AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture — AF25-0000-0000

B. SECONDARY: Soil fertility,fertilizers,and plant nutrition

2. TITLE AND SUBTITLE

Recent developments in fertilizer production technology and economics,with special reference to ammonia and compound fertilizers

3. AUTHOR(S)

Hignett,T.P.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1974	73p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

(Presented at Sem.on Future Patterns of Fertilizer Demand and Supply in Asian Countries,Taipei)

9. ABSTRACT

10. CONTROL NUMBER

PN- RAA-233

11. PRICE OF DOCUMENT

12. DESCRIPTORS

Ammonia
Complex fertilizers
Product development

13. PROJECT NUMBER

14. CONTRACT NUMBER

RSSA TV 02-74 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

7

TVA 275-16

RECENT DEVELOPMENTS IN FERTILIZER PRODUCTION TECHNOLOGY AND ECONOMICS WITH SPECIAL REFERENCE TO AMMONIA AND COMPOUND FERTILIZERS

By

Travis P. Hignett
Fertilizer Consultant
Tennessee Valley Authority
Muscle Shoals, Alabama 35660, USA

Paper Presented at Seminar on Future Patterns of Fertilizer
Demand and Supply in Asian Countries
Taipei, Republic of China
May 28-June 5, 1974

RECENT DEVELOPMENTS IN FERTILIZER PRODUCTION TECHNOLOGY AND ECONOMICS, WITH SPECIAL REFERENCE TO AMMONIA AND COMPOUND FERTILIZERS

By

Travis P. Hignett
Fertilizer Consultant
Tennessee Valley Authority
Muscle Shoals, Alabama 35660, USA

The purpose of this paper is to examine current trends in fertilizer manufacturing, to analyze the reasons for these trends, and to project them into the future.

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 77 million tons* in 1973 and has approximately doubled in just 8 years, and tripled in 14 years. In other words, more chemical fertilizer production 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 quadrupled in the last 14 years (1959-1973). 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.

TVA's latest projection (1) of fertilizer consumption (Fig. 1) indicates that total consumption of the three major nutrients will reach 87 million tons in 1975 and 114 million tons in 1980.

*Unless otherwise stated all tons are metric tons in this paper.

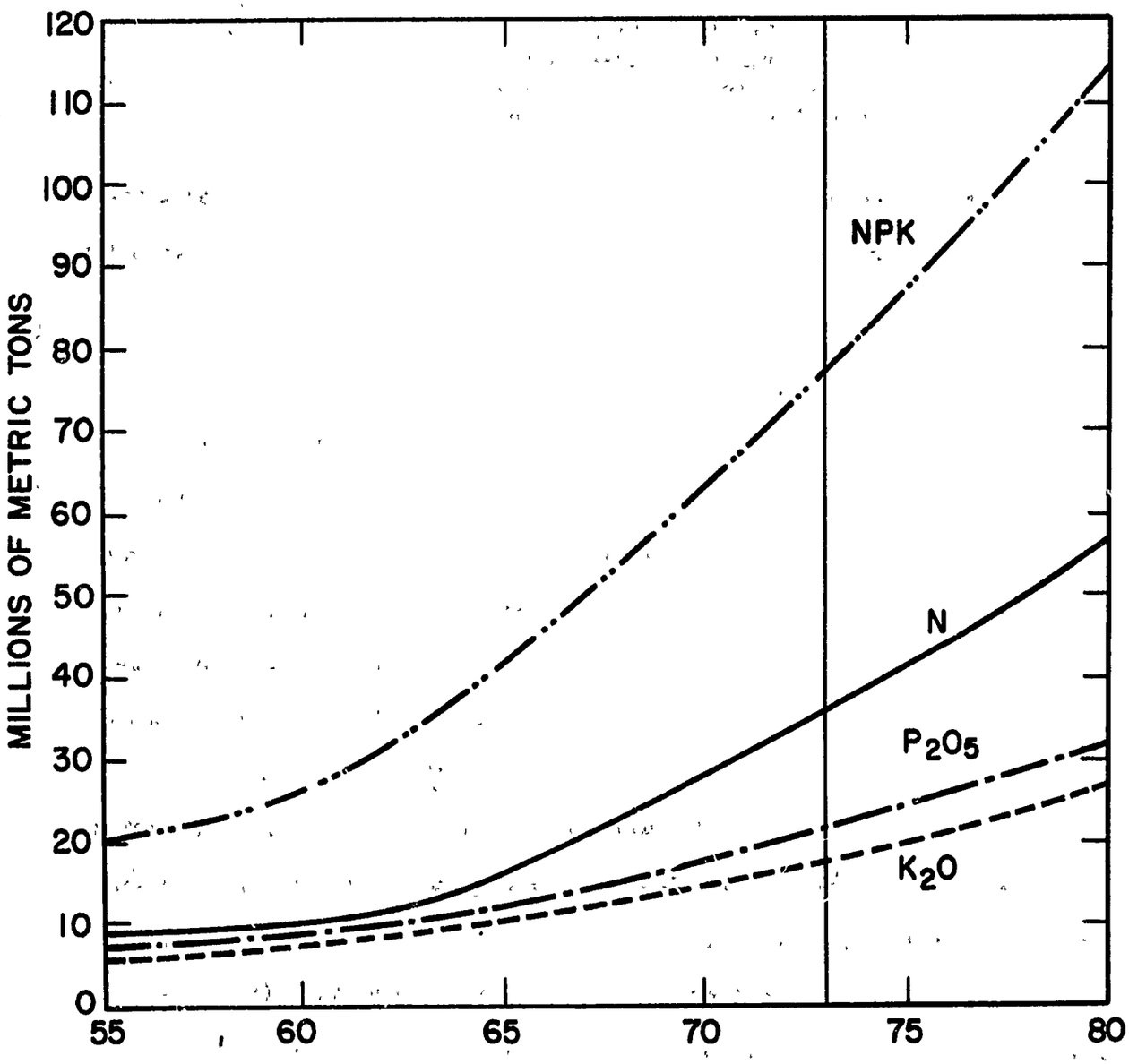


Figure 1. WORLD CONSUMPTION OF FERTILIZERS

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; even in countries that have a surplus of food crops, a farmer can seldom 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 land was plentiful and labor was cheap. Now the practice has become uneconomical in many areas.

TVA's latest projection of fertilizer consumption is based on estimated effective demand, not on food requirements. A higher growth rate would be desirable, particularly in the developing countries of Asia, Africa, and Latin America. Numerous problems have slowed the growth rate in these areas. Production facilities have operated at only about 60% of capacity, leading to high production costs. Marketing and transportation of increased quantities of fertilizer have been difficult. High fertilizer costs and low prices for farm products have provided little incentive for farmers to increase fertilizer use rapidly in some countries. If TVA's forecast of fertilizer consumption is correct, food production in developing areas may fall short of the needs of the rising population. Per capita food production, which is already inadequate, may decline. While these statements apply to developing continents as a whole, there is a wide variety of situations in individual countries; some of them have made substantial progress toward improved quantity and quality of food supplies.

Concentration

An important trend in fertilizer technology is increase in the concentration of N, P_2O_5, and K_2O. Figure 2 shows this trend for three countries where the concentration of compound fertilizers has increased at rates ranging from 0.7 to 1.0% per year during the last decade. Of the three countries, the United Kingdom has attained the highest average concentration, nearly 43%. 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.

Precise data are lacking for many countries, but the trend toward high concentration is evident in the increased emphasis on higher analysis materials. For instance, in South Korea, diammonium phosphate is granulated with potassium chloride to produce a 14-37-12 or 12-32-16 grade, which is blended with urea to make a variety of grades; 22-22-11 is typical. Likewise, some new plants in India produce urea - ammonium phosphate compound fertilizers containing more than 50% nutrients. Similar processes are in use in Japan.

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. Also, lower analysis materials are likely to be more economical for local use in some areas.

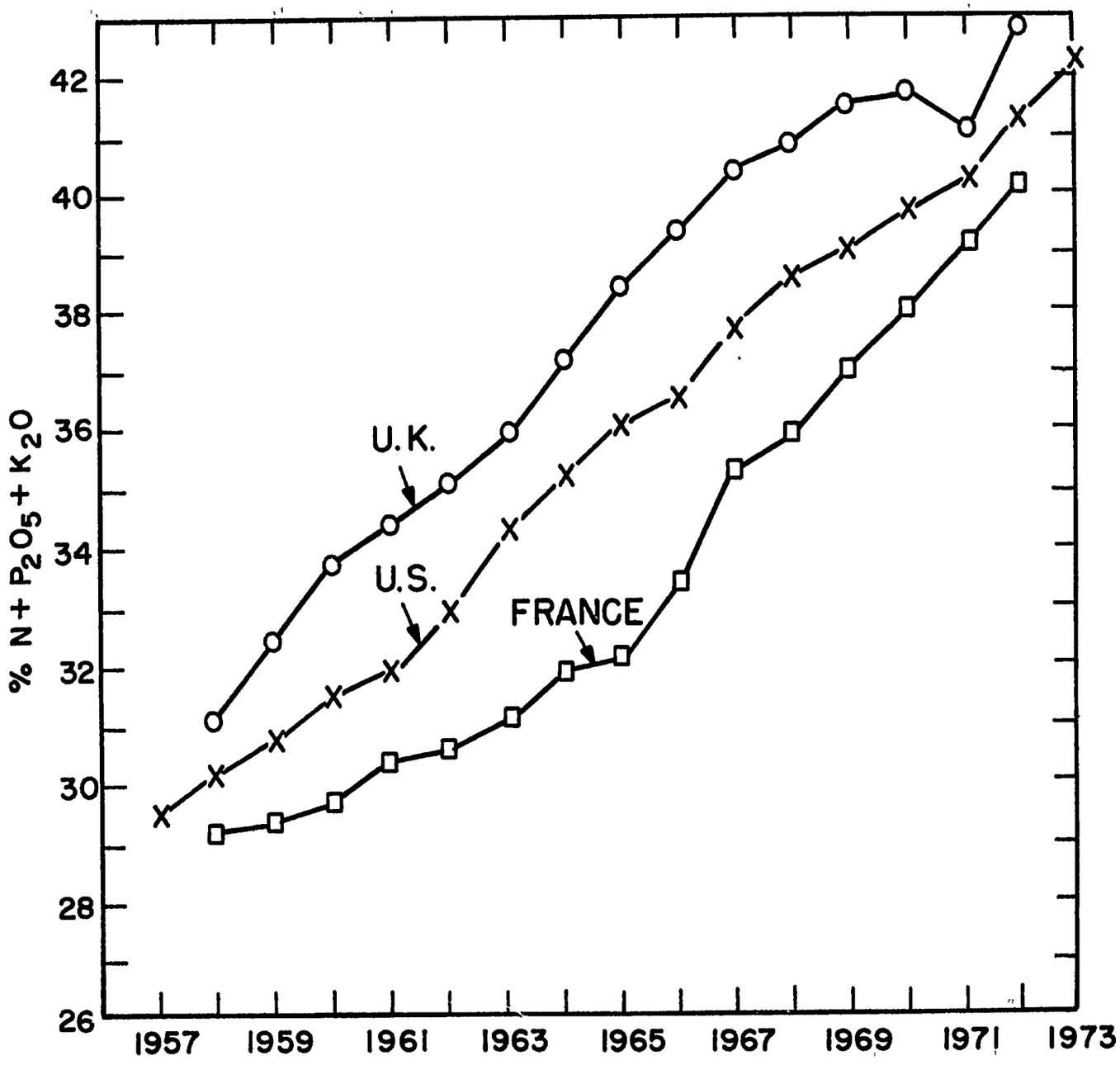


Figure 2.
TRENDS IN CONCENTRATION OF COMPOUND FERTILIZERS

Trend Toward Compound Fertilizers[1]

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 1958 to 1973, compound fertilizers in Western Europe increased from 35 to 58% of all fertilizers. In Japan the increase was from 56% in 1962 to 78% in 1972. In the United Kingdom, 92% of the P_2O_5 (other than basic slag), 90% of the K_2O, and 51% 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 1971, 26% of the N, 82% of the P_2O_5, and 67% of the K_2O were supplied to the farmer in compound fertilizers. Extensive use of anhydrous ammonia for direct application has limited the use of nitrogen-containing compound fertilizers.

The reason for the trend toward compound fertilizers 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 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

---

[1] The term "compound fertilizer" is used in this paper to apply to all fertilizer containing more than one of the three primary nutrients, N, P_2O_5, and K_2O.

plants now planned for 1975 will 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, and because further increase in scale will result in only minor decrease in production cost.

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.

The growing pressure to control pollution of the air, rivers, and lakes increases the complexities of manufacturing operations. These problems can be dealt with more economically in a few large plants than in many small plants. Some small plants have been closed because it was uneconomical for them to comply with pollution control regulations, and probably more will do so in the future. So we can expect that pollution control regulations will accelerate the trend toward larger factories.

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.[1] The time is approaching and has already arrived in

[1] Although chlorine was established as an essential micronutrient element in 1954, no case of naturally occurring deficiency is known, perhaps because of the abundance of the element (2).

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 1972, nearly 150,000 tons of micronutrient materials were used in fertilizers plus unknown amounts of materials supplying secondary elements.

In Japan in 1970, 842,000 tons of fertilizer contained boron, magnesium, or manganese.

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.

Farmers in some areas demand a combination of herbicides or other pesticides with fertilizer, which further increases the complexity of formulation. The advantage to the farmer is that application of fertilizer and pesticide together saves time and labor. Slow-release nitrogen is desirable in some situations and may be provided by incorporation of slowly soluble nitrogen materials or nitrification inhibitors in compound fertilizers.

Increased Use of Intermediates

In order to take advantage of the economics of large-scale manufacture and still provide for flexibility of formulation of compound fertilizer, various new systems are being developed. The general characteristics of these systems are (1) production of fertilizer intermediates in large plants where raw material 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 may combine the functions of manufacturing and retailing.

The principal intermediates are ammonia, urea, ammoniating solutions containing free ammonia and ammonium nitrate or urea, urea-ammonium nitrate solution, monoammonium or diammonium phosphate, ammonium polyphosphate solution, triple superphosphate, phosphoric acid, and potash salts.

Overseas shipments of phosphoric acid for use as an intermediate is growing rapidly. Several countries that have phosphate rock or sulfur or both are planning new or expanded plants to supply phosphoric acid on the world market. Announced plans indicate that about 1.7 million tons of P_2O_5 will be available for export by 1977. Most of this acid is expected to be available at a concentration of 54% P_2O_5. However, if the present high freight rates persist, superphosphoric acid should be more economical. One United States manufacturer is producing a low-polyphosphate superphosphoric acid (69-70% P_2O_5) for use on the domestic market. It has a lower viscosity than more concentrated superphosphoric acid, so it is easier to transport and pump. It is priced $10/ton of P_2O_5 higher than 54% P_2O acid. The delivered cost of superphosphoric acid (69% P_2O_5) would be less than that of 54% P_2O_5 acid per unit of P_2O_5 whenever the freight cost is higher than $25 per ton. Also the more concentrated acid would decrease port storage terminal costs, alleviate sludge precipitation, and enhance versatility in granulation processes.

Powdered monoammonium phosphate (MAP) is another intermediate that is growing rapidly in popularity. Plants now in operation or under construction will have a total capacity of about 3.4 million tons of MAP (1.87 million tons of P_2O_5). Most of this MAP will be used in granulation plants at the plant site or shipped to other sites for use in granulation processes.

Ammonia and urea probably will enter into world trade in increasing quantities as more plants are located at the source of low cost natural gas. These products may be used as intermediates for further processing or used directly as fertilizers.

Trends in Types of Nitrogen Materials

A prominent feature of the world nitrogen industry is the rapid rise in popularity of urea, as shown in figure 3.

Capacity for urea production will increase from 13 million tons of N in 1972 to 22 million in 1977. By 1977, well over 40% of the world nitrogen fertilizer capacity will be in the form of urea, either as such or as a component of compound fertilizers or nitrogen solutions. Ammonium nitrate and ammonium sulfate capacity will have relatively small increases and will supply a declining percentage of the market. The estimated capacities in figure 3 include urea and ammonium nitrate for industrial as well as fertilizer use. They also include urea, ammonium nitrate, and ammonium sulfate that may be used in nitrogen solutions or compound fertilizers as well as straight fertilizers. They do not include ammonium nitrate and ammonium sulfate formed by direct use of nitric and sulfuric acids in complex fertilizer processes.

The growing demand for urea is attributed to its high analysis and to improvements in technology that have lowered its cost. At present, urea is less expensive than ammonium nitrate per unit of nitrogen both in capital and production

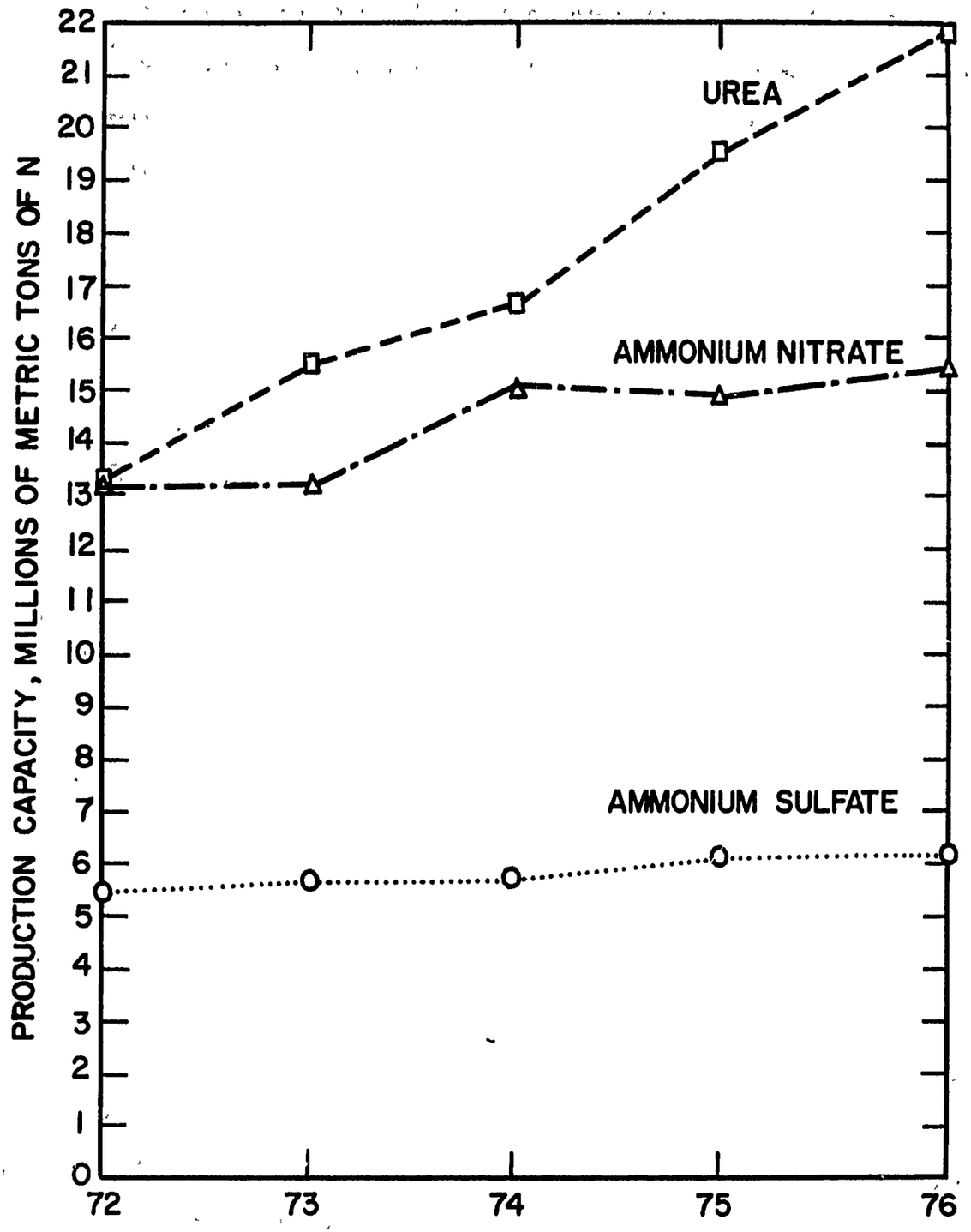


Figure 3.

TRENDS IN NITROGEN FERTILIZER PRODUCTION CAPACITY

(DATA FROM TVA MARKETING ANALYSIS STAFF, DOES NOT INCLUDE USSR OR COMMUNIST ASIA)

costs. Manderson (3) estimates the production cost of urea to be about 12% less than ammonium nitrate; when distribution and application costs are included, urea's cost advantage is about 20% under United States conditions. In comparison with ammonium nitrate, which has been the leading form of nitrogen since about 1960, urea has advantages of freedom from fire and explosion hazards; also, it is agronomically preferable for rice.

The usual commercial prilled urea has several faults. The particle size is too small for use in bulk blends. The small particle size also increases caking tendency and rate of moisture absorption. Also, some types of broadcast spreaders operate less efficiently with small particle size prilled urea. The usual prilled urea is weak; it has a low crushing strength and poor resistance to abrasion. This weakness may lead to excessive fines formation in bulk shipments and in some types of applicators. In view of the extensive development that has taken place in improving the efficiency and economy of the urea synthesis process, it seems odd that so little study has been given to improving the quality of the final product.

There is a trend toward producing urea in a granular form rather than prilled. Five plants in North America now operating or under construction are producing or will produce granular urea, typically about 1.7 to 3.3 mm. in size although any desired size can be made. The granules are harder and more resistant to abrasion than prilled urea and are better suited for bulk blending. The cost of granulation is said to be about the same as prilling.

TVA has developed a pan granulation process for urea through a pilot-plant stage, and is now using this process in a full scale plant (about 8 tons/hr). The process has proved capable of producing closely sized, well-rounded granules in any desired size range. Crushing strength and resistance to abrasion were quite satisfactory.

In view of the expected plentiful supply, consideration of ways of using it is appropriate. With the world trend toward farmer preference for mixed (compound) fertilizer, use of urea in granular mixtures is receiving attention in many countries.

The technology of utilizing urea in granular compound fertilizers, with or without ammonium sulfate, is well advanced in Great Britain (4), Japan (5), and several other countries. There are some technical problems, but ways of dealing with them have been developed.

In most countries, the cost of ammonia is only about half that of urea per unit of nitrogen. So wherever ammonia can be applied as such it is the least expensive source of nitrogen. Direct application of ammonia to the soil (or in irrigation water) supplies about 37% of the nitrogen fertilizer used in the United States. Use of anhydrous ammonia or aqua ammonia is also popular in Denmark and some other European countries. There are some difficulties in using this technique in developing countries, but the comparatively low cost of ammonia should be a strong incentive for solving them.

Growth in use of anhydrous ammonia is mainly attributable to its low cost, which more than offsets increased storage, transportation, and application costs. The average prices paid by farmers in the United States in 1970 for various nitrogen fertilizers are shown below (6).

	Price, $/kg of N
Anhydrous ammonia	0.10
Urea	0.20
Ammonium nitrate	0.20
Nitrogen solution	0.19
Ammonium sulfate	0.28

Trends in Types of Phosphate Materials

Figure 4 shows world trends in types of phosphate materials with projections to 1978. A striking feature is the decline in relative importance of single superphosphate from 73% of the total P_2O_5 supply in 1955 to 23% in 1972. A further decline to 15% is 1978 is forecast. The decline in actual tonnage has been small. In fact, 1966 was the year in which the largest tonnage of single superphosphate was produced, and the 1970 tonnage exceeded that of 1960. However, most of the expansion in the phosphate industry has been in higher analysis products, particularly triple superphosphate, ammonium phosphate, and other complex fertilizers. Concentrated superphosphate has maintained a nearly steady level of 15 to 20% of the total. The group, ammonium phosphates, complex fertilizers, and other phosphates, has risen from 10% in 1955 to 39% in 1969; further increase to 62% in 1978 is predicted. Probably as much as three-quarters of this group consists of ammonium phosphate, including straight ammonium phosphate and that formed in complex fertilizers. Most of the remainder is the P_2O_5 content of nitric phosphates. Basic slag is expected to supply a declining percentage of fertilizer P_2O_5 in the future.

Decline in use of single superphosphate (and ammonium sulfate) may bring about a need for alternative sources of sulfur. Substantial responses to sulfur have been noted in some parts of nearly all states of the United States and in at least 47 other countries, including many developing countries (7). Most soils in tropical and subtropical regions are inherently deficient in sulfur. Sulfur-deficient areas become more numerous and serious when heavy rates of nitrogen and other primary nutrients are applied. Much sulfur is supplied by rainfall in highly industrialized areas where it originiates from burning or coal and oil. In these areas, sulfur is seldom

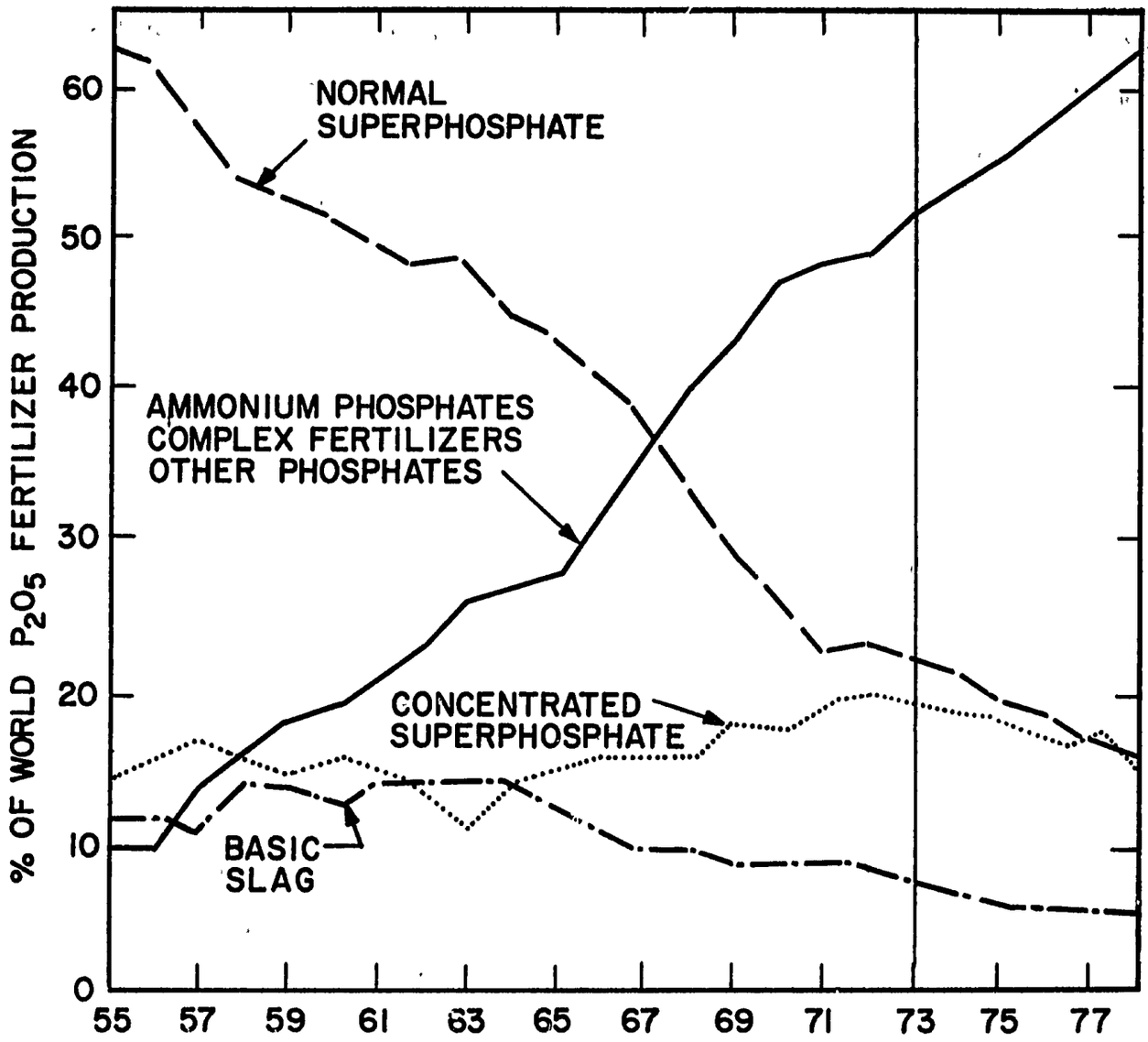


Figure 4.

WORLD TRENDS IN TYPES OF PHOSPHATIC FERTILIZER MATERIALS
(NON-COMMUNIST WORLD)

needed in fertilizers. However, as plans for prevention of atmospheric pollution materialize, much more need for supplying sulfur in fertilizers can be expected.

Ideally, sulfur should be supplied in fertilizers only when it is needed. To attain this ideal, an alert, efficient agricultural advisory service should be available to every farmer. Even in the most developed countries, this is often lacking for many farmers. In developing countries, little may be known about the need for sulfur. Sulfur deficiencies may appear only after several years of cropping with sulfur-free fertilizers.

In some cases, single superphosphate may be the most economical source of sulfur. However, elemental sulfur has been proved to be economical and effective in many cases. Elemental sulfur can be incorporated in granular fertilizer by spraying it in liquid form in the granulator.

Ammonium Polyphosphate

The term "ammonium polyphosphate" is used in fertilizer parlance to denote materials containing condensed phosphates. Ammonium polyphosphate is produced as solutions or solids by ammoniation of superphosphoric acid. 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[a]
Ortho	49	20	41
Pyro	42	37	54
Tripoly	8	23	4
Tetrapoly and higher	1	16	1

[a] Made from electric-furnace phosphoric acid.

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. TVA has recently demonstrated this process in a full-scale plant, producing a granular product (12-57-0) containing 25 to 30% of the P_2O_5 as polyphosphates.

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 fertilizers are triammonium and tetraammonium pyrophosphate, $(NH_4)_3HP_2O_7$ and $(NH_4)_4P_2O_7$, and pentaammonium tripolyphosphate, $(NH_4)_5P_3O_{10}$.

Ammonium polyphosphates are particularly useful in liquid fertilizers because they sequester the impurities normally present in wet-process phosphoric acid, thus avoiding precipitation of insoluble iron, aluminum, and other compounds when the acid is ammoniated. Also, the ammonium polyphosphates are more soluble than the orthophosphates, permitting production of higher analysis solutions.

Terman and Engelstad (8) 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 (9) concluded from experiments in France that ammonium polyphosphate supplied as liquid fertilizer was consistently superior to other phosphorous sources as the result of better phosphorous utilization. Most of these tests were made on calcareous soil.

Gourny and Conesa (10) reported that liquid fertilizer containing 34 to 82% of its phosphate as nonorthophosphate was slightly inferior to ammonium orthophosphate on acid soil, but markedly superior on calcareous soil.

Conesa (10) demonstrated that plants can take up polyphosphate without previous hydrolysis.

Singh and Dartigues (12) reported that polyphosphate was superior to ammonium orthophosphate on two zinc-deficient calcareous soils.

Soubies and Baratier (13) emphasize the advantage of band placement of ammonium polyphosphate solution near the seed as compared with broadcast solid orthophosphate. They claimed that the band placement used with liquids was not possible with solids.

Mortvedt and Giordano (14) reported that liquid polyphosphate fertilizers were effective carriers of iron sulfate in greenhouse tests for crops grown on iron-deficient soils, whereas application of iron sulfate alone or in several granular fertilizers was ineffective.

In a recent series of field tests in the United States (15), ammonium polyphosphate solution gave higher yields of maize, wheat, and milo than orthophosphate fertilizer in either liquid or solid form.

Nitric Phosphates

Nitric phosphate-type processes are particularly attractive for countries with limited raw material resources for fertilizer manufacture. The only feed materials required are ammonia and phosphate rock--either or both of which can be imported. Economics are more favorable for nitric phosphates when sulfur prices are high.

The approximate location of nitric phosphate plants in the world is given in figure 5 (16). About eighty plants are believed to be producing solid nitric phosphates--with about two-thirds of these located in Europe.

Recent process improvements have made the nitric phosphate process more versatile and have removed some of the earlier objections to these products. It is now possible to produce high-analysis grades such as 20-30-0 and 23-23-0 with over 80% of the P_2O_5 water soluble in large, efficient plants (17

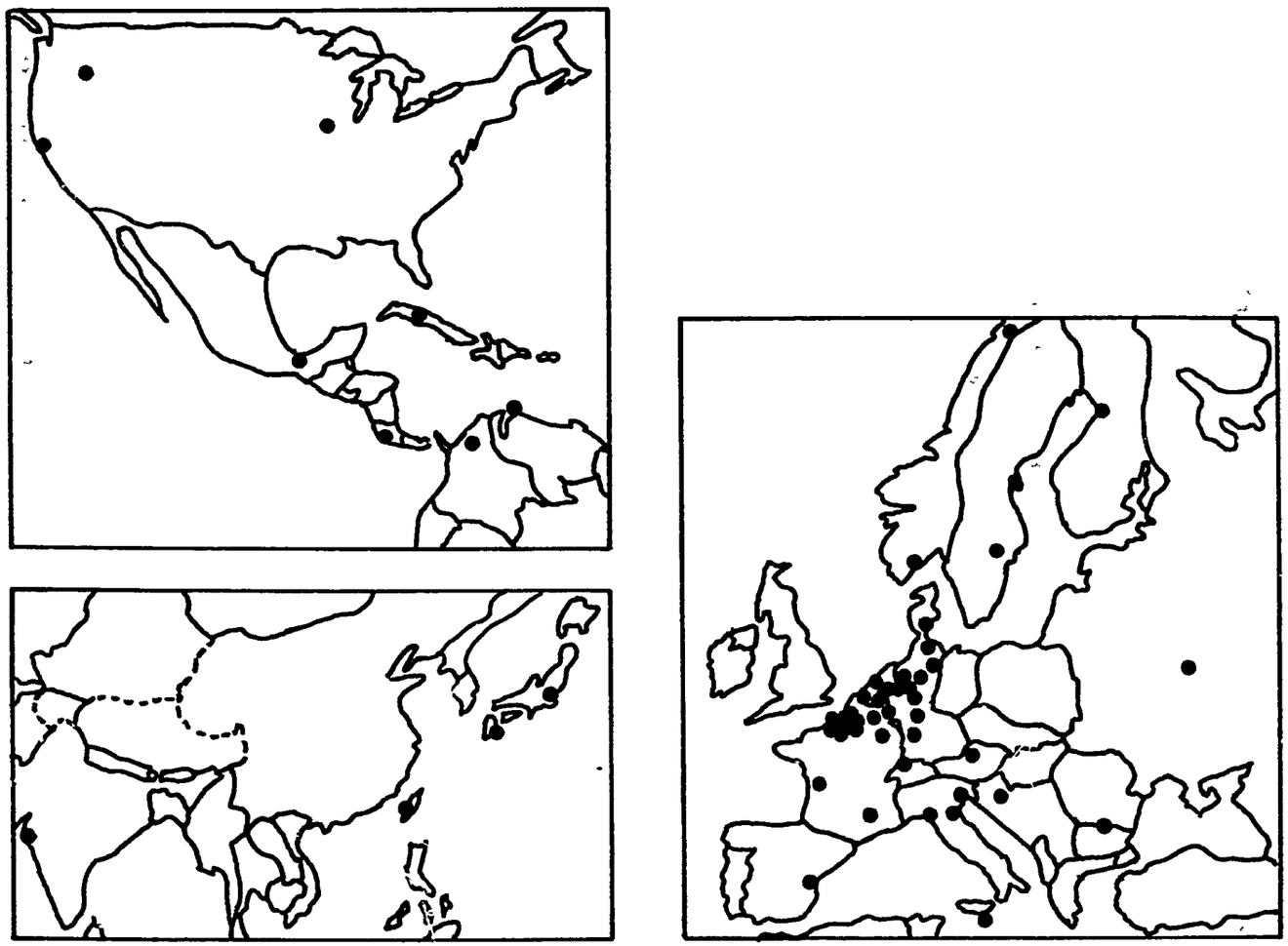


Figure 5.
APPROXIMATE LOCATION OF NITRIC PHOSPHATE PLANTS IN THE UNITED STATES, ASIA, AND EUROPE

Estimates usually indicate that nitric phosphate processes are more economical than production of equivalent amounts of nitrogen and phosphate fertilizers as ammonium phosphate and ammonium nitrate or urea. When compared with the urea plus ammonium phosphate, the cost advantage is small and may be offset by higher transportation costs if the products are shipped very far (16).

Potassium Phosphates

There has been much interest in potassium phosphates because of their very high analysis and good agronomic properties. The potassium phosphates under consideration include the orthophosphates, KH_2PO_4 and K_2HPO_4, and the polyphosphates ranging from pyro and tripoly to long-chain polyphosphates commonly called "metaphosphate." The orthophosphates and short-chain polyphosphates are quite soluble, whereas the metaphosphates may be either soluble or insoluble, depending on their method of preparation and impurity content.

There is some small use of potassium orthophosphate in specialty fertilizers to make water-soluble mixes for foliar application or transplanting solution. There is also some use in liquid fertilizers for farm use; one company in the United States produces a 0-26-27 potassium polyphosphate solution for use in liquid mixed fertilizers. All of these materials are produced from potassium hydroxide or carbonate, and hence they are too expensive for general use.

Many research projects have been aimed at producing potassium phosphates from potassium chloride, the cheapest source. Most of these projects have not proved economical because of the difficulty of utilizing or disposing of the byproduct hydrochloric acid. Even if the hydrochloric acid is utilized to react with phosphate rock, calcium chloride becomes a byproduct which is difficult to dispose of in many locations.

A process was developed in Ireland by Goulding Fertilisers on a pilot-plant scale that produces KH_2PO_4 and anhydrous HCl gas (18). A similar process was developed in the United States by Pennzoil, and the two companies have agreed to pool their information. It is claimed that anhydrous HCl can be utilized in certain organic oxychlorination processes where its value will be comparable with that of elemental chlorine. A small plant in California is being adapted to production of potassium phosphates by the Goulding-Pennzoil process with initial operation expected this year (19).

Trends in Economics of Fertilizer Production

Recent shortages of fertilizers and raw materials have caused some concern. Feedstocks for nitrogen fertilizers are in short supply and the price has increased four-fold in some cases. Construction costs of ammonia and urea plants have increased by about 50% in the last year. Prices of phosphate rock have doubled or tripled in the last few months. Sulfur is in short supply and the price is rising. All phosphate fertilizers are in short supply and the world market price has doubled. Freight costs are sharply higher.

The fertilizer industry has been through several cycles of shortages and surpluses. It seems inevitable that the industry as a whole overreacts to each cycle. Each cycle of shortage and high prices brings on a wave of new plant construction which causes a surplus and brings prices down so far that there is little profit in production. All expansion then ceases and experienced engineering and construction personnel are dissipated, and are no longer available when the next shortage sets off a new wave of construction. During shortages, producers naturally seek to make extra profits to offset losses sustained during years of surpluses.

There is no evidence that the present shortage is greatly different from previous ones. Announced plans for construction of phosphate fertilizer facilities seem sufficient to produce an adequate supply in 2 to 4 years and probably a surplus. Plans for expansion of phosphate rock mining should be more than adequate to supply the new plants. Higher sulfur prices should increase the supply although some time will be required. High freight costs should bring increased shipping capacity and lower rates. The increased supply of products and raw materials should result in a drop in prices although not to their previous level.

The nitrogen fertilizer situation is somewhat different. Announced plans for new plants seem fully adequate to end the shortage in 3 to 5 years. The feedstock supply and price is related to the world energy supply and demand. Most observers expect an increased supply of feedstocks at somewhat lower prices than current ones. Sharply increased construction costs for nitrogen fertilizers may affect production cost as much as higher feedstock prices. Heretofore, improvements in technology and increase in scale have more than offset higher construction costs with the result that the cost of nitrogen fertilizers has steadily declined over the last 50 years. At present there is no technological advance in view to offset rising construction costs, and relatively little saving can be expected from further increase in scale.

The next section of this paper will attempt to review the economics of urea and ammonia production in the light of recent changes in construction costs and feedstock prices.

Economics of Ammonia and Urea Production

The economics of ammonia and urea production are characterized by predominance of capital-related costs. Within the last year or two plant investment costs have increased sharply, even more sharply than general construction costs. The wave of new construction of nitrogen fertilizer plants probably has contributed to the sharp increase in cost; the cost of engineering and construction services are responsive to supply and demand relationships. Labor and material costs have increased substantially, also.

Feedstocks--Before discussing the effect of the capital investment costs on operating and production costs, some discussion of feedstocks and their costs may be in order. Because of the lower investment cost, natural gas has been the favored feedstock, followed by naphtha. The present shortage of all energy sources has sharply increased the cost of all feedstocks. Naphtha cost has increased more sharply than some other fuels.

Natural gas is in a special category because, unlike other fuels it cannot be transported cheaply or easily to consuming areas. When natural gas is available in or near consuming areas, its value* may be determined by that of alternate energy sources, such as oil or coal. However, much of the world's reserves of natural gas are located far from consuming areas. Therefore, expensive methods of transporting the gas to consuming areas are necessary. The principal methods are pipelines which may be several thousand miles long, and overseas shipment of liquified natural gas (LNG).

LNG is a comparatively recent development. The first commercial ocean shipment of LNG was in 1959 from Lake Charles, Louisiana, USA, to Canvey Island in the United Kingdom. The second project was production of LNG at the CAMEL plant in Algeria. Three more LNG plants are now in operation

---

*In this discussion, "value" is not necessarily synonymous with price, since the price may be artificially controlled.

in Alaska, Brunei, and Algeria. About 30 more LNG projects are in various stages of construction or planning, and several others are possible.

At first thought it might seem logical to ship LNG rather than nitrogen fertilizer since only 0.75 tons of LNG is required per ton of ammonia or 0.45 tons of LNG per ton of urea. However the situation is much more complicated than a comparison of weight to be transported.

A minimum economical size for an LNG operation may be about 300 million scf/day. This is approximately enough to supply 8 ammonia plants of 1000 tons/day capacity. Obviously LNG is not likely to be an attractive feedstock if a single ammonia plant is the only user. However, LNG might be an economical feedstock in countries where other uses (power generation, petrochemical production, etc.) create a sufficient demand for LNG to justify importation of a large quantity.

Capital requirements for LNG operations are enormous. The costs for a typical LNG operation delivering 500 million scf/day from Indonesia to Japan are estimated to be approximately:

	Capital Cost, U.S. $ Million
Liquefaction	260
Ships	398
Receiving Terminal	357
TOTAL	1,015

The operating cost, including liquefaction, transportation, and receiving terminal expenses, is reported to be in the order of $1.00 per M cu.ft. of gas. To this must be added the cost of collecting and purifying the gas and delivering it to the liquefaction plant plus whatever profit the producer may demand.

The producer of gas for LNG is likely to set a price that will make the cost of LNG in the consuming area comparable with the cost of alternate energy sources in that area. For example, if petroleum cost in the consuming area is $80/ton a comparable LNG cost would be about $1.87/Mcf. Allowing $1.00 for liquefaction, transportation, and terminal costs, the price of gas entering the liquefaction process could be set at $0.70/Mcf. (About 20% of the gas is utilized to supply energy for liquefaction and transportation plus losses.) Since natural gas is a "clean" fuel it may bring a premium price as compared with high-sulfur oil or coal. Utilization of gas for LNG will affect the price of gas for alternate use as ammonia feedstock. Gas suitable for LNG will likely be priced according the energy market conditions.

There are many gas fields that are too small for economical LNG operations. Also there is natural gas associated with petroleum in quantities to small for LNG. When the associated gas cannot be used it is often flared. In many cases the amount of gas is adequate for a large-scale ammonia plant. The true value of gas from such sources where there is no alternate economical use may be only the cost of collection and delivery to a plant site which has been estimated to be in the range of $0.11 to $0.28 in various locations. To be on the safe side and to allow the producer a profit, a cost of $0.40 per M cu.ft. is assumed in this paper.

Thus, the most economical source of natural gas for ammonia production is that for which there is no alternate economic use provided that the location is such that the nitrogen fertilizer can be delivered to a market area economically.

In areas where natural gas is not available and LNG cannot be imported economically, naphtha is likely to be a preferred source. However, naphtha is in short supply and its cost has increased sharply because of the demand for gasoline.

Heavy fuel oil may be an economical feedstock in some areas. The heavy oil is a residue from refining operations; it contains most of the sulfur that was present in the petroleum entering the refinery. In areas where pollution control regulations are strict, the high-sulfur residual oil is not a desirable fuel for power generation, and may be available at a comparatively low cost. Heavy oil can be used as a feedstock for ammonia production in a partial oxidation process. Its high sulfur content is no great disadvantage; the sulfur is readily removed from the gas stream leaving the partial oxidation unit as H_2S. In fact, recovery as elemental sulfur could be profitable in some cases.

Partial oxidation processes can utilize a variety of liquid and gaseous hydrocarbon feedstocks, including crude petroleum, refinery gases and heavy oil; this flexibility is an advantage that is difficult to evaluate.

Direct use of coal as a feedstock is rarely economical. In addition to the high investment costs, the operating reliability of most coal-based plants has been poor. In fact, many of the coal-based plants have been converted to other feedstocks.

In the future, indirect use of coal as a feedstock may become economical in some areas through the development of methods for making synthetic natural gas (SNG) from coal.

Capital Investment--Estimated costs for ammonia and urea plants contracted for in early 1974 including necessary auxiliary and support facilities for a United States mainland location, based on natural gas feedstock are:

Ammonia		Urea		Total complex	
Capacity, metric tons NH_3/day	Plant cost, $ million	Capacity, tons Urea/day	Plant cost, $ million	Tons N per Day as Urea	Plant Cost $ million
200	16.6	333	11.6	153	28.2
600	31.6	1000	22.1	460	53.7
1000	43.6	1667	30.5	767	74.1
1500	55.6	2500	45.8	1150	101.4

The costs are approximately 50% higher than those quoted a year ago. Firm quotes for a specific project are needed for an accurate estimate; the above estimates are illustrative only.

Ammonia plant costs also depend on the feedstock that they are designed to operate on. Following are approximate ratios of plant costs for various feedstocks.

Feedstock	Process	Ratio Based on Natural Gas
Natural Gas	Steam Reforming	1.0
Naphtha	Steam Reforming	1.12
Heavy fuel oil or crude oil	Partial Oxidation	1.28
Coal or Lignite	Partial Oxidation	1.81

It is a common assumption that plant investment costs are 25% higher in a developing country than in an industrialized country. More precisely, the plant costs increase with the distance from industrialized centers. Also isolated locations require more auxiliary and supporting facilities, and extreme climatic conditions increase costs. Thus, costs may be as high in some portions of developed countries such as Alaska or Siberia as in developing countries. Naturally the increased cost depends on many factors but for purposes of this discussion, a 25% increase in cost will be taken as typical of an average developing country, and a 50% increase in cost will be assumed for an isolated location remote from industrial centers.

Application of these factors results in the following plant investment costs for an ammonia-urea complex.

Investment Costs for Ammonia-Urea Complex, $ Million[a]

Capacity, Tons of Urea/Day	Industrialized Area	Average Developing Area	Isolated Area
333	28.2	35.3	42.3
1000	53.7	67.1	80.6
1667	74.1	92.6	111.2
2500	101.4	126.7	152.1

[a]Based on natural gas; for plants contracted for in early 1974 with completion dates of 1976-77.

The above plant investment costs should not be confused with the total project cost which will include working capital, startup expense, and perhaps housing colonies, harbor development, pipelines, and various other facilities depending on the situation.

Capital investment costs also depend on the date of initiation and completion of construction. Plants completed in 1972 or 1973 may cost only 70% as much as those started in 1974 with completion scheduled for 1977. Plants completed earlier may cost even less. Future projects may cost more; at present, construction costs are said to be escalating at a rate of 1% per month. Perhaps the escalation rate will decline, but in general the prospect is that costs will continue to rise.

Approximate plant investment costs for ammonia production facilities in a developing country for plants in the capacity range of 200 to 1000 tons per day are shown in Fig. 6 and are tabulated below for 600 and 1000 tons/day. These estimated costs are for plants contracted for in 1974 with completion date in 1977.

Estimated Plant Investment for Ammonia Production in a Developing Country, $ Million

Feedstock	Process	600 tons/day	1000 tons/day
Natural Gas	Steam Reforming	39.5	54.5
Naptha	Steam Reforming	44.1	60.8
Heavy Oil	Partial Oxidation	51.0	69.3
Coal	Partial Oxidation	72.2	97.6

Ammonia Production Costs--Approximate estimates for the cost of production of ammonia as affected by type and cost of feedstock and scale of operation are shown in Figure 7.

The gate sales price for ammonia was estimated by adding 20% return on total investment (R.O.I.) before taxes to the production cost. These prices are shown in Figure 8. The total investment for this purpose was the plant investment plus working capital. No sales cost or distribution cost is included in the gate sales price.

The scales of feedstock costs in Figures 7 and 8 are aligned according to equivalent fuel values. Since the main use for fuels is heating or electrical power generation, their costs are often related to their fuel value. However, their value for ammonia production is quite different from their fuel value. To illustrate this point, Tables 1 and 2 show price of feedstocks that would result in the same ammonia cost (Table 1) or the same ammonia price (Table 2) including 20% R.O.I.

For instance, to produce ammonia at a price of $150/ton, natural gas at $2.00/Mcf would be required. The same ammonia price would result with naphtha at $78/ton, heavy oil at $63/ton, or coal at $13/ton. The following tabulation compares feedstock value for ammonia production with fuel value.

Feedstock	Equivalent Value for Ammonia Production	Equivalent Value for Fuel
Natural Gas	$2.00/Mcf	$2.00/Mcf
Naphtha	$78/ton	$93/ton
Heavy Oil	$63/ton	$86/ton
Coal	$13/ton	$56/ton

Table 1

Required Feedstock Prices for Equal Ammonia Cost (No R.O.I.) for 1000 tons/day Ammonia Plant, Operating at 100% Capacity

Ammonia Cost, $/ton	120	100	80	60	40
Natural gas cost, $/Mcf	2.23	1.72	1.20	0.70	0.20
Naphtha cost, $/ton	96	73	49	27	4
Heavy Oil Cost, $/ton	83	62	44	20	negative
Coal Cost, $/ton	28	19	10	0	negative

Table 2

Required Feedstock Prices for Equal Ammonia Prices (Including 20% ROI) for 1000 tons/day Ammonia Plant Operating at 100% Capacity

Ammonia Price, $/ton	175	150	120	100	80
Natural gas cost, $/Mcf	2.60	2.00	1.28	0.80	0.30
Naphtha cost, $/ton	105	78	47	26	5
Heavy Oil Cost, $/ton	95	63	33	13	negative
Coal Cost, $/ton	23	13	0	negative	negative

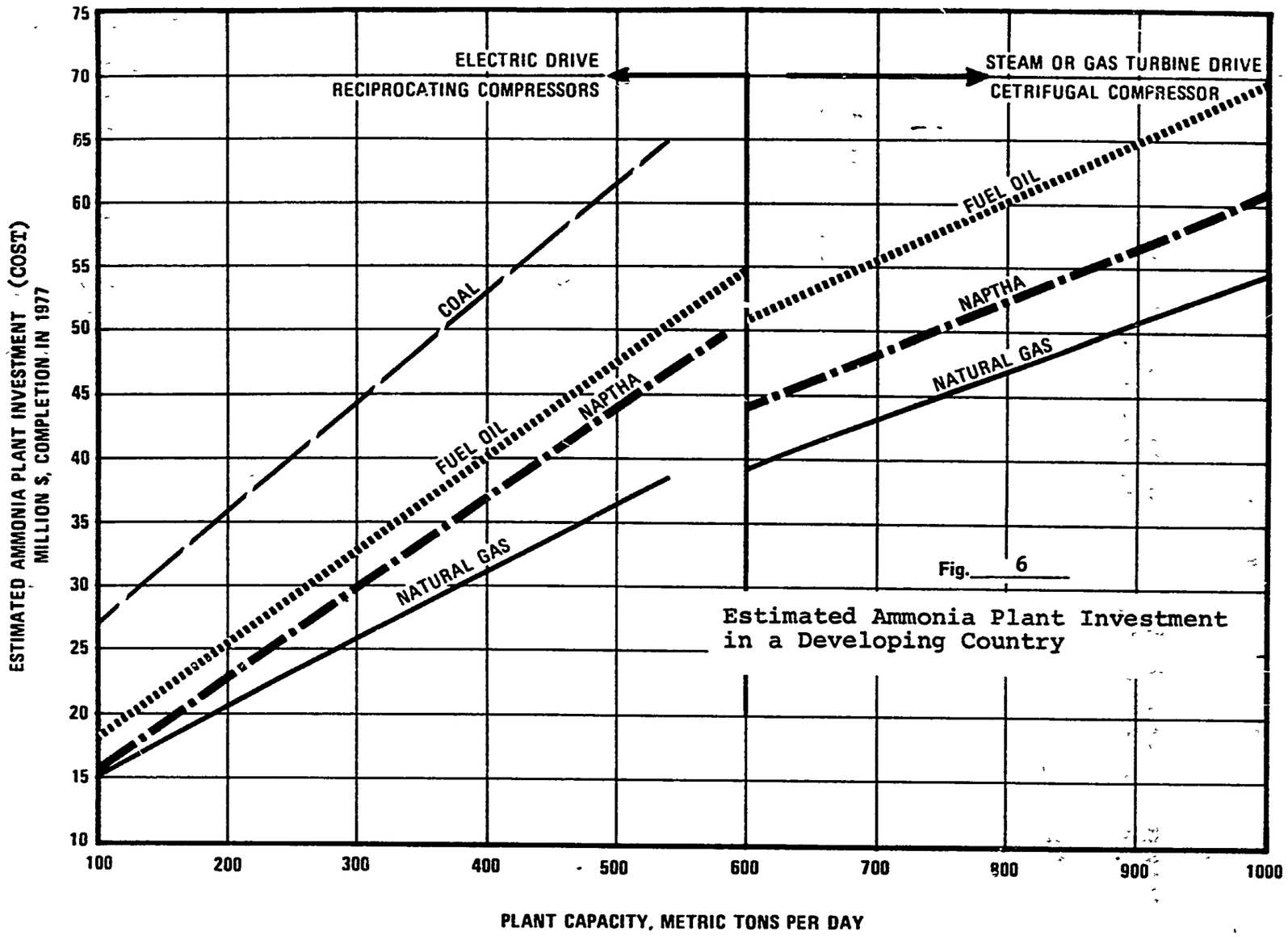


Fig. 6

Estimated Ammonia Plant Investment in a Developing Country

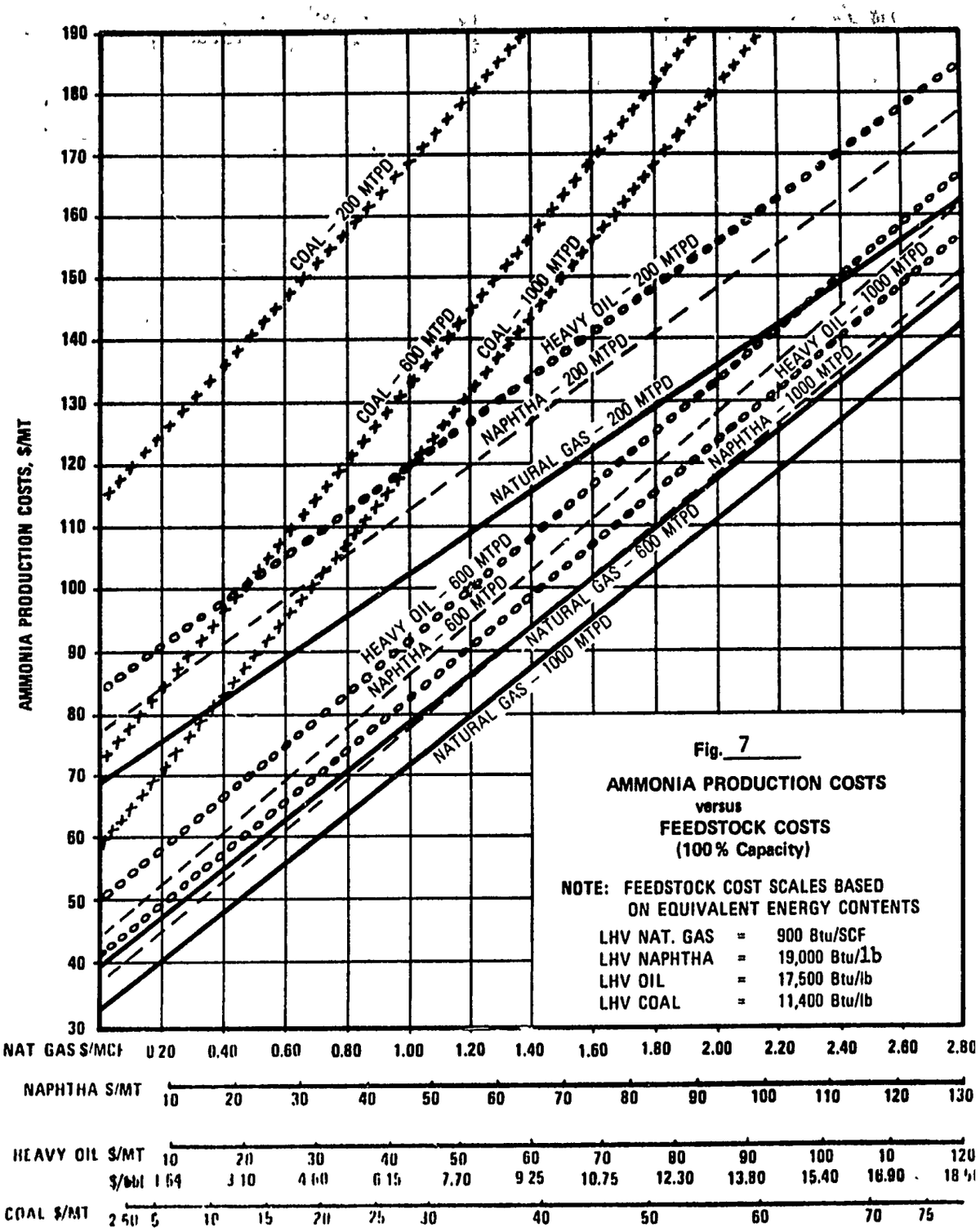


Fig. 7

AMMONIA PRODUCTION COSTS
versus
FEEDSTOCK COSTS
(100% Capacity)

NOTE: FEEDSTOCK COST SCALES BASED ON EQUIVALENT ENERGY CONTENTS

LHV NAT. GAS	=	900 Btu/SCF
LHV NAPHTHA	=	19,000 Btu/lb
LHV OIL	=	17,500 Btu/lb
LHV COAL	=	11,400 Btu/lb

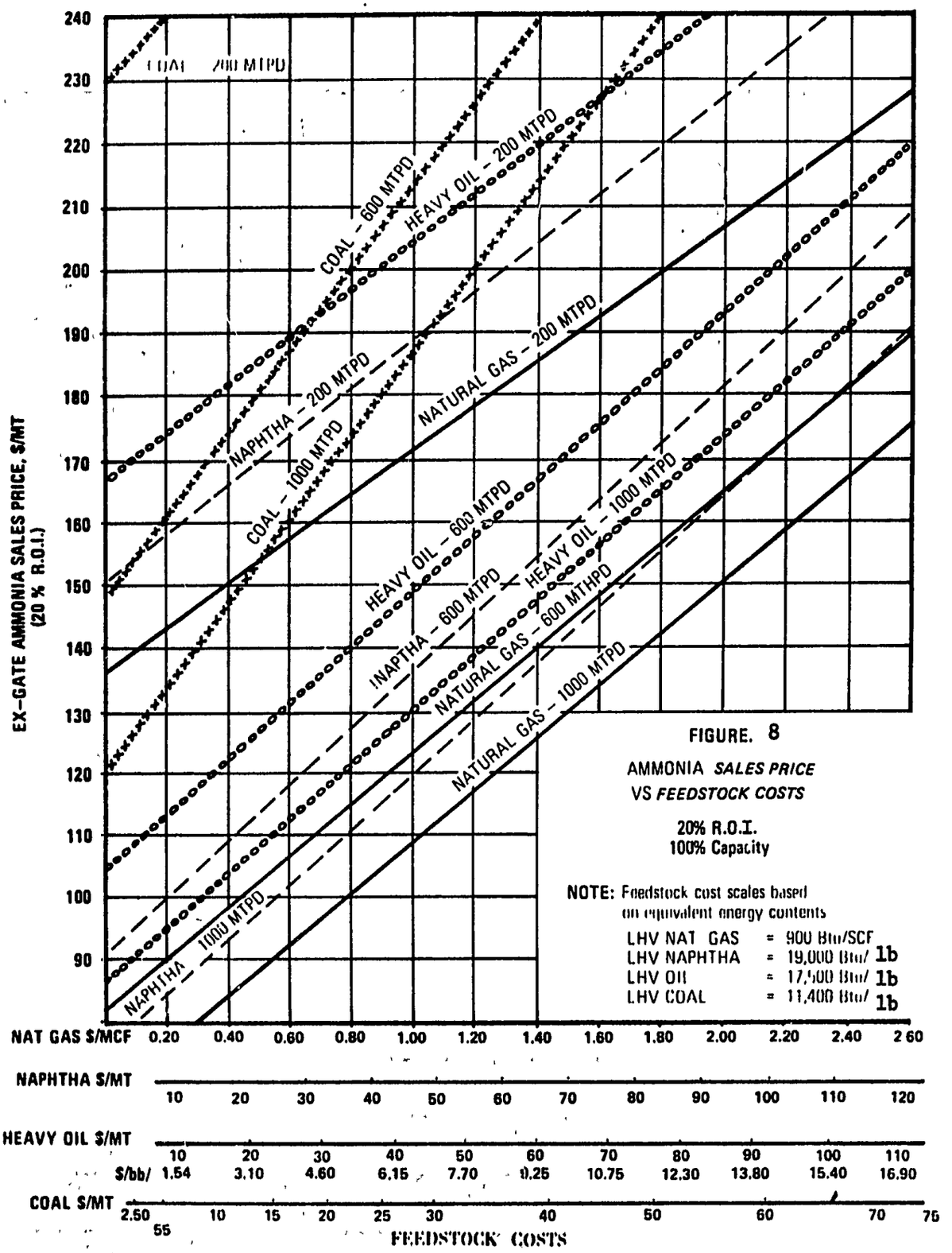


FIGURE. 8

AMMONIA *SALES PRICE* VS *FEEDSTOCK COSTS*

20% R.O.I.
100% Capacity

Effect of Capacity Utilization--With a few exceptions, ammonia plants seldom operate at full capacity. (In this paper, annual capacity is assumed to be 330 x daily rated capacity.) In developed countries, an average of 90% capacity utilization usually can be attained when production is not limited by the market. Production losses may be caused by electric power interruptions, lack of feedstock, and various mechanical failures. In developing countries, as a whole, the annual production averages between 60 and 70% of capacity although there are instances of plants operating above rated capacity. The shortcoming has a variety of causes; poor quality or inadequate supply of feedstock, more frequent power failures, long delays in obtaining spare parts or other maintenance materials, lack of operating or maintenance skills.

Figures 9 and 10 show the effect of capacity utilization on producti cost and price of ammonia. Operation at 60 percent of capacity can increase ammonia price by $50 per ton for natural gas plants, or $60 per ton with plant based on heavy oil. The increase in cost is about equal to increasing the cos of gas by $1.30/Mcf for a plant operated at full capacity, or increasing the cost of oil by $62/ton. Thus a plant with high feedstock cost may be able to offset this disadvantage by operating at a high percentage of capacity in comparison with a plant that has low feedstock cost and a low capacity utiliza An even greater disadvantage of low capacity utilization is loss of fertilizer production and resulting loss of food production. If all plants in non-Communist developing Asia could be operated at full capacity the nitrogen fertilizer supply would be sufficient to meet the estimated 1974 demand and fewer new plants would be needed in the future to keep pace with the demand. There are many reasons why operation at full capacity may be difficult or impossible in certain cases. However, some plants have operated above rated capacity for several years. It seems possible that a higher return on investme

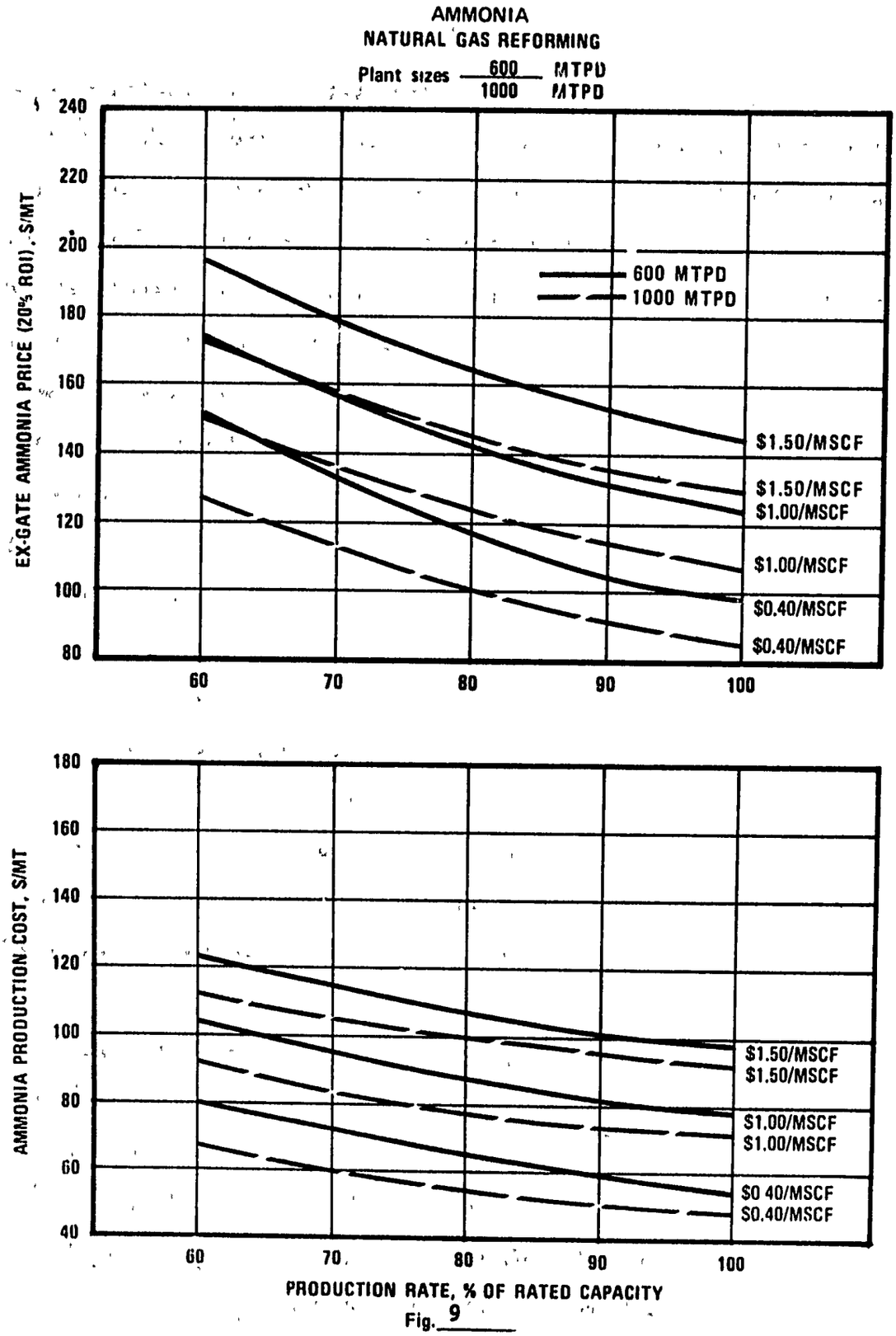


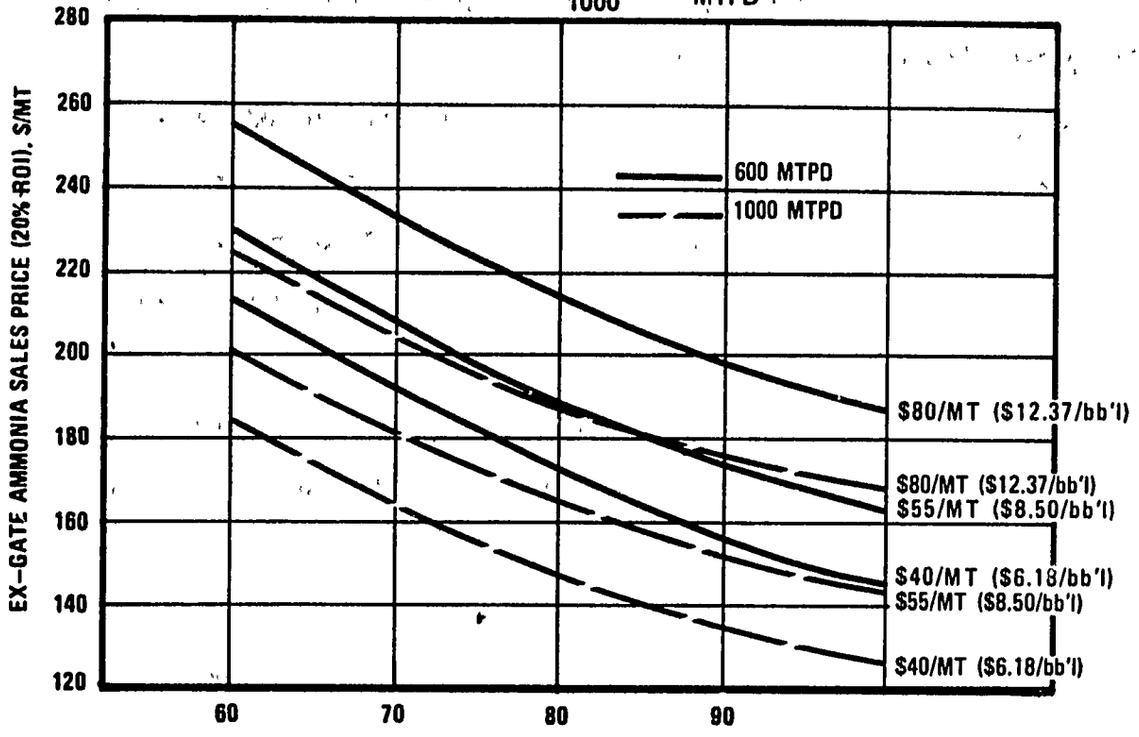
Fig. 9

EFFECT OF CAPACITY UTILIZATION

AMMONIA

HEAVY (FUEL) OIL–PARTIAL OXID.

Plant Sizes 600 MTPD / 1000 MTPD



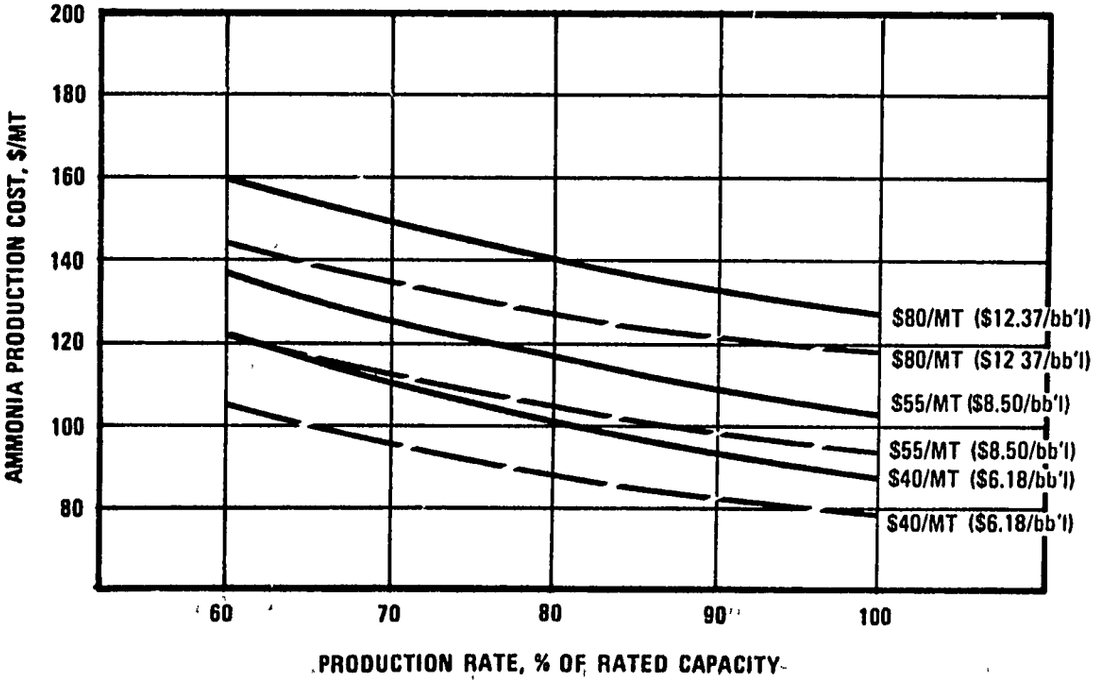


Fig. 10

EFFECT OF PLANT TURNDOWN

could be obtained by bringing present plants up to near rated capacity than by building new plants, although both are needed.

Ammonia-Urea Complexes--In developing, non-Communist Asia as a whole, estimated 1978 urea capacity is 85% of the total nitrogen capacity. Most plants are ammonia-urea complexes in which most or all of the ammonia is converted to urea. It is therefore appropriate to consider the economics of ammonia-urea complexes as a whole.

There is an interdependence between the ammonia and urea units. The urea unit cannot operate when the ammonia plant is shut down because of lack of carbon dioxide which usually is uneconomical to store. The ammonia plant can operate when the urea plant is shutdown to the extent that ammonia storage is available. It is evident that the urea unit will have a larger percentage of downtime than the ammonia plant, since it has its own shutdowns plus that of the ammonia plant. When urea is the only product, this interdependence can create problems. If each unit has an operating reliability of 85%, the urea unit can operate only 72% of the time.

The best solution to this problem is to provide adequate ammonia storage and to build the urea plant with excess capacity, so that when the urea plant is shutdown, ammonia can be stored and when the urea plant is in operation, it can use the entire output of the ammonia plant plus ammonia from storage.

Estimated plant investment costs for a new plant in a developing country with natural gas feedstock are shown in Figure 11 and Table 3 for ammonia-urea complexes ranging in capacity from 333 to 2500 tons of urea per day. For the largest plant two urea units were assumed as a single unit for 2500 tons per day may not be feasible. However, a single train ammonia plant was assumed in each case.

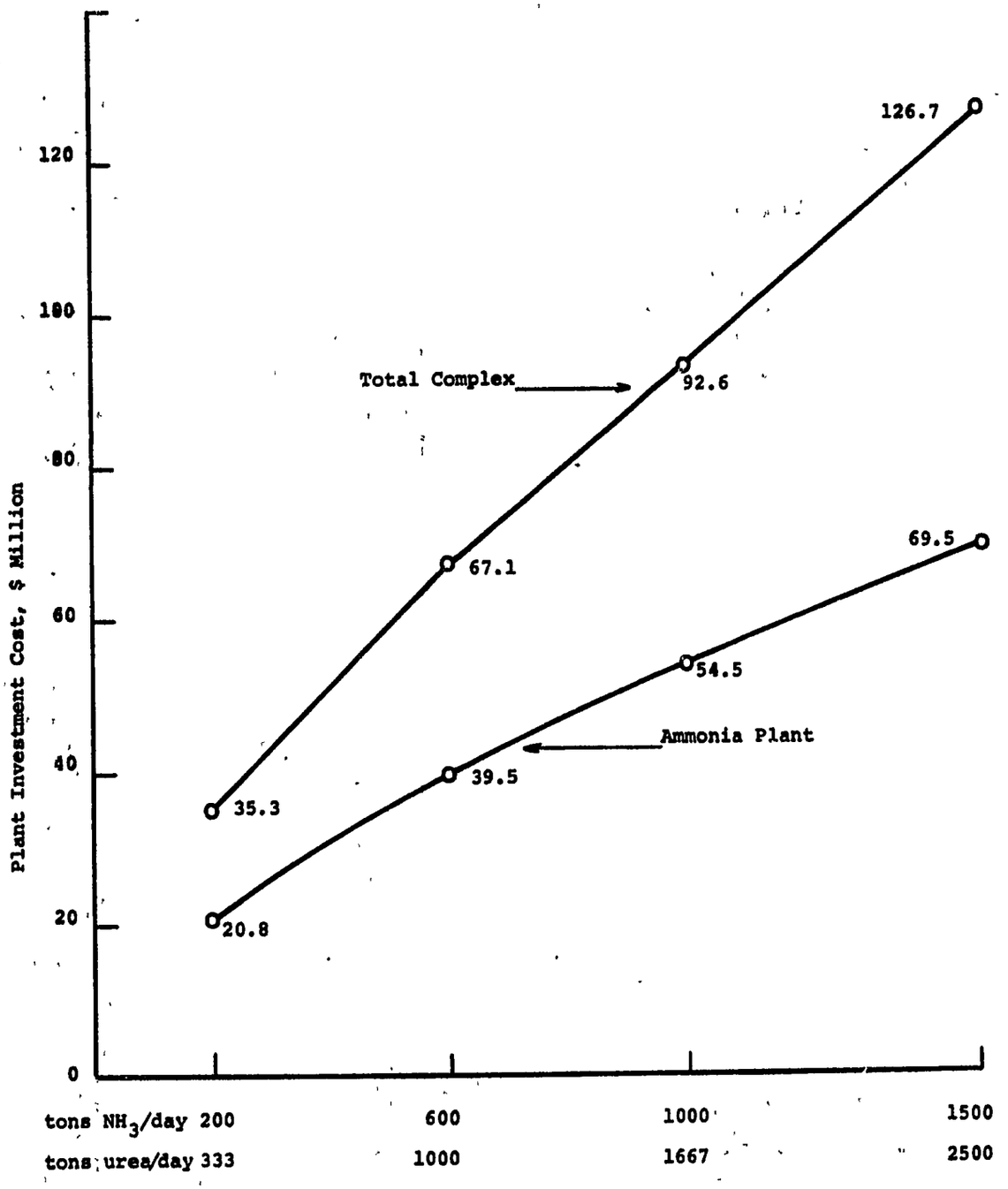


Figure 11. Estimated Plant Investment Cost for Production of Ammonia and Urea in a Developing Country (Natural Gas Feedstock)

Table 3

Plant Investment Cost for Ammonia-Urea Complex in a Developing Area
(Natural Gas Feedstock)

Ammonia		Urea		Total Complex	
Capacity, Tons NH_3/day	Plant Cost, $ million	Capacity, Tons Urea/day	Plant Cost, $ million	Capacity, Tons N/day as urea	Plant Cost, $ million
200	20.8	333	14.5	153	35.3
600	39.5	1000	27.6	460	67.1
1000	54.5	1667	38.1	767	92.6
1500	69.5	2500	57.2[a]	1150	126.7

[a] Two urea units assumed for 2500 tons/day

Production costs and gate sales prices are shown in Tables 4 and 5. In Table 6, the components of bulk urea price are classified into feedstock costs, capital-related charges (capital-related operating costs + 20% R.O.I.) and other costs. When natural gas cost is $0.40/Mcf the feedstock cost is 6.2 to 12.3% of the urea price. Capital related costs range from 79 to 82% of the total. Other costs range from 8.5 to 11.6%. These calculations assume that the complex operates at rated capacity. When output falls below rated capacity, capital costs per ton of product increase. Failure to operate at or near rated capacity can be financially disastrous.

Table 7 shows the effect of location, completion date, and capacity utilization on the price of bulk urea produced in a urea-ammonia complex with a rated capacity of 550,000 tons of urea per year (1667 tons/day) based on natural gas at $0.40/Mcf. The estimates show that maintaining a relatively high capacity utilization is more important than any reasonable variation in feedstock cost. For instance for a new (1976-77) plant in a developing country, lowering the capacity utilization from 100 to 60% would increase the price of bulk urea by $43/ton. To obtain an equivalent price increase by increasing the price of feedstock, the cost of natural gas would have to be increased from $0.40 to $2.26/Mcf.

The estimates also show that it may not always be wise to build a plant in a remote location to take advantage of low cost feedstock, if the remote location involves unusually high investment costs and low capacity utilization. For instance a new plant in a developing country operating at 100% capacity would produce urea at a $33/ton lower price than a similar plant in a remote location at the same feedstock price. This differential is equivalent to increasing the cost of feedstock from $0.40 to $1.83/Mcf. If in addition the urea must be shipped from the remote location to the market area at a cost (for example) of $20 per ton, the cost differential is $53, which is enough to pay for natural gas at $2.70 MCF or naphtha at about $110/ton.

The estimates also bring out the advantage of the lower capital investment of plants already built; particularly if these plants can be operated at or near full capacity. A comparatively small investment for stocking spare parts and maintenance materials, or for training programs or for breaking whatever bottlenecks may exist should increase capacity utilization and yield a much better return on investment than new plant construction.

Another conclusion may be drawn; unless developing countries improve their capacity utilization they are not likely to be competitive with developed countries even when the developing countries have low-cost feedstock.

The cost of ammonia (including 20% R.O.I.) produced in a 1000 ton/day plant is equivalent to $102.60/ton of nitrogen (table 11), while the cost of bagged urea is about $209/ton of nitrogen. Thus, ammonia is a much less expensive source of nitrogen. This cost differential should stimulate studies of means for using ammonia as such or as aqua ammonia for direct application or in irrigation water.

Table 4

Ammonia Production Cost in a Developing Country
100% Operating Capacity. Feedstock, Natural Gas

Plant Capacity, Tons NH_3/day	200	600	1000	1500
M tons NH_3/year	66	198	330	495
Plant investment, $ million	20.8	39.5	54.5	69.5
Working capital, $ million[a]	1.4	2.8	4.0	5.4
Total investment	22.4	42.3	58.5	74.9
Natural gas 38,500 cf x 0.40/Mcf	15.40	15.40	15.40	15.40
Cooling water, 55 m. gal.	1.10	1.10	1.10	1.10
Boiler feed water, 600 gal.	0.30	0.30	0.30	0.30
Electricity, 33 Kwh x 0.015	0.50	0.50	0.50	0.50
Catalysts and Chemicals	0.60	0.60	0.60	0.60
Labor, $237,600/yr.	3.60	1.20	0.72	0.48
Analyses, 20% of Labor	0.72	0.24	0.14	0.10
Overhead, 100% of Labor	3.60	1.20	0.72	0.48
Maintenance, 5% of P. I.	15.75	9.98	8.25	7.02
Interest, 8% of ½ P. I.	12.60	7.98	6.60	5.62
Taxes and Insurance, 2% of P. I.	6.30	3.99	3.30	2.81
Depreciation, 15 years	21.01	13.31	11.05	9.36
Production Cost	81.68	55.80	48.68	43.77
20% R.O.I.	67.27	42.73	35.45	30.26
Ammonia Price	148.95	98.53	84.13	74.03

[a] 25% of annual production cost

Table 5

Urea Production Cost

Plant capacity, tons/day	333	1000	1667	2500
M tons/year	110	330	550	825
Plant investment, $ million	14.5	27.6	38.1	57.2
Working capital, $ million[a]	2.3	4.4	6.7	8.7
Total investment, $ million	16.8	32.0	44.8	65.9
		Cost, $/ton of urea		
Ammonia 0.60 tons[b,c]	49.01	33.48	29.21	26.26
Natural gas component of ammonia cost	(9.24)	(9.24)	(9.24)	(9.24)
Cooling water[c]	0.58	0.58	0.58	0.58
Steam, 429 lb. x $1.5/m lb.[c]	0.63	0.63	0.63	0.63
Labor	3.60	1.60	0.96	0.96
Electricity, 30 Kwh x $0.015[c]	0.45	0.45	0.45	0.45
Maintenance, 5% of P. I.	6.59	4.18	3.46	3.46
Taxes and Insurance, 2% of P. I.	2.64	1.67	1.39	1.39
Depreciation, 15 years	8.79	5.58	4.62	4.62
Analyses	0.72	0.32	0.19	0.19
Interest, 8% of ½ P. I.	5.27	3.35	2.77	2.77
Overhead, 100% of labor	3.60	1.60	0.96	0.96
	81.88	53.44	45.22	42.27
R.O.I. on ammonia, P. I., 20%	37.82	23.94	19.81	16.85
R.O.I. on urea, P. I., 20%	26.36	16.73	13.85	13.85
R.O.I. on working capital, 20%	4.18	2.67	2.25	2.11
Bulk price	150.24	96.78	81.13	75.08
Bags and bagging	15.00	15.00	15.00	15.00
Bagged price	165.24	111.78	96.13	90.08

[a] 25% of annual production cost for total complex
[b] At production cost, see table 11
[c] Differences in gas and utilities requirements have been ignored

Table 6

Classification of Components of Urea Cost
for an Ammonia Urea Complex

Total plant investment, $ million	35.3	67.1	92.6	126.7
Capacity, tons urea/day	33.3	1000	1667	2500
Costs	$/ton of urea			
Natural gas @ $0.40/Mcf	9.24	9.24	9.24	9.24
Capital related production costs	56.70	35.93	29.75	27.14
Capital related R.O.I.[a]	66.91	42.54	35.25	32.26
Total capital related costs	123.61	78.47	65.00	59.34
Other costs[b]	17.34	9.07	6.89	6.52
Total bulk price	150.24	96.78	81.13	75.08
Bags and bagging	15.00	15.00	15.00	15.00
Total bagged price	165.24	111.78	96.13	90.08
Costs, % of total price of bulk urea				
Feedstock	6.2	9.5	11.4	12.3
Capital related	82.3	81.1	80.1	79.0
Other	11.6	9.4	8.5	8.7

[a] R.O.I. on plant investment plus 70% of R.O.I. on working capital

[b] Labor, utilities, 30% of R.O.I. on working capital, etc.

Table 7

Effect of Location, Date of Completion, and Capacity Utilization on Price of Urea from a Urea-Ammonia Complex[a]

Location	Completion Date	Factor	Complex Cost, $ million	Urea Price, $/ton 100% Capacity	80% Capacity	60% Capacity
Industrial	1972-73	0.67	49.6	55	65	81
Developing	1972-73	0.83	61.5	59	70	88
Industrial	1976-77	1.00	74.1	68	81	103
Developing	1976-77	1.25	92.6	81	97	124
Remote	1976-77	1.50	111.2	94	114	156

[a] Basis: Capacity of complex - 1667 tons of urea/day, 550,000 tons per year. Bulk price of urea assuming natural gas at $0.40/Mcf.

Compound Fertilizers

As mentioned earlier, compound fertilizers are gaining rapidly in popularity in most countries of the world. In Japan the major portion of domestic fertilizer consumption is in the form of compounds, and several other Asian countries produce and consume substantial and increasing amounts of compounds.

For the purpose of this discussion, it will be assumed that the nitrogen content of compound fertilizers will be supplied by urea, ammonium sulfate, and ammonium phosphate. The ammonium phosphate and sulfate may be supplied as such or formed during manufacture of the compound from ammonia and sulfuric or phosphoric acid.

Urea will be the major source in Asia; planned 1978 urea capacity for non-Communist developing Asia is 10.3 million tons of N, about 85% of the total N capacity (1). These estimates do not allow for industrial uses, but it is evident that urea will be the predominant source of fertilizer nitrogen.

It will be assumed that the phosphate content of compound fertilizers will be derived from phosphoric acid either directly or as ammonium phosphate. Where single superphosphate is available, it may be an economical ingredient of compound fertilizers for local use. However, total 1978 estimated production of single superphosphate in developing Asia plus Japan is only 278,000 tons of P_2O_5 (1). Estimated 1978 phosphate supply and demand in developing Asia and Japan are:

	Thousands of tons of P_2O_5		
	Demand	Total Supply	Fertilizer Supply
Developing Asia	2,168	1395	1281
Japan	745	865	782
Total	2,913	2260	2063

The above estimates are the midpoint demand and supply estimated by TVA (1); fertilizer supply has been estimated by allowing 10% of demand for industrial use in Japan and 5% in developing Asia. (The TVA estimates did not allow for industrial use.) It is evident that much of the phosphate will have to be imported unless new facilities not now planned are built.

Methods for Production of Compound Fertilizers

The principal methods for producing compound fertilizer are bulk blending, granulation, and liquid mixing. The main discussion in this paper will be concerned with granulation methods. Bulk blending and liquid mixing have been discussed elsewhere (20, 21).

Granulation processes may be subdivided into methods that merely mix straight fertilizers and granulate them by use of steam and/or water, and those that involve reaction of ammonia with acids (sulfuric and/or phosphoric). Steam granulation is often suitable for small plants when the demand does not justify the more complex equipment required for use of acids and ammonia, or in locations where these materials are not economically available. Although chemical reactions are not a necessary feature of steam granulation, some reactions between ingredients are likely to occur. Typical materials used in steam (or water) granulation are urea, ammonium sulfate, ammonium phosphates, superphosphates, and potash salts. granulation processes of tyis type have been described (4,22).

Use of ammonia and acids in granulation is advantageous because ammonia is a low-cost source of nitrogen; and because the heat of reaction promotes granulation at low moisture levels, minimizing drying requirements. Combinations of urea and ammonium phosphate (UAP) are particularly advantageous because of their high concentration (usually 56% to 64%) which minimizes the cost of bagging, storage, and transportation to farms. Inclusion of ammonium sulfate in the formulations may be desirable when low-cost byproduct ammonium sulfate is available or when there is an agronomic need for sulfur as a nutrient or for acidifying the soil.

Several plants have been built recently to produce UAP products in India, Spain, Japan, and elsewhere. TVA has recently started production of UAP (28-28-0) on a scale of about 400 tons per day. Other grades which have been made in the TVA pilot plant or in large-scale plants include 25-35-0, 36-18-0, 22-22-11, and 19-19-19.

One type of UAP process is based on the TVA diammonium phosphate profess (23). As used in the Coromandel plant in India, the process involves use of prilled urea. Phosphoric acid is partially neutralized with ammonia and the resulting slurry coats urea prills in a granulator where the slurry is further ammoniated to diammonium phosphate. Potash is added in the granulator, if desired. Grades are 28-28-0 and 22-22-11.

Plants in Korea also use a diammonium phosphate process. Potash is added during granulation to make grades such as 14-37-12 or 12-32-16 and prilled urea is added later by dry mixing (blending) to make a variety of NPK grades.

Some plants in Japan use urea solution or a combination of solid and solution in UAP processes. A plant in Spain uses powdered monoammonium phosphate (MAP) which is granulated with urea and potash salts (24). The MAP is further ammoniated during granulation and in some cases sulfuric acid and additional ammonia are used. A wide variety of grades is produced--18-18-18 is one. Some Japanese plants use similar processes.

In the TVA plant, wet-process phosphoric acid (54% P_2O_5) is neutralized with ammonia by a procedure that evaporates the water content and produces a melt containing monoammonium phosphate and ammonium polyphosphate. From 20% to 50% of the P_2O_5 may be in the form of polyphosphates. The melt is granulated with concentrated urea solution (less than 1% moisture) and recycled fines in a pug mill. Since all materials entering the granulation step are anhydrous or nearly so, no drying is required. The product is cooled, screened, and the fines and crushed oversize recycled. The screened product (28-28-0) has exceptionally good physical properties owing to its polyphosphate content. Results of the plant-scale operation have not been published, but the pilot-plant work has been reported (25). Although a pug mill was used in most of the work, recent studies show that rotary drum granulation is feasible and may be preferable. Solid urea may be used instead of solution, decreasing the recycle ratio. However, when prilled urea was used, the product was not entirely homogeneous. Probably crushed prills or crystalline urea would be more satisfactory. So far, only 28-28-0 and 11-57-0 (no urea) have been produced in the large-scale plant. Grades made in the pilot plant include 36-18-0, 21-42-0, 19-19-19, and 22-22-11.

Economic Comparison of UAP Processes--Obviously, the choice of process will depend on what materials are available or can be purchased, their price, the scale of the operation, and the desired grades. When ammonia and phosphoric acid are available at the plant site or can be purchased economically, diammonium phosphate-based process may be preferable for reasons that will be explained later.

Of the DAP-based processes, the Korean process is probably preferable from an economic viewpoint. As mentioned earlier, in this process, potash salts are incorporated during granulation. Addition of potash salts tend to decrease the required recycle rate and increase the plant capacity. Grades such as 10-25-25, 12-32-16, and 14-37-12 may be produced. These grades may be blended with prilled or granular urea to make 19-19-19, 22-22-11, and 28-14-7. (The grades attainable will depend to some extent on the percentage of impurities in wet process phosphoric acid.) The blends are not homogeneous, but they are satisfactory provided the particle size of the urea and the NPK granules is sufficiently closely matched to avoid serious segregation. When homogeneous granular products are desired, a DAP-based process such as that used at Coromandel or Madras (India) may be preferable. When ammonium sulfate is economically or agronomically preferable, a DAP-based process can be used to make homogeneous granular grades such as 18-22-0 and 14-14-14.

The TVA melt-granulation process may be preferable when the cost differential of ammonia and urea is small, when solid urea is not available, or when polyphosphate is agronomically desirable.

Advantages of DAP-Based Processes

One of the advantages of using phosphoric acid as an intermediate in a granulation plant is its ability to convert other fertilizer materials into more valuable forms. For instance, in converting phosphoric acid to diammonium phosphate (18-46-0) 1 ton of P_2O_5 combines with 0.40 ton of N (as ammonia). In most countries, solid nitrogen fertilizer (urea) costs about twice as much per unit of N as ammonia. For instance if ammonia costs \$100/ton (\$119/ton of N), urea may cost \$110 per ton (\$238/ton of N). Therefore, conversion of ammonia to N to solid N increases its value by \$119/ton of N in these assumed conditions. Since one ton of P_2O_5 as phosphoric acid is capable of fixing 0.40 tons of N, the value enhancement of the N is 0.40 x \$119 = \$57.60 per ton of P_2O_5.

Another advantage of DAP (18-46-0) is its high concentration. One ton of DAP is equivalent to 1 ton of TSP (0-46-0) plus 0.39 tons of urea (46-0-0). This high concentration results in savings in storage, handling, bagging, and shipping costs. If bagging costs \$15 per ton, and transportation to market costs another \$15 per ton, these costs amount to \$30 per ton of DAP as compared with about \$42 for the equivalent amount of TSP and urea. The saving (\$12 per ton of DAP) is equivalent to \$26 per ton of P_2O_5. In some cases, bagging costs may be as high as \$20 (in 25 Kg. bags) and distribution costs may be as much as \$25 per ton. The savings in this case would be \$17.50 per ton of DAP or \$38 per ton of P_2O_5, as compared with equivalent amounts of TSP and urea.

The total value enhancement due to utilization of ammonia and high concentration is \$84 to \$96 per ton of P_2O_5 in phosphoric acid.

An alternate use of phosphoric acid is production of triple superphosphate. In this process, P_2O_5 from phosphate rock is converted to an "available" form. In general, one ton of acid P_2O_5 will convert 0.43 ton of rock P_2O_5 to available P_2O_5. (This ratio will vary slightly depending on the composition of the rock.) Assuming rock containing 33% P_2O_5 at a delivered price of $50 per ton and a conversion efficiency of 93%, the cost of the rock P_2O_5 entering the process is $163. If TSP can be imported for $110 per ton, its value is about $242 per ton of P_2O_5. Thus the value enhancement per ton of acid P_2O_5 is ($242-$163) x 0.43 - $34. This is much less than the value enhancement previously calculated for the DAP process. If a low-cost phosphate rock were available locally, the value enhancement would be greater.

Granulation Costs

The capital cost of a DAP-based granulation plant in a developing country is likely to be in the range of $3 to $5 million (battery limits cost for a plant contracted for in 1974) for capacities in the range of 600 to 1000 tons of 18-46-0. (Capacities for potash-containing grades would be substantially higher.) Various auxiliary facilities including storage and bagging would be needed; the total cost might be double the battery limits cost depending on the circumstances. If ammonia or phosphoric acid or both are imported, suitable terminals and storage facilities would be required which would increase the cost further. Typical operating costs for the granulation unit only are in the range of $6 to $10 per ton of product.

Controlled-Release Fertilizers

Fertilizers that release plant nutrients slowly throughout the growing season or even several growing seasons continue to attract the 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 avoidance of burning of vegetation or damage to seedlings. This is an impressive list of potential advantages.

The term "controlled-release fertilizers," as used in the following discussion, refers to fertilizers that for any reason release their nutrient content over an extended period. Even a simple choice among materials inherently slow to dissolve is viewed as a measure of control.

Controlled-Release Phosphate Fertilizers

Numerous controlled-release phosphorus compounds have been tested, and some are in use. Prominent among them are ground phosphate rock, calcined aluminum phosphate ore, basic slag, defluorinated phosphate rock (tricalcium phosphate), fused calcium magnesium phosphate, Rhenania phosphate, bone meal, dicalcium phosphate, magnesium ammonium phosphate, calcium metaphosphate, and potassium metaphosphate. (The so-called metaphosphates are more properly designated as polyphosphates.)

Ground phosphate rock containing about 1.8 million metric tons of P_2O_5 was applied to the soil in 1969-70 (26). This probably represented some 6 million tons of rock. About half was used in the U.S.S.R., and the remainder was widely distributed among many countries.

The effectiveness of ground phosphate rock varies widely with variation in its reactivity. A good indication of reactivity is solubility in neutral ammonium citrate. The effectiveness of the most reactive rocks, such as those from Gafsa and North Carolina, may approach the effectiveness of water-soluble phosphates on some soils and with certain crops. The least reactive rocks, such as igneous apatite and Udaipur (India) rock, are quite ineffective on all soils. Effectiveness depends on soil pH and is greatest on acid soils; on high-pH soils, even highly reactive rocks are quite ineffective. As an exception, calcined aluminum phosphate ores, such as those from Senegal or Christmas Island, are more effective on neutral or alkaline soils.

Basic slag containing about 1.3 million metric tons of P_2O_5 was used in 1971-72 (1). Gross weight of the slag probably was about 8 million tons. Basic slag is generally regarded as quite effective except on calcareous soils. It is also valued for its content of the secondary nutrients calcium and magnesium and for its micronutrient content.

Calcined aluminum phosphate ore is used mainly in France. It tends to be more effective on high-pH than acid soils. The main source of aluminum phosphate ore is Senegal. However, several other occurrences are known, and some is now being mined on Christmas Island. Its effectiveness depends on the calcination temperature and on fine grinding, and may be indicated by solubility in neutral or alkaline ammonium citrate. It is more soluble in the alkaline reagent.

Straight dicalcium phosphate is manufactured for fertilizer use in relatively small quantities in France and Belgium. However, substantial amounts are present in nitric phosphates and ammoniated superphosphates. It is fully soluble in neutral ammonium citrate and is generally considered to be an effective fertilizer, particularly on acid soils when broadcast in fine particle size and incorporated with the soil.

Fused calcium magnesium phosphate is manufactured mainly in Japan. It is effective on acid soils when finely ground. It supplies magnesium and silica, which may be quite helpful in some soil-crop combinations.

Most of the insoluble or slightly soluble phosphate materials are used either because they are less expensive than soluble phosphates or because they supply other elements. Very seldom if ever can any agronomic superiority be attributed to their slow release of nutrient in the soil. In fact, the slightly soluble materials often give inferior results, particularly in the first year of application. However, some of them are valued for specialty uses because they may be safely placed in contact with seeds or roots, whereas soluble phosphates might damage seedlings or roots in some situations.

Soluble phosphates react rapidly with the soil to form relatively insoluble products (26). So even fully soluble phosphates become slow-release fertilizers in the soil. The main effort has been to find ways to increase the release rate. When soluble phosphates are applied in granular form, the reaction with the soil is delayed, and pockets of relatively soluble phosphate may persist at the granule sites for several weeks. Thus, good results usually are obtained by placement of soluble granular phosphate fertilizers near the seed.

Controlled-Release Nitrogen Fertilizers

The need for a slow release nitrogen fertilizer seems more acute than for phosphate (or potash). Utilization of applied nitrogen fertilizer by crops seldom exceeds 50% and is often as low as 20%. Most of the remainder is lost through leaching, decomposition, or volatilization. While the utilization of phosphate is also low during a single year, the remainder stays in the soil and benefits future crops, so long-range utilization often is high.

With the present high price and shortage of nitrogen fertilizer, improved utilization is particularly important. If the recovery of nitrogen could be increased by one-third (for example) the effect would be equivalent to increasing the nitrogen supply by that amount. Nitrogen losses are especially heavy with flooded rice, especially when grown under conditions of intermittent flooding or poor water control.

Slightly Soluble Materials--One group of controlled-release nitrogen fertilizers comprises chemical compounds that are only slightly soluble. It may be noted that the rate of release of nutrient from most of these slightly soluble compounds is not directly related to water solubility. Instead, the release rate is related to microbiological attack which converts the nitrogen to forms that can be utilized by plants. However, the rate of attack is related to the rate of solution, which depends, in turn, on solubility, particle size, and other factors.

Urea-aldehyde compounds are the principal representatives of this group that are produced commercially. Isobutylidene diurea (IBDU) is produced in Japan through the reaction of urea with isobutyraldehyde in 2:1 mole ratio. When pure, it contains 32.18% N. Hamamoto (27) reported methods for its preparation and discussed its usefulness as a fertilizer. Crotonylident diurea (CDU), also called cyclodiurea, is produced in Japan and Germany through the reaction of urea with crotonaldehyde or acetaldehyde. The pure compound contains about 32% N.

Ando (5) reported a Japanese consumption of 1800 tons of N as IBDU and 1400 tons as CDU in 1968--a total of 3200 tons of N or 10,000 tons of the two slow-release materials. This was more than twice the 1966 use. Tsuno* reported construction of a 40,000 ton/year plant (13,000 tons of N) in

*Tsuno, Tomohai, Proc. Fert. Ind., Round Table, 1972, pp. 21-42.

Japan in 1972. The materials were used to prepare compound fertilizers in which about half of the nitrogen was in slow-release form.

Hamamoto (27) discussed agronomic studies made in Japan with IBDU and other slow-acting nitrogen materials. The release rate from these slightly soluble materials is a function of the particle size. Under Japanese conditions, use of these materials was often advantageous in improving yields and in saving labor by decreasing the number of applications. Hamamoto stated that the cost of IBDU to farmers was over twice that of conventional nitrogen fertilizers per unit of nitrogen. Compound fertilizers of 1:1:1 ratio with half of the nitrogen supplied as IBDU cost about 20% more than conventional fertilizers. For this reason they were used mainly on vegetables and cash crops and not so much on grains.

Urea-formaldehyde reaction products, usually called "ureaform," are produced by about six manufacturers in the United States and in several other countries. Unlike IBDU and CDU, ureaform is not a definite chemical compound. It contains methylene ureas of different chain lengths; the solubility increases with decrease in chain length. It usually contains about 38% N.

Perhaps the most useful component of ureaform as a slow-release nitrogen material is trimethylene tetraurea; shorter chain lengths are too rapidly decomposed, and longer chains are highly resistant to decomposition. Unfortunately it is very difficult to produce commercially a pure trimethylene tetraurea; ureaform contains both shorter and longer chains.

A typical ureaform may contain 30% of its nitrogen in forms that are soluble in cold water (25° C.). The quality of the remaining 70% is judged by the percentage that is soluble in hot (boiling) water as determined by prescribed analytical procedures. At least 40% of the nitrogen insoluble in cold water should be soluble in hot water for acceptable agronomic response; typical values are 50 to 55%.

The consumption of ureaform in the United States is approximately 50,000 tons per year. Most of the production goes into compound fertilizer for specialty uses, such as for lawns, flower gardens, and golf courses. The wholesale price of ureaform per unit of nitrogen is about three times that of urea, ammonium nitrate, or ammonium sulfate.

Ureaform is used in Japan as a component in compound fertilizers. Kuwabara (28) described technology for granulation of ureaform with other materials, including urea, ammonium sulfate, ammonium phosphate, and potash.

In TVA's tests of many other organic nitrogen-containing compounds as fertilizers, some proved readily available, some slowly available, some inert, and some toxic. Among those that showed promise as slow-release fertilizers were oxamide, glycouril, cyanuric acid, ammeline, and ammelide. For lack of a practical process, none of these materials has been manufactured commercially for fertilizer use.

Coated Soluble Materials--A wide range of materials and techniques have been explored with the object of making controlled-release fertilizers by coating soluble fertilizer materials with plastic films, resins, waxes, asphaltic materials, or other barriers. The only known commercial production of coated controlled-release fertilizer utilizes a process developed by Archer Daniels Midland Company (ADM). The main component of the coating is a copolymer of dicyclopentadiene with a glycerol ester (29). Applied in several layers that vary in composition, the coating releases fertilizer solution by osmotic exchange with moisture from the soil. The coated granular fertilizer was manufactured by ADM under the trade name Osmocote starting in 1964. It now is produced and marketed by Sierra Chemical Company under exclusive license from ADM. Three grades of Osmocote are available: 14-14-14, 18-9-9, and 36-0-0. The

nitrogen in the first two grades is supplied by ammonium nitrate and ammonium phosphate; the third grade is coated urea. The weight of the coating ranges from 10 to 15% of the gross weight.

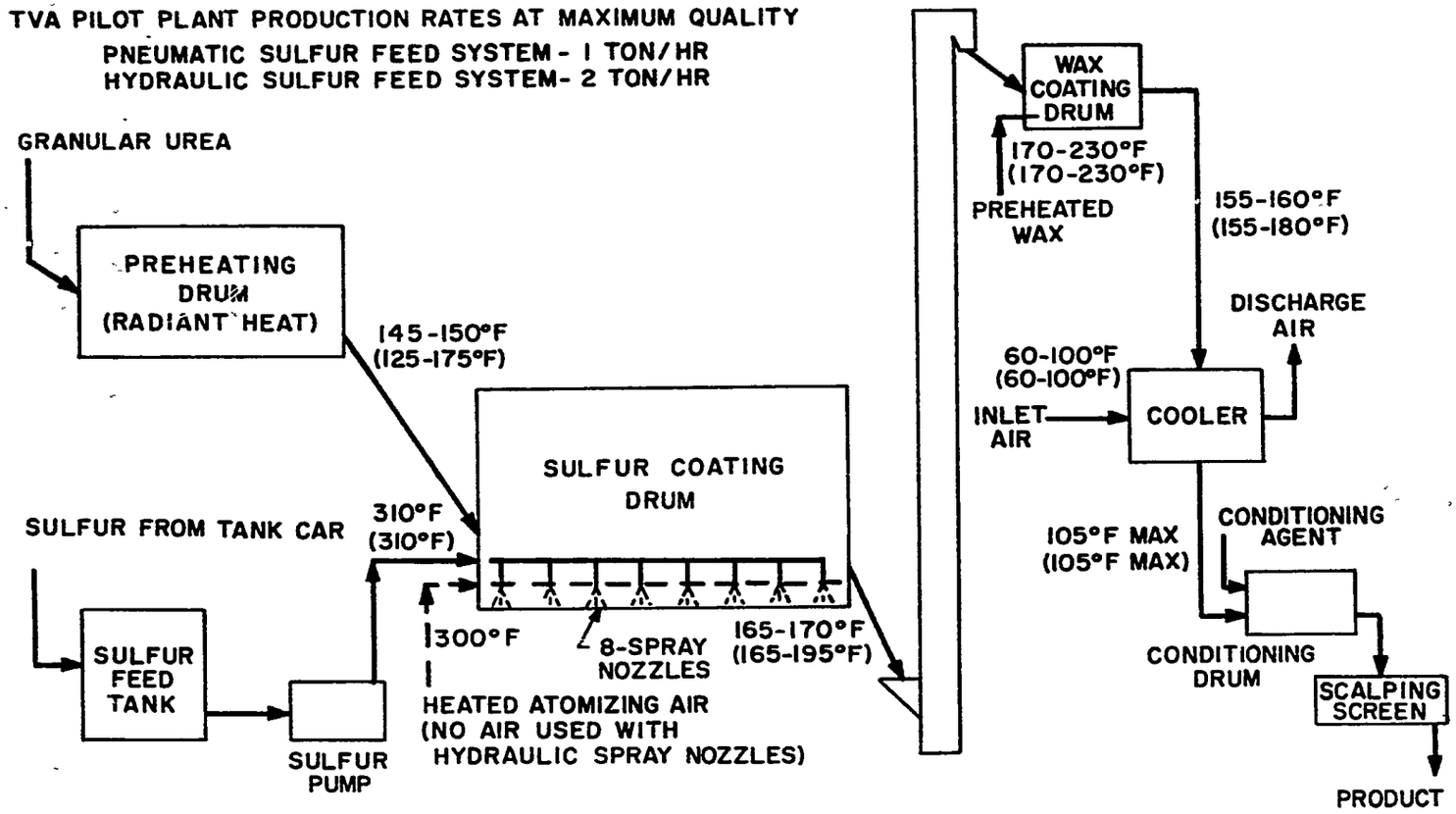
Osmocote products are recommended for turf, floriculture, nursery stock, and high-value row crops. The retail price was reported to be about $0.73 to $0.95 per kilogram in 1974.

Sulfur-coated urea (SCU) is a controlled-release material that has been under development by TVA for 13 years. Sulfur was selected as the coating material on the basis of economy and efficiency after several coating materials were tried. Urea was selected as the material to be coated because of its high nitrogen content, low cost, and commercial availability.

Initial studies indicated that sulfur alone was not adequately resistant to moisture penetration. The discovery that an oily wax sealant was required with the sulfur provided a breakthrough to a successful coating. However, subsequently satisfactory sulfur-only coatings were developed.

In early laboratory work, 1 to 7 kilogram batches of urea were coated in small drums. The development then was shifted to a small continuous pilot plant with a production rate of about 150 kilograms per hour. Development of the process in a large pilot plant with a design capacity of 2 tons per hour is nearing completion. Shirley (30) has summarized results from the large plant operation. Production in a demonstration-scale unit at 10 tons per hour is planned about 1976.

A schematic flow diagram of the pilot plant is shown in figure 12. Granular urea is preheated in the first rotating drum with electric radiant heaters to prevent the sulfur from freezing too rapidly on the granules. The molten sulfur is atomized and sprayed onto the rolling bed of granules in the second drum. Both air atomization and hydraulic atomization were studied. Wax is applied in the third drum. The coated granules are then cooled in a



TEMPERATURE CONDITIONS FOR PROCESS WITH A HYDRAULIC SULFUR FEED SYSTEM ARE SHOWN IN PARENTHESIS

FIGURE 12. FLOWSHEET OF PROCESS FOR SULFUR-COATING UREA WITH ADDITION OF A WAX SEALANT USING EITHER PNEUMATIC OR HYDRAULIC SULFUR SPRAYING SYSTEM

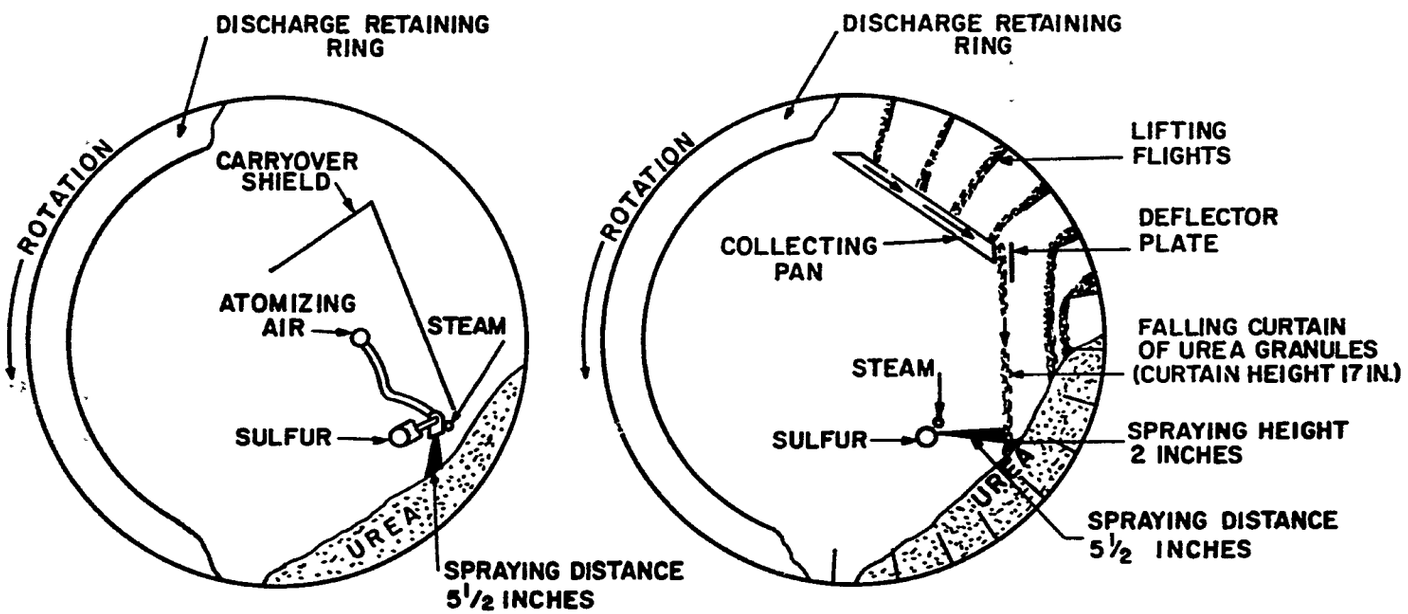
fluidized bed cooler, and a powdery conditioner is applied in a fourth drum to eliminate the tacky condition of the wax.

Figure 13 shows arrangement of nozzles and other internal parts in the sulfur coating drum when using pneumatic or hydraulic nozzles. The hydraulic nozzles have the advantage that less sulfur mist is formed that would require collection and recycle or disposal. Also, higher capacities are possible with the hydraulic nozzles.

Most of the work was done with commercial granular urea (1.7 to 3.3 mm) produced by the spray-drum granulation process and with pan-granulated urea. Some tests were made with prilled urea, but its smaller particle size results in greater surface area per unit weight of urea; this greater surface requires a coating that is higher in percentage by weight of the product for a given coating thickness. For this reason, large, well-rounded granules are preferred for coating.

The rate of dissolution of coated urea can be varied by varying the thickness of the coating. As an indication of the dissolution rate, a laboratory test is used in which the percentage of the urea that dissolves in 7 days in water at 38°C. is measured. Current agronomic information indicates that in general the best results are obtained with materials that have a 7-day dissolution of 20 to 30%. Such material can be produced with a total coating weight of as little at 15% (10% sulfur, 2% sealant and 3% conditioner). The product would contain about 39% N. A similar dissolution rate can be obtained with a sulfur coating with a coating weight of about 20% (36 to 37% N in product). The sulfur-only coating is less expensive, and the process is simpler.

Dissolution rates in soil at 3 temperatures are shown in Figure 14 for a typical pilot-plant product coated with 20% sulfur without sealant. For comparison, dissolution rate in water at 25°C. is unknown. This product had a



USING PNEUMATIC SULFUR SPRAYING

USING HYDRAULIC SULFUR SPRAYING

FIGURE 13. SULFUR COATING DRUM OPERATION

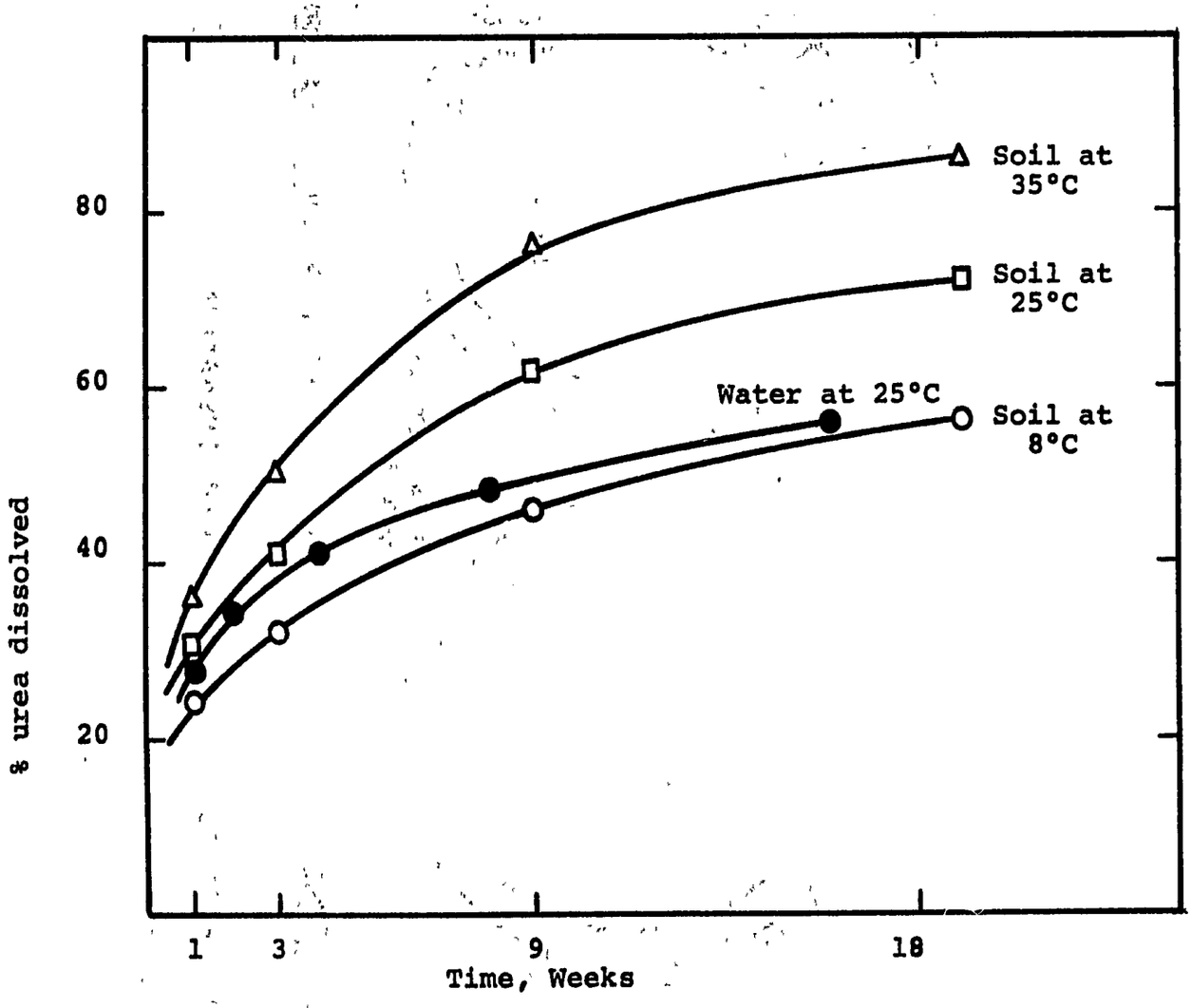


Figure 14. Dissolution of Sulfur-Coated Urea in Soil or Water
Sulfur Coating, 20%, No Sealant

dissolution rate of 26% by the standard laboratory test procedure (7 days in water at 38°C.). It is evident that the dissolution rate is strongly dependent on temperature and is somewhat higher in soil than in water. However, many factors may affect the rate of dissolution in soil. Allen et al. (31) have published data on the rate of dissolution in the soil as affected by coating weight, temperature, and placement.

In addition to the controlled-release characteristics, coated urea has excellent storage and handling characteristics and might even be handled in bulk in humid climates. Also, it may be blended with triple or single superphosphates, which are incompatible with uncoated urea.

Agronomic tests have been completed or are in progress in 29 countries and in 36 states of the United States. Some results of TVA tests have been reported (32, 33, 34).

Coated urea was advantageous for use on sugarcane, pineapple, rice grown with delayed or intermittent flooding, and in general for long-season crops or for conditions conducive to heavy leaching or to decomposition losses.

Rough estimates indicate that with granular urea at $150/ton and sulfur at $60/ton, a coated product (20% S) could be produced at a cost of about $140/ton. Thus, the cost per ton of coated product would be somewhat lower than straight urea, although the cost per ton of N would be about 16% higher. Since many tests with rice have shown as much as 33% increased efficiency, a 16% increase in cost could readily be justified. The improved physical properties of the product would be an additional advantage.

The sulfur-coating technique may be applied to fertilizers other than urea. Experimental work has included coating of diammonium phosphate, potassium chloride, potassium sulfate, and various compound fertilizers, including a pan granulated urea-potassium chloride product of 32-0-16 grade.

Nitrification Inhibitors--Nitrogen fertilizers in the ammonium form are immobilized in the soil by sorption on clay particles and hence are resistant to leaching. However, the ammonium form is rapidly converted to the nitrate form in most soils by microbiological processes called nitrification. The nitrate form is more readily available to most plants, although some plants (e.g., rice) can readily use the ammonium form. Thus, some of the purposes of controlled release (resistance to leaching and delayed availability) may be attained by delaying nitrification of ammonium nitrogen.

Numerous organic chemicals have been identified as nitrification inhibitors. The inhibition is due to the toxicity of these chemicals to organisms that convert ammonium nitrogen to nitrite, which is the first step of the nitrification process.

One of the nitrification inhibitors that has received attention in the United States is 2-chloro-6-(trichloromethyl) pyridine. The Dow Chemical Company is promoting it under the trade name N-Serve. The minimum concentration of N-Serve in the soil for delaying nitrification at least 6 weeks is said to range from 0.5 to 10 parts per million.

Dow points out that a nitrification inhibitor is helpful only when conditions favor high nitrogen loss from the soil. Such conditions are heavy rainfall or heavy irrigation, coarse textured soil, soil in the pH range where nitrification readily occurs, and anaerobic soil conditions.

Potassium azide (2 to 6% KN_3) dissolved in anhydrous ammonia was effective in lowering the rate of nitrification in tests conducted by the U. S. Department of Agriculture in cooperation with agricultural experiment stations in the states of Louisiana (35) and Washington (40). PPG Industries, Inc., is exploring this and other agricultural uses (e.g., as a herbicide in rice culture) for the azide.

Another nitrification inhibitor that has received much attention in Japan is 2-amino-4-chloro-6-methyl pyrimidine. It is manufactured by Mitsui Toatsu Chemicals, Inc., (formerly Toyo Koatsu Industries, Inc.) under the trade name AM. Japanese companies produced 15,400 metric tons of NPK fertilizers containing AM in 1968.

Controlled-Release Potash Fertilizers

Some interest has been shown in controlled-release potassium fertilizers. TVA conducted tests with potassium polyphosphates and potassium calcium pyrophosphates. Some of the materials were only slightly soluble in water by the AOAC procedure. Agronomic evaluation of the materials was reported by Engelstad (37). Their only advantage was reduced injury to germinating seeds. Most of the materials were as readily available as soluble potash salts. Some of the least soluble materials showed slow-release characteristics when applied as large particles (about 7 mm), but there was no conclusive evidence of increased efficiency.

More recently, sulfur-coated potassium chloride has been prepared by TVA for agronomic tests. Some of these tests were promising in that yields were increased in comparison with uncoated potassium chloride (42). More information is needed for agronomic and economic evaluation. Controlled-release N-K products may also offer some promise and are under study at TVA.

Conclusions About Controlled-Release Fertilizers

Controlled-release nitrogen fertilizers very probably will prove useful for some field crops in some situations. Much more study will be required, however, to determine the place of controlled-release nitrogen fertilizers in the farm economy. Recent drastic increases in the price of nitrogen fertilizers should increase the attractiveness of controlled-release fertilizers for some uses.

Controlled-release fertilizers are most likely to prove advantageous where labor is scarce and expensive. In developing countries where labor is plentiful and inexpensive, multiple applications of soluble fertilizer can be used to attain improved yields and higher efficiency of utilization with less cost. However, field results have shown that use of sulfur-coated urea on intermittently flooded rice increases yields in comparison with the use of uncoated urea, even when the latter is applied in split applications.

Prospects for improvement of phosphate and potassium fertilizers through controlled release seem relatively less hopeful than for nitrogen.

Summary

Conspicuous trends in the world fertilizer situation include a rapid rate of growth in production and consumption; increasing concentration of N, P_2O_5, and K_2O; and a growing preference for compound rather than single-nutrient fertilizers. Variety and complexity of formulation of compound fertilizers are increasing to meet requirements of various crops and soils. To an increasing extent, fertilizer manufacturers will concern themselves with secondary and micronutrient elements, as well as the three major nutrients.

Dramatic reductions in cost of producing basic fertilizer materials have been achieved through improvements in technology and increased scale of operation. There is a growing tendency to use these basic materials as intermediates in small local mixing plants that combine them into compounds that meet the needs of their area. Highly concentrated intermediates, such as ammonia, ammoniating solutions, phosphoric acid, ammonium phosphates, and refined potash salts, are being used to an increasing extent in local plants; developments in transportation of intermediates contribute to the economics of their use. The local plants are of three types--dry mixing, including bulk blending; liquid mixing; and granulation.

High-analysis materials, particularly urea and ammonium phosphates, will supply increasing percentages of the world's fertilizers, whereas lower analysis materials will decline in importance. Ammonium polyphosphate is an interesting new material. New nitric phosphate processes are available that provide high water solubility and higher concentration. The nitric phosphate processes are often economically attractive, but lack of versatility has limited their acceptance in some regions.

The economics of ammonia and urea production are strongly influenced by capital investment costs which have increased sharply. Capital related costs can be minimized by operation at or near full capacity. As ammonia costs less than half as much as urea, the next cheapest nitrogen material, studies of means for utilizing ammonia for direct use as fertilizer seem justified.

Utilization of natural gas as feedstock may be particularly attractive where gas is available for which there is no economic alternative use provided the location is not so remote as to involve unusually high investment costs, poor capacity utilization, or excessive product shipping costs. However, use of imported LNG may also be attractive for countries that have sufficient total demand to justify expensive facilities for importing it. Heavy fuel oil may be an attractive feedstock under some circumstances.

Controlled-release fertilizers are a subject of much interest. Controlled-release nitrogen fertilizers offer some definite advantages for some crops and soils. Their future will depend on technological developments to allow production costs commensurate with their advantages. The present high cost and shortage of nitrogen fertilizers should stimulate development work on controlled release nitrogen fertilizers where improved efficiency of these products has been demonstrated.

References

1. Harre, E. A., Livingston, O. W., Shields, J. T. World Fertilizer Market Review and Outlook. Tennessee Valley Authority, Muscle Shoals, Alabama 35660. April 1974. Bulletin Y-70.
2. Stc[illegible], P. R. J. Agr. Food Chem. 4, No. 12, 1000-6 (December 1956).
3. Manderson, M. C. Chem. Eng. Progr. 68, No. 4, 57-61 (April 1972).
4. Nitrogen, No. 66, 29-34 (July-August 1970).
5. Ando, Jumpei. Proc. 20th Annual Meeting Fertilizer Industry Round Table (Memphis), 84-92. Office of Secretary-Treasurer, Glen Arm, Maryland 21057. 1971.
6. Fertilizer Situation. Economic Research Service, U. S. Department of Agriculture, Washington, D. C. March 1971.
7. Beaton, J. D., Fox, R. L. "Fertilizer Technology and Use," 2nd ed., Chapt. XI. R. A. Olsen, Editorial Committee Chairman. American Society of Agronomy, Madison, Wisconsin. 1971.
8. Terman, G. L., Engelstad, O. P. Com. Fertilizer 112, 30, 32-3, 36, 40 (June 1966).
9. Fourcassie, F., Gadet, R. Bull. Ass. Fr. Etude Sol. 8, 213-37 (1966).
10. Gourny, P., Conesa, A. P. "Possibilities d'Utilisation par la Plante des Polyphosphates Incorpores au Sol." Presented at VI Congres Mondial des Fertilisants, Lisbon, Portugal, October 1968.
11. Conesa, A. P. C. R. Acad. Sc. Paris, 268D, 2063-6 (April 21, 1969).
12. Singh, Y., Dartigues, A. Plant Soil 32, 397-411 (1970).
13. Soubies, L. A., Baratier, J. P. Fertilizer Soln. 12, No. 6, 48-57 (November-December 1968).

14. Mortvedt, J. J., Giordano, P. M. Fertilizer Soln. 14, No. 4, 22-7 (July-August 1970).

15. Fertilizer Soln. 15, No. 6, 88-91 (November-December 1971).

16. Slack, A. V., Blouin, G. M., Livingston, O. W. Farm Chem. 130, No. 6, 124-6, 128, 130, 132 (June 1967).

17. Hignett, T. P. Proc. Fertiliser Soc. (London), No. 108. 1969.

18. Thompson, W. H. Chem. Eng. 83-5 (April 5, 1971).

19. Phosphorous and Potassium No. 68. November-December, 1973.

20. Hignett, T. P. Proc. Fertiliser Soc. (London) No. 87, 1965.

21. Hignett, T. P. Chem. Tech. 2, pp. 627-37, 1972.

22. Fert. International 27, p. 4. September 1971.

23. Young, R. D., Hicks, G. C., Davis, C. H. Ag. and Food Chem. 10, pp. 42-7, 1962.

24. Helmsley, J. D. C., Roig, F. ISMA Tech. Conf. Paper LTE/72/7, 1972.

25. Lee, R. G., Meline, R. S., Young, R. D. Ind. and Eng. Chem, Process Des. Dev. 11, pp. 90-94, 1972.

26. Huffman, E. O. Proc. Fertiliser Soc. (London), No. 71. 1962.

27. Hamamoto, Masao. Proc. Fertiliser Soc. (London), No. 90. 1966.

28. Kuwabara, M. and Hatakeyama, A. Paper presented at 166th ACS meeting. August, 1973.

29. Powell, Robert. "Controlled Release Fertilizers." Noyes Development Corporation, Park Ridge, New Jersey 07656. 1968.

30. Shirley, A. R., Meline, R. S. Paper presented at 167 ACS meeting. April 1974.

31. Allen, S. E., Hunt, D. M., Terman, G. L. Agron. J. 63, No. 4, 529-33 (July-August, 1971).

32. Allen, S. E., Mays, D. A., Terman, G. L. Crops Soils 21, 13-5 (December 1968).

33. Mays, D. A., Terman, G. L. Sulphur Inst. J. 5, No. 3, 7-10 (1969).

34. Mays, D. A., Terman, G. L. Agron. J. 61, 489-92 (1969).

35. Parr, J. F., Carroll, B. R., Smith, S. Soil Sci. Soc. Amer. Proc. 35, No. 3, 469-73 (1971).

36. Papendick, R. I., Parr, J. F. Smith, S., Smiley, R. W. Soil Sci. Soc. Amer. Proc. 35, No. 4, 579-83 (1971).

37. Engelstad, O. P. "The Role of Potassium in Agriculture," 63-77, ed. V. J. Kilmer, S. E. Younts, N. C. Brady. American Society of Agronomy, Madison, Wisconsin. 1968.

38. Allen, S. E., Mays, D. A. J. Agr. Food Chem. 19, No. 5, 809-12 (September-October 1971).