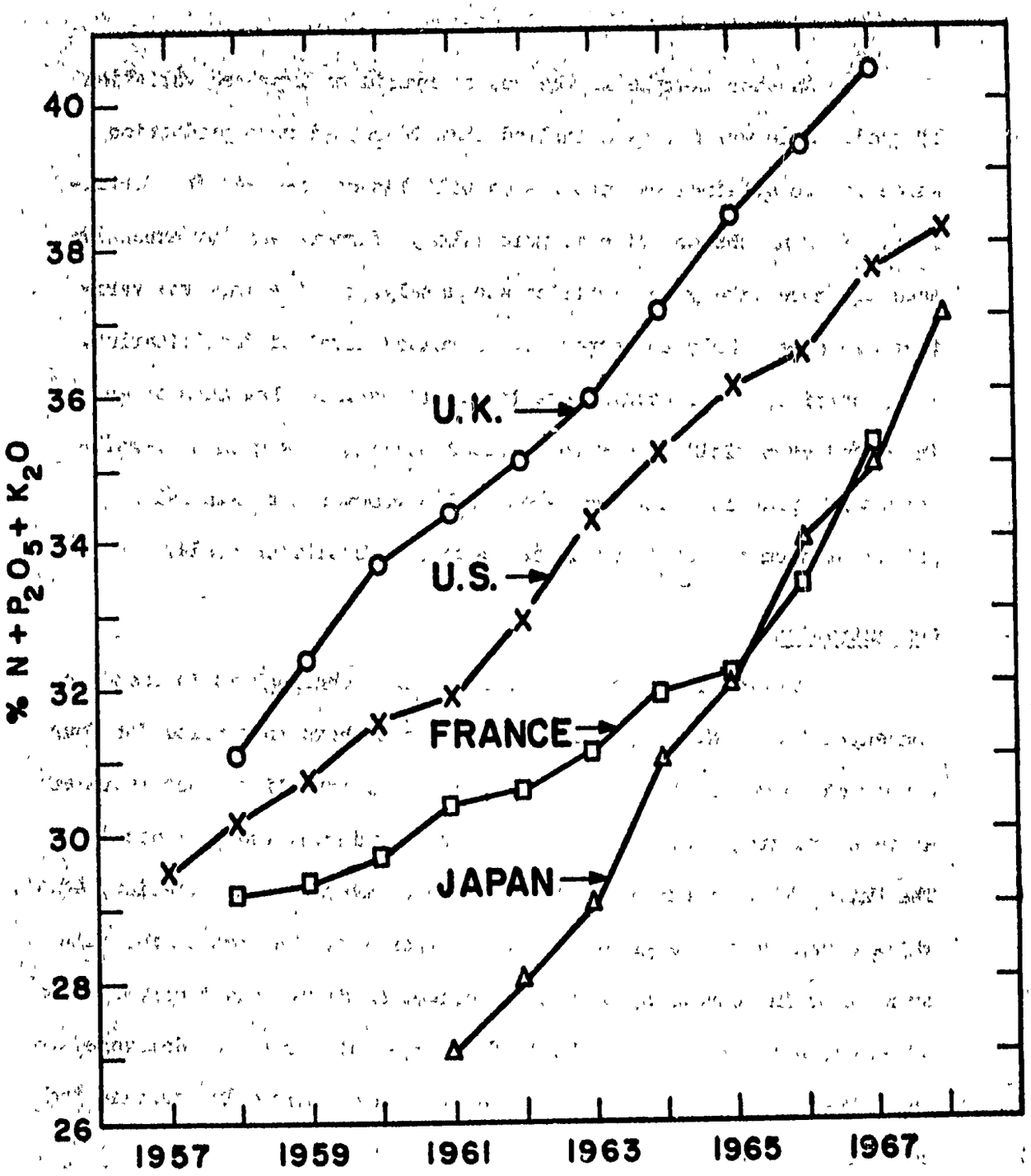

FIGURE 2
TRENDS IN CONCENTRATION OF COMPOUND FERTILIZERS

Increased concentration is attained by using higher analysis materials--ammonium nitrate, urea, nitrogen solutions, or anhydrous ammonia instead of sodium or calcium nitrate or ammonium sulfate; triple superphosphate or ammonium phosphate instead of single superphosphate.

In many countries, single superphosphate was the principal phosphatic material for compound fertilizer. As fertilizer demands grew, the higher analysis phosphates were used as a supplemental source to upgrade compound fertilizers. Thus, it would be more accurate to say that the higher analysis phosphates have supplemented superphosphate rather than replacing it. In the world as a whole, superphosphate production has not declined, but it supplies a declining percentage of the P_2O_5 content of fertilizers because of the rapidly increasing use of more concentrated phosphates.

Superphosphate contains two elements other than phosphorus that are essential to plant growth, sulfur and calcium. Many soils are deficient in sulfur. However, adequate supplies of sulfur are brought down by rainfall in many industrial areas where large amounts of coal or other sulfur-containing fuels are burned. In some areas the need for supplying sulfur is well established. In such cases it is well to consider whether superphosphate is the most economic source. One alternative is elemental sulfur which may be incorporated in granular fertilizers by spraying molten sulfur into the granulator. Ammonium bisulfite or ammonium thiosulfate may be used to supply sulfur in liquid fertilizers.

In our enthusiasm for producing ever higher analysis fertilizers, we should not ignore the possibility that some of the elements which we are leaving out may have to be put back in. Careful agronomic tests should be made to determine whether sulfur is needed in each agricultural area.

In the next decade the concentration of fertilizers will continue to increase and may reach an average of 50% in some countries. Planned new facilities indicate that urea and diammonium phosphate will be favorite materials. With these materials and high-grade potassium chloride, compound fertilizers containing nearly 60% N + P_2O_5 + K_2O are possible. However, a growing realization of the frequent importance of including secondary and micronutrient elements in fertilizers may slow the growth in concentration of the primary elements.

Trend Toward Compound Fertilizers

Another trend we see is toward greater use of compound fertilizers. Compound fertilizers have always been popular in the United States, but in many European countries and Japan, straight fertilizers have been more popular. During the period of 1958 to 1968, compound fertilizers in Western Europe increased from 35 to 52% of all fertilizers. In Japan the increase was from 27% in 1961 to 42% in 1968. In the United Kingdom, 97% of the P_2O_5 (other than basic slag), 92% of the K_2O, and 63% of the N are supplied in compound fertilizers. Comparable figures are not available for the United States partly because some of

the materials sold as straight fertilizers are actually compounds or are subsequently mixed by blenders to form compounds. A rough estimate indicates that in 1963, 35% of the N, 87% of the P_2O_5, and 86% of the K_2O were supplied to the farmer in compound fertilizers.

The reason for this trend is that farmers no longer have the time or inclination to apply several fertilizers separately nor do they have the equipment to mix them. Supplemental dressings of nitrogen are often applied separately for reasons of efficiency or economy, but the basic application is preferred in the form of compound or mixed fertilizer.

Larger Factories

Another trend we see is the concentration of manufacturing operations in large factories. Plants geared to turn out 1000 or more tons per day of ammonia, urea, ammonium nitrate, phosphoric acid, ammonium phosphate, triple superphosphate, or potassium chloride are becoming commonplace. Some European plants now produce as much as 2 million tons of fertilizers per year. The reason for this trend lies in economics; as the scale of the operation is increased, the cost per unit decreases.

No doubt the average size of plants that produce basic fertilizer materials will continue to increase during the next decade. It is doubtful whether there will be much advantage in increasing plant size beyond that of some of the largest ones that have been built recently because of the cost of transporting the products over a wide area.

On the other hand, there is a need for smaller plants, not to manufacture basic materials, but to combine them into compounds that will satisfy local needs, as will be discussed later.

Complexity of Formulation

A rather wide range of $N:P_2O_5:K_2O$ ratios is needed for various crops and soils. Moreover, it is known that ten other elements are equally necessary to plant growth--the secondary elements, calcium, magnesium, and sulfur; and the micronutrients, manganese, iron, boron, copper, zinc, molybdenum, and chlorine. The time is approaching and has already arrived in many areas when the industry can no longer limit its concern to the primary nutrients. The farmer has a right to expect that agronomists will prescribe and technologists will supply compound fertilizers containing the elements needed in the correct proportion for economical crop production on his farm. Already in the United States a great many compound fertilizers contain one or more of the "other ten" elements; in 1967, over 100,000 tons of micronutrient materials were used in fertilizers plus unknown amounts of materials supplying secondary elements.

The trend toward more complex formulations is likely to continue because (1) more adequate fertilization with primary nutrients often results in one of the other ten elements becoming a limiting factor; (2) increased crop yields more rapidly exhaust soil supplies of

these elements, (3) improved diagnostic techniques and accelerated research will result in identification of more cases of needs, and (4) increasing concentration of the three primary plant nutrients in fertilizers has been attained at the expense of eliminating some of the other ten.

A Dilemma

Ten years ago in a lecture to The Fertiliser Society in London, Howard Cunningham (3) commented on the growing complexity of farmers' needs. He said:

> N, P and K must always be the main preoccupation of The Fertiliser Society but their very success in producing bigger yields of crops and stock is taxing the supply of other elements and leading to problems for farmers. Fertiliser manufacturers should apply to the solution of these problems as much skill and determination as they have applied with such success to the three major ingredients.

At the same time he was aware that the size and complexity of a granulation plant imposed serious limitations on flexibility in formulation, for he said:

> It is not easy to reconcile low cost production and special mixtures for a customer, a crop or even a district.

A New System

In the United States a system is evolving which takes full advantage of the economies of large-scale manufacture and still permits flexibility in formulation. The system is characterized by (1) production of fertilizer intermediates in large plants located

where raw materials costs are low, (2) transportation of the intermediates in concentrated form to the various market areas, and (3) production of the final mixture in small local plants that combine the functions of manufacturing and retailing. These small plants serve an area 10 to 20 miles in radius. They offer prescription mixing, custom application, soil sampling and analysis, and various other services.

Two types of mixed fertilizers are available from this system--liquid mixes and solid bulk blends. Both types can be made economically in small local plants, and both are capturing an increasing share of the market. Together, they now represent about 40% of all mixed fertilizer in the United States.

No one is quite sure which of several advantages of bulk blends and liquids is responsible for their popularity. However, prescription mixing is one of the advantages, and the solution for Cunningham's problem of providing "special mixtures for a customer, a crop or even a district" without special cost has been achieved, at least in principle, although there are still some problems in practice.

A system involving shipment of intermediates to numerous local plants requires dependable transportation. Much of the success of the system in the United States is due to advances in transportation methods. Granular fertilizer materials are shipped in bulk by rail in covered, hopper-bottom cars. Tank cars are available for shipment of liquid materials. For shipment of superphosphoric acid,

insulated stainless steel-lined tank cars are preferred. Shipment by barge is attractive between points located on waterways. Pipeline transportation of ammonia has started, and perhaps other fertilizer materials will be transported by pipeline in the future.

A small granulation plant based mainly or entirely on shipped-in intermediates is another solution to the problem of maintaining flexibility of formulation. Although granulation plants do not have as much flexibility as bulk blend or liquid mix plants, a small local plant can produce formulations that are needed by farmers in the area for their crops and soils.

A typical small granulation plant may use superphosphate produced at the site. It may also use a higher analysis phosphatic intermediate--triple superphosphate, ammonium phosphate, or phosphoric acid. Nitrogen may be supplied by ammonia, ammoniating solutions, urea, or some combination of these materials. Potash is supplied as the chloride or sulfate.

Most small granulation plants attempt to operate with a formulation such that drying is accomplished mainly by the heat generated in chemical reactions. Several small plants have operated successfully without any dryer at all.

Superphosphoric acid has been used in small batch granulation plants (4), and more recently in a small, continuous granulation plant without a dryer (5), to promote granulation at low moisture

contents. Grades were 12-18-18-3MgO and 15-15-15-4MgO. Formulations containing about 200 pounds of superphosphoric acid and 70 to 100 pounds of sulfuric acid per ton of product gave good results. The acids were neutralized with ammonia - ammonium nitrate solutions. The granular products were hard and dry (less than 1.0% moisture) and had good storage properties. The formulations used are shown in Table I.

(Table I)

Another approach to a simplified granulation system is to use a powdered monoammonium phosphate (MAP) with special properties that are well suited to granulation. Three processes are available for producing this material (6, 7, 8). The MAP may be used to supplement and upgrade superphosphate or to replace it. Granulation may be promoted through the use of steam, ammonia or ammoniating solution, or a combination of these practices. A typical grade of the powdered MAP is 10-50-0; it may be produced at low cost and shipped in bulk to granulation plants (9). In most cases it may be preferable to manufacture MAP at the plant where phosphoric acid is produced rather than to deal with the problems of shipping the acid.

Liquid Fertilizers

A logical solution to the problems of granulation is found in liquid fertilizers. The purpose of granulation is to provide free-flowing, noncaking, homogeneous fertilizers that are well adapted to

TABLE I

Formulations Containing Superphosphoric Acid

for Granulation Without Drying

Material	Pounds per short ton	
	15-15-15-4MgO	12-18-18-3MgO
Ammoniating solution[a] (45% N)	344	374
Ammonium sulfate (21% N)	302	250
Ammonium nitrate (34% N)	150	-
Sulfuric acid (66° Be.)	100	70
Diammonium phosphate (18-46-0)	200	150
Superphosphoric acid (70.5% P_2O_5)	200	196
Triple superphosphate (46% P_2O_5)	145	330
Muriate of potash (60% K_2O)	505	600
Magnesium oxide (85% MgO)	94	70

[a] Composition, 25% NH_3 and 69% NH_4NO_3.

mechanical handling and application--an end result fully met by liquid fertilizers at less cost. Complicated plants are not required, and we need not go to a large scale to attain economical operation. Within reasonable limits, special mixes can be made without special cost.

A special advantage of liquid fertilizers is that they are unaffected by hygroscopicity problems that render storage and handling of solid fertilizers difficult.

From the viewpoint of the farmer, liquid fertilizers offer the advantage of convenience and trouble-free mechanical handling and application. Liquid mixed fertilizers are available from local mixers who offer prescription mixing. Liquid fertilizers may be applied in irrigation water. They are adaptable to foliar application.

A disadvantage of liquid mixed fertilizers is the comparatively low analysis, particularly those grades that contain a high proportion of potash. The disadvantage is minimized by shipping highly concentrated intermediates to local mixing plants; the final product is seldom shipped very far.

From the viewpoint of manufacture, a primary advantage is the simplicity and low cost of the equipment for production, storage, handling, and transportation. Economical manufacture does not require large plants. Dust and fume problems are practically nonexistent. Losses are very small. Control of composition is simple. Problems of hygroscopicity, dustiness, and caking are absent. Storage, loading,

and handling are not expensive because pumps and piping are cheaper than conveyors, elevators, power shovels, and cranes, both in capital cost and in operating cost.

The rising popularity of liquid mixed fertilizers in the United States is shown by the growth in number of plants (see Fig. 3). In 1955, only 147 plants produced liquid mixed fertilizer; in 1968 there were 1724. Most of the plants are quite small; the average annual output of each plant is less than 2000 tons. Like bulk blenders, the typical manufacturer of liquid mixed fertilizer combines the roles of mixer and retail merchant. Most of the liquid mixers also market straight nitrogen liquids--anhydrous ammonia, aqua ammonia, and nitrogen solutions. Consumption of straight nitrogen liquids and liquid mixes has increased rapidly in the United States since 1965, as shown in the following tabulation.

	Consumption of liquid fertilizers in U. S., millions of tons			
	1965	1966	1967	1968
Anhydrous ammonia	1.5	2.0	2.4	3.1
Aqua ammonia	0.7	0.9	0.8	0.8
Nitrogen solutions	1.9	2.3	2.5	2.7
Liquid mixed fertilizers	1.0	1.6	2.0	2.5
Total liquid fertilizers	5.1	6.8	7.7	9.1

(Figure 3)

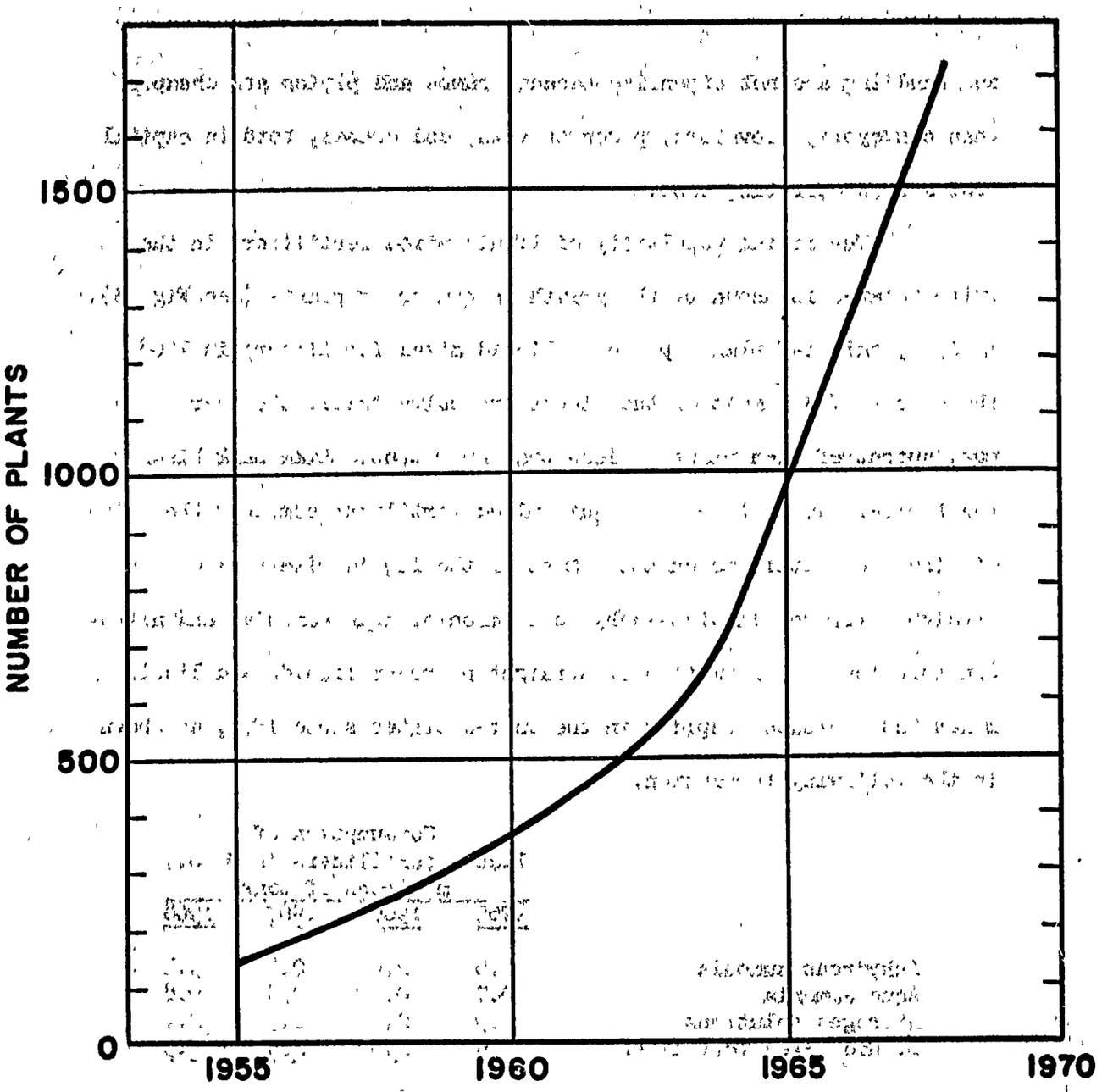

FIGURE 3
GROWTH OF LIQUID MIXED FERTILIZER IN THE UNITED STATES

The figures shown for consumption of liquid mixed fertilizer are very rough estimates; good statistics are lacking. The estimated 2.5 million tons of liquid mix in 1968 is about 12% of all mixed fertilizer; the total liquid fertilizer consumption of 9.1 million tons is about 23% of the total fertilizer consumption.

In some states, liquid fertilizer plants are so numerous that, if evenly spaced, no farm would be more than 10 miles from a source of supply.

Use of liquid fertilizers is increasing rapidly in several European countries, particularly in France.

Generally speaking, liquid fertilizers are less expensive than granular solid fertilizers. Most solid fertilizers are manufactured by processes that go through a liquid step, and much of the expense of the solid material is related to conversion of the liquid to an acceptable solid form.

The usual nitrogen materials for liquid mixed fertilizer are urea - ammonium nitrate (UAN) solutions (28 to 32% N) and solid urea. UAN solutions are preferred because they are cheaper, more convenient, and give high solubility in grades containing little or no potash. Solid urea gives higher solubility in most N-P-K grades.

Ammonium polyphosphate solution is the most popular phosphatic material. Solid ammonium polyphosphate also may be used. The ammonium polyphosphate materials are prepared by reaction of superphosphoric acid

with ammonia. The superphosphoric acid may be made from elemental phosphorus (thermal process) or by concentrating wet-process phosphoric acid. At present, most of the liquid products are made from wet-process superphosphoric acid. The usual solution grade is 10-34-0 or 11-37-0. At present, only the Tennessee Valley Authority (TVA) produces the solid material. Its grade is 15-62-0 (made from thermal acid). "Soluble" refined potassium chloride (62 to 63% K_2O) is the usual potash source.

Suspension Fertilizers

A disadvantage of clear liquids is the low analysis of grades that contain a substantial proportion of K_2O. For instance, the average analysis of liquid mixed fertilizer (including a small proportion of suspensions) in the United States in 1967 was 7.5-16.2-6.1 as compared with 8.6-16.6-12.7 for all mixed fertilizer. This disadvantage is minimized by the marketing system; the final mix is seldom transported far. Nevertheless, the relatively low analysis often has a significant effect on the cost of transportation and application.

Suspension fertilizers are a means for overcoming the disadvantage of low analysis. They are liquids containing solids--usually soluble salts in their saturated solution. The mixtures are treated to minimize settling by inclusion of 1 to 3% of a gelling-type clay in their formulation.

With suspensions, the analysis can be on a level comparable with granular solid or bulk blended fertilizers. Popular grades of suspension fertilizers are 7-21-21, 3-10-30, 10-20-20, and 15-15-15--about twice the nutrient content obtainable in clear liquids with these ratios.

Another advantage of suspensions is greater flexibility in formulation; the materials need not all be soluble. This is a particular advantage when secondary elements or certain micronutrients must be supplied; magnesium and manganese compounds, for example, are only slightly soluble in liquid mixed fertilizer.

Some of the advantages of liquids may be lost in going to suspensions. Handling and application of suspensions, in their present state of development, are not as simple, convenient, and trouble-free as for clear liquids. From the farmer's viewpoint, the main advantage of liquids is convenience of handling and application, and this convenience is not as well developed for suspensions. In the immediate future, therefore, most farmers probably will continue to prefer clear liquids over suspensions.

Ammonium Polyphosphate

The term "ammonium polyphosphate" is used in fertilizer parlance to denote materials containing condensed phosphates. As discussed previously, solutions or solids produced by ammoniation of

superphosphoric acid are favorite intermediates for compounding liquid fertilizers. Typical compositions of the three most popular polyphosphate materials are given below.

	Phosphate species in ammonium polyphosphate, % of total P_2O_5		
	10-34-0 solution	11-37-0 solution	15-62-0 solid
Ortho	49	20	41
Pyro	42	37	54
Tripoly	8	23	4
Tetrapoly and higher	1	16	1

Ammonium polyphosphates may also be made directly from orthophosphoric acid by a process that utilizes the heat of reaction of the acid with ammonia to dehydrate the ammonium phosphate. This process is in an advanced stage of pilot-plant study.

Chemically, ammonium polyphosphates are the ammonium salts of polyphosphoric acids. The general formula for polyphosphoric acid is $H_{n+2}P_nO_{3n+1}$. The specific ammonium polyphosphates most abundant in liquid fertilizers are triammonium and tetraammonium pyrophosphate, $(NH_4)_3HP_2O_7$ and $(NH_4)_4P_2O_7$, and pentaammonium tripolyphosphate, $(NH_4)_5P_3O_{10}$.

The chemical and agronomic properties of ammonium polyphosphates are complex and fascinating. Terman and Engelstad (10) summarizing studies in the United States concluded that ammonium polyphosphate usually was equal or slightly superior to monoammonium phosphate. Both were usually superior to concentrated superphosphate

for early growth response. Fourcassie and Gadet (11) concluded from experiments in France that ammonium polyphosphate supplied as liquid fertilizer was consistently superior to other phosphorus sources as the result of better phosphorus utilization. Field tests at six locations in Japan indicated that response to ammonium polyphosphate was generally greater than to ammonium orthophosphate, although early growth was sometimes slightly delayed. There was some suggestion that better utilization of native or applied micronutrients may have been a factor in the favorable results with polyphosphates. Experiments in the United States have not shown a uniform superiority of polyphosphates, although the results have occasionally favored polyphosphates.

Since crops cannot utilize polyphosphates as such efficiently, it is clear that any superiority of polyphosphate as a fertilizer must be related to changes that take place in the soil and possibly to the phosphorus distribution patterns around granule sites (or liquid band placement sites) which are different from patterns around orthophosphate application sites.

Ammonium polyphosphates hydrolyze in soils at rates that depend on the temperature, the microbiological activity, and other factors. For instance, in a series of tests using a simulated band placement of solid ammonium polyphosphates in moist soil, an average of about 43% of the polyphosphate hydrolyzed to orthophosphate in

1 week at room temperature (about 25° C.). After the first week the rate was slower; only 55% was hydrolyzed after 5 weeks.

Reaction products of polyphosphates with soils and soil minerals are quite different from those formed with orthophosphates and generally require longer periods of time to precipitate. There is some indication that in a concentrated solution such as may form in the soil in the vicinity of an ammonium polyphosphate granule the orthophosphate content of the solution does not form the insoluble precipitates that would be formed in the absence of polyphosphates. Also, some tests indicate that ammonium polyphosphate solutions are capable of extracting substantial proportions of micronutrients from the soil. The selective retention of polyphosphates by soil colloids, and the ability of the polyphosphate to form soluble metal complexes, may be responsible for these two effects.

It is evident that there is much to be learned about the behavior of polyphosphates in the soil, and continued research seems justified. Hopefully, we may identify some combinations of conditions of use and product characteristics that will result in substantially better fertilizer efficiency than is usually obtained with conventional materials.

Urea - Ammonium Phosphates

Compound fertilizers containing urea and ammonium phosphate (or polyphosphate) are particularly interesting because of the very high analysis attainable. Also, as compared with ammonium nitrate-containing materials, the urea compounds are free from fire or explosion hazards and may be agronomically superior for some uses.

Urea - ammonium phosphates may be produced by cogranulation of ammonium phosphate slurry with urea solution or solid urea. Pilot-plant studies have been reported (12) of a process which is basically the TVA diammonium phosphate process except for addition of urea in the ammoniator-granulator. The products contained urea and ammonium phosphate, mainly in the diammonium form. The granular products remained in good condition in long-term bagged storage when dried to about 1% moisture and conditioned with diatomaceous earth.

In other pilot-plant tests, ammonium phosphate slurry and concentrated urea solution were cogranulated in a pan granulator (13). The pan granulator was considered preferable for compounds of high urea content such as 34-17-0 and was also suitable for granulation of straight urea. No ammoniation was carried out in the pan granulator since it is not well adapted to ammoniation; the products contained monoammonium and diammonium phosphate in about 70:30 ratio.

In the processes described above, some problems were encountered in drying urea - ammonium phosphate products. It was desirable to dry the products to a low moisture content ([illegible] %) to ensure good storage properties. The temperature of the material leaving the dryer was limited to about 95° C. to avoid decomposition of the urea by hydrolysis. It was found necessary to limit the temperature of the air entering the rotary dryer to a range of 150° to 175° C. for countercurrent flow, or about 200° C. for cocurrent flow, to prevent the material from melting and sticking to the shell and flights of the dryer. Because of these limitations, the drying rate was slow, and a long retention time would be required to reduce the moisture content below 1%.

To avoid the drying problem, processes were devised in which the ammonium phosphate was supplied as a nearly anhydrous melt, and the urea was supplied either as a solid or a highly concentrated solution containing 1% water or less. The two materials were cogranulated in a pug mill (14, 15). The ammonium phosphate melts contained monoammonium orthophosphate and ammonium polyphosphate (mainly triammonium pyrophosphate). Good granulation was obtained when the ammonium phosphate melt contained about 15 to 60% of its P_2O_5 content in the polyphosphate form. The granular products had satisfactory storage properties without drying. Typical grades made when using wet-process phosphoric acid were 28-28-0, 34-17-0, and 19-19-19.

In further experiments, ammonium polyposphate melt and urea solution (1% H_2O or less) were mixed and prilled in an oil bath (15, 16). The oil prilling process is adaptable to a rather wide range of polyphosphate and is also suitable for straight urea. As compared with air prilling, oil prilling has the advantages that larger size prills can be made and compositions can be used that crystallize too slowly for air prilling. Some typical grades of oil-prilled urea - ammonium polyphosphates are 39-13-0, 38-16-0, and 30-30-0. These grades were made using ammonium polyphosphate melts derived from electric-furnace superphosphoric acid. Initial tests using wet-process acid were not encouraging. The feasibility of adding other materials (such as potash) in the oil prilling process has not been thoroughly investigated.

Controlled-Release Fertilizers

Fertilizers that release plant nutrients slowly throughout the growing season or even several growing seasons continue to attract attention of technologists and agronomists. Potential advantages claimed for controlled-release fertilizers are increased efficiency of uptake by plants; minimization of losses by leaching, fixation, or decomposition; reduction in application costs through reduction in number of applications; elimination of luxury consumption; and prevention of burning of vegetation or damage to seedlings. This is an impressive list of potential advantages.

Experiments with controlled-release phosphorus and potassium materials have not been promising, and there is reason to believe that little advantage can be expected from supplying these elements in a slowly available form. However, promising results have been obtained with some controlled-release nitrogen materials.

The only commercially available materials (other than natural organics) are the urea-aldehyde compounds: crotonylidene-diurea in Germany, urea-formaldehyde reaction products (ureaform) in the United States, and isobutylidene-diurea in Japan. These materials have found a place in specialized uses--home gardens, golf courses, and the like. They are too expensive for general farm use.

Several processes for producing coated granules of nitrogen (or compound) fertilizers have been announced. Controlled or delayed release is obtained by coating granules of soluble fertilizer with a plastic film (17), with sulfur plus additives (18), or with an asphalt-wax mixture (19).

In a process developed by TVA on a small pilot-plant scale, urea granules are sprayed with molten sulfur in a rotating drum to form a coating that typically ranges from 10 to 25% by weight. Then the granules receive a 3% coating of wax to seal microscopic pores or cracks in the sulfur coating. A small amount of a microbicide (such as coal tar) is incorporated in the wax to prevent soil microbe attack on the wax. Finally, about 1.5% of a conditioner (such as kieselguhr)

is added to give good handling properties. Exacting control of the conditions during application of each coating is necessary for good results. It has been possible to produce coated products that release 1% or less of their nitrogen per day when immersed in water or moist soil with total coating weights of as little as 20%.

Results from some tests show greater yields of fescue grass from application of sulfur-coated urea than from single applications of uncoated urea or ammonium nitrate (20). The best results were obtained with mixtures of coated urea and uncoated ammonium nitrate.

Further tests of the coated urea are in progress in several locations in the United States and in several other countries including India. Promising results have been obtained in several of these tests.

The cost of producing sulfur-coated urea on a commercial scale has been estimated at 25 to 50% higher per unit of nitrogen than uncoated product (21). Some farm uses may justify the differential. For example, a single application of coated material might be cheaper than two or three split applications of uncoated fertilizers. Many of the popular farm crops do not benefit from controlled-release nitrogen, however, and much work will be required to determine what place coated materials may find in the farm economy.

Elemental Phosphorus

The production of elemental phosphorus and its use as an intermediate for fertilizer purposes has so many advantages that it is likely to find a substantial place in the fertilizer technology of the more or less distant future. Some of the advantages are:

The electric-furnace process can utilize efficiently many types of low-grade rock without beneficiation.

Elemental phosphorus is a highly concentrated intermediate equivalent to 229% P_2O_5. This property can lead to important savings in transportation, storage, and handling if an appropriate production, distribution, and marketing system is employed.

Elemental phosphorus is a versatile material which is capable of producing excellent-quality, high-analysis fertilizers and also food and animal-feed phosphates and industrial phosphates. New phosphate fertilizer products can be made through the use of elemental phosphorus that cannot be made from wet-process phosphoric acid, very possibly including some ultrahigh-analysis products that have not yet been conceived.

The electric-furnace process does not require sulfur. It does require a low-cost source of electricity which may, in the future, be more widely available, more abundant, and more dependable than sulfur.

Like other chemical and metallurgical processes, the economics of elemental phosphorus production is highly dependent on the scale of operation and on engineering advances. Most present-day electric-furnace plants are geared to the needs of the chemical phosphate markets and cannot produce phosphorus at a low enough cost to compete in the fertilizer market with wet-process phosphoric acid.

The state of development of elemental phosphorus technology may be compared with ammonia technology 20 to 25 years ago. It would not be surprising if future advances would bring about as dramatic an impact on costs as we have experienced in ammonia production. Does this mean that we must wait 20 to 25 years before elemental phosphorus becomes economically competitive for fertilizer production? Perhaps not; the problem is being attacked by people with vision and competence, and some interesting ideas are on the drawing board.

Conclusions

Advances in fertilizer technology, together with changes in marketing and distribution patterns, are bringing about a dramatic improvement in the kind and cost of fertilizers available to the farmer.

Production of fertilizer intermediates in very large plants at well-chosen locations has brought about substantial economies. Decentralized use of these intermediates in local or regional plants has brought to the farmer a wide range of compound fertilizers--granular,

blended, and liquid--which can be tailored more precisely to his needs. The future will see a continued increase in the concentration of fertilizers, more emphasis on prescription mixing, more attention to secondary and micronutrients, and probably more combinations of fertilizers with herbicides, pesticides, and growth regulators.

The greatest benefit from advances in fertilizer technology will come through an integrated effort involving marketing and distribution systems, transportation and handling systems, improved methods for generating and disseminating agronomic information, as well as all other sectors of the agroindustrial complex.

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