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

Market trends and agronomic suitability of key fertilizers commonly sold in world trade (a directory)

3. AUTHOR(S)

Stangel,P.J.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1974	50p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

TVA

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

(Presented at Fertiliser Assn.of India,Sem.on Optimising Agr.Production under Limited Availability of Fertilisers,New Dehli)

9. ABSTRACT

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-RAA-236	

12. DESCRIPTORS

Assimilation
Chemical analysis
Directories
Marketing

13. PROJECT NUMBER

14. CONTRACT NUMBER

RSSA TV 01-74 GTS

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

4

TVA 136

Market Trends and Agronomic Suitability of Key Fertilizers Commonly Sold in World Trade

by
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Paper to be presented at seminar on Optimising Agricultural Production Under Limited Availability of Fertilizers, sponsored by the Fertiliser Association of India and held December 13-14, 1974, in New Delhi, India

The present shortage of fertilizer and attendant high prices have provided renewed interest by many in ascertaining the current trends and long-term forecast in the production and use of specific types of fertilizers. For the moment many are particularily interested under present conditions in the economic and agronomic effectiveness of a fertilizer or particular group of fertilizers. Quite frequently this interest is due to a specific set of conditions which may be temporary or highly localized.

The purpose of this paper is to examine present usage patterns as to type of fertilizer from a regional (ie. Asia, North America, Europe) or global basis and assess their agronomic suitability for a particular crop from a similarily general basic point. Further, the main discussions will center around likely market potential and the agronomic suitability of a fertilizer or group of fertilizers for use on food crops. It is recognized that conclusions drawn from such a general base may not apply to more specialized crops such as rubber, oil palm, tea, cocoa, etc. Such discussions are beyond the scope of this paper.

World Trends in Fertilizer Production Capacity

Since fertilizer plants represent significant capital investments and thousands of these are now in operation. Major shifts in these patterns of production are not likely to rapidly occur at least over the mid-term (3-6 years) period.

Therefore, probably one of the best indicators not only as to what is now being produced but what can be expected over the next several years is to look at the capacity the fertilizer industry now has or soon will have to produce a given type of fertilizer.

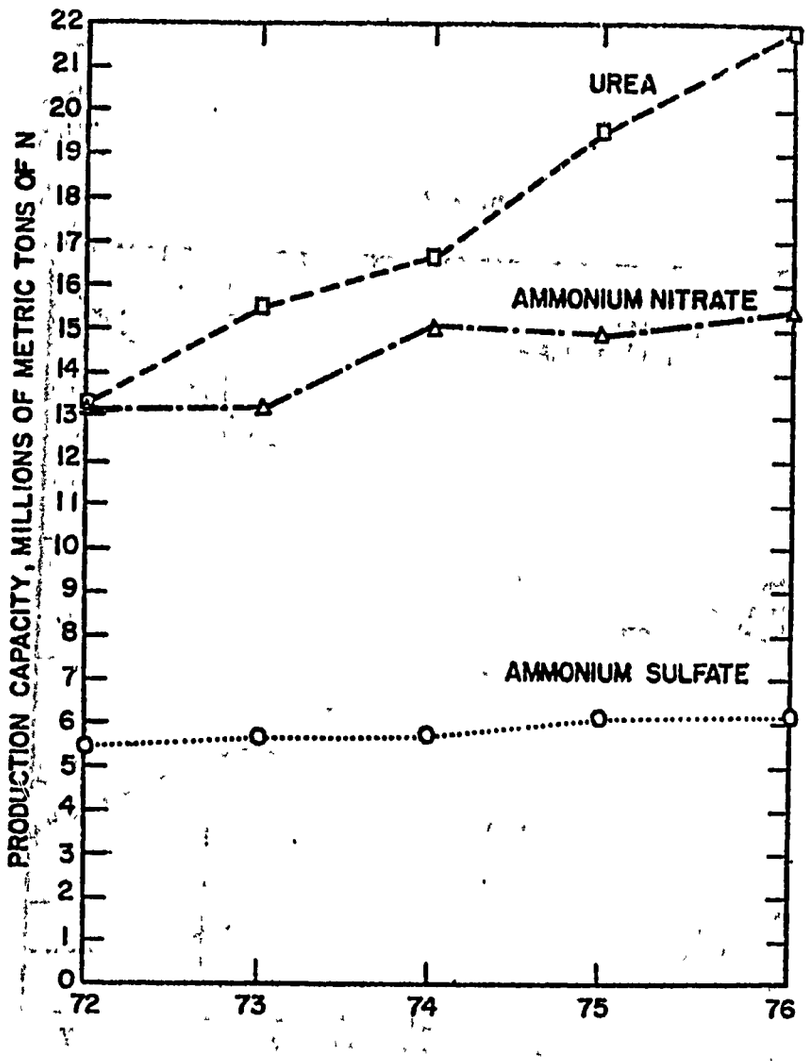
The current and near future capability of the world fertilizer industry to produce nitrogen and phosphate fertilizer appear in figures 1 and 2.

It is clear that over the next 3-5 years urea will continue to increase its dominance as primary dry nitrogen fertilizer used in world agriculture. By 1976 urea will equal the combined capacity levels for both ammonium nitrate and ammonium sulfate (figure 1).

Ammonium phosphates and complex fertilizers will increase their dominance as the prime phosphate fertilizer produced in the world. This will come primarily at the expense of normal superphosphate which, since 1955 has played a decreasing role of importance in the phosphate industry (figure 2). Surprisingly, concentrated superphosphate (CSP) is not forecast to follow the increasing role played by ammonium phosphates. If anything, CSP, like basic slag, will decline importance relative to ammonium phosphates as a phosphate fertilizer.

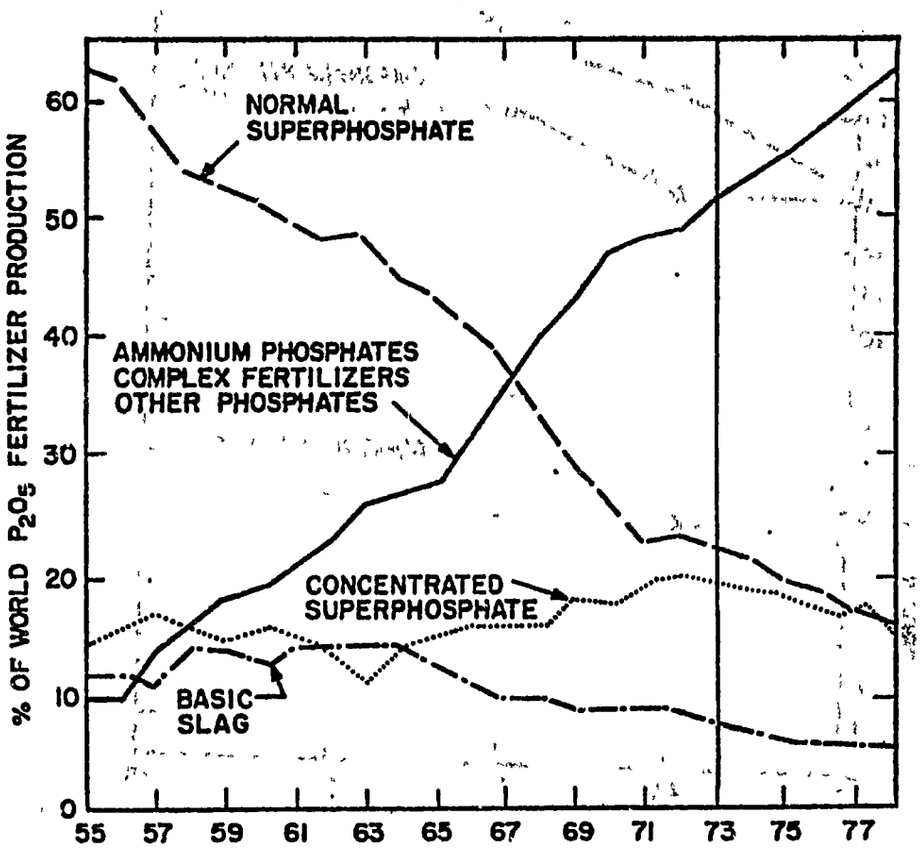
The trends in nitrogen just described for the world are even more pronounced for developing Asia. For example, urea now commands 72% of all the N capacity in that region (figure 3). This will probably increase more in the years to come. The importance of ammonium sulfate, ammonium nitrate, and other nitrogenous products are therefore minor compared to urea. The pattern is not as clear for phosphates in developing Asia. While there has been a general decline in the share of normal superphosphate has of the total phosphate capacity, ammonium phosphates, CSP, and compounds all seem to be playing an equal share in future growth (figure 4). Thus there is not a clear dominance of one material replacing normal superphosphate.

Figure 1



TRENDS IN NITROGEN FERTILIZER PRODUCTION CAPACITY
(DATA FROM TVA MARKETING ANALYSIS STAFF, DOES NOT INCLUDE USSR OR COMMUNIST ASIA)

Figure 2



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

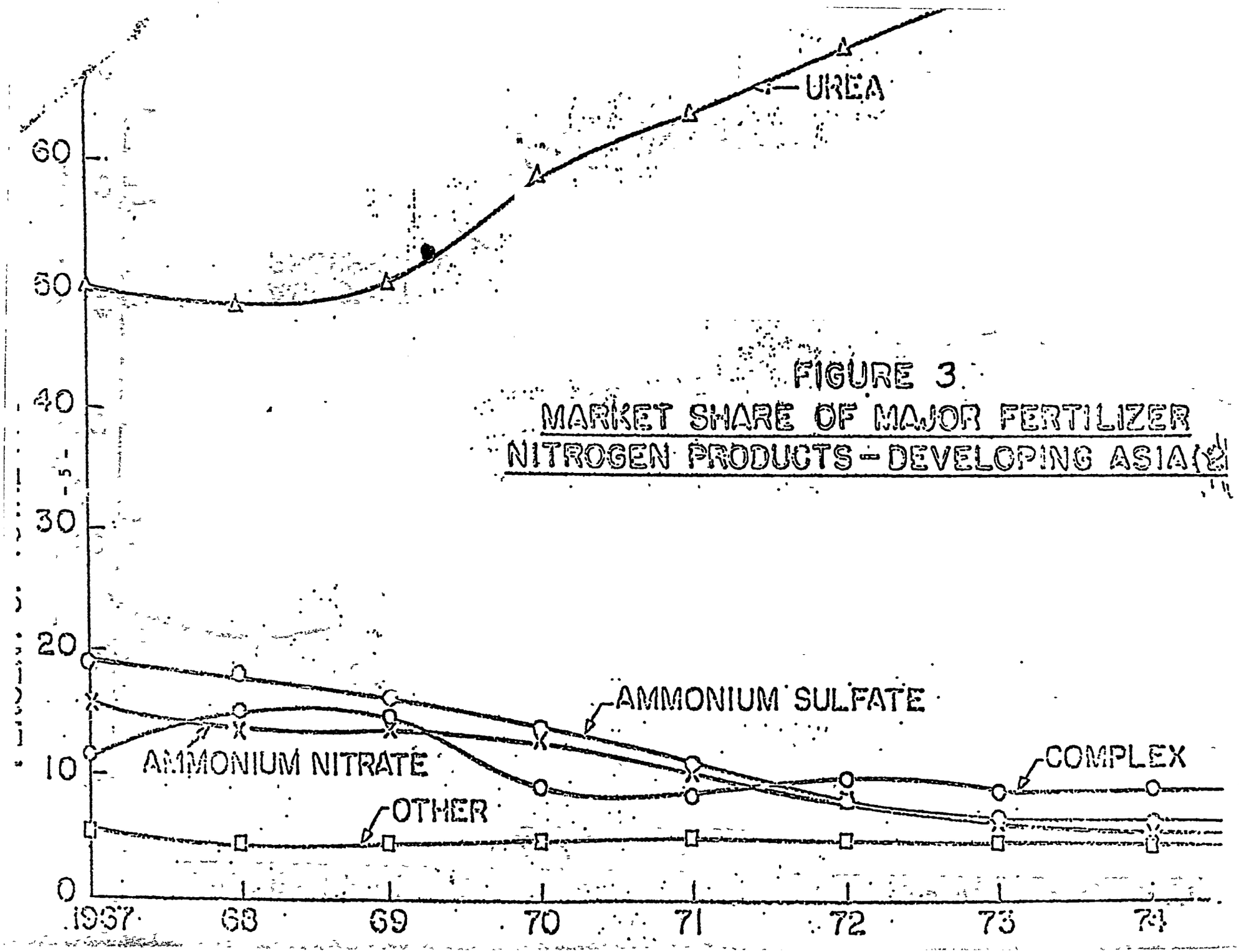
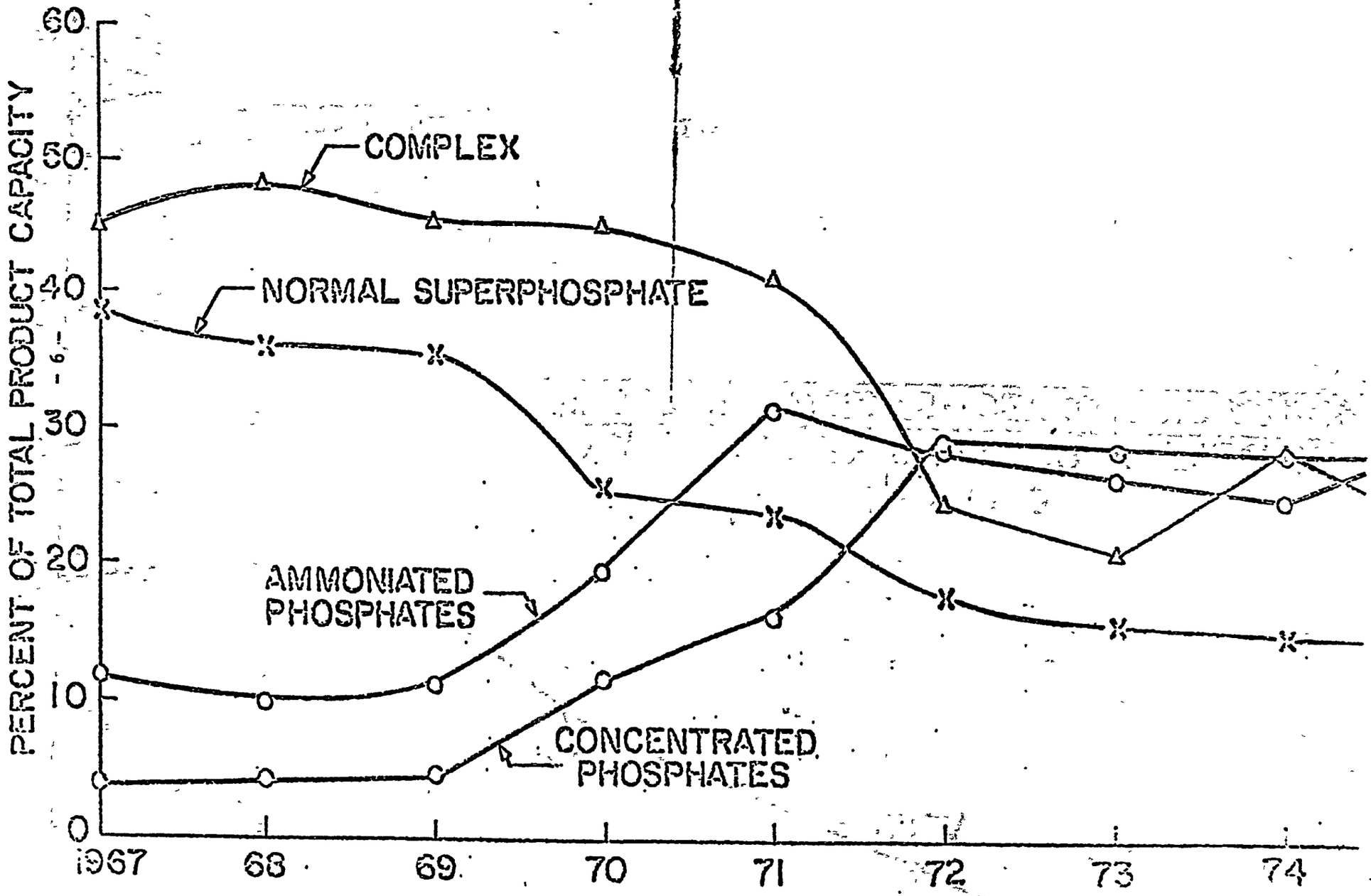


FIGURE 3
MARKET SHARE OF MAJOR FERTILIZER NITROGEN PRODUCTS – DEVELOPING ASIA

FIGURE 4

MARKET SHARE OF MAJOR FERTILIZER PHOSPHATE PRODUCTS

DEVELOPING ASIA[2]



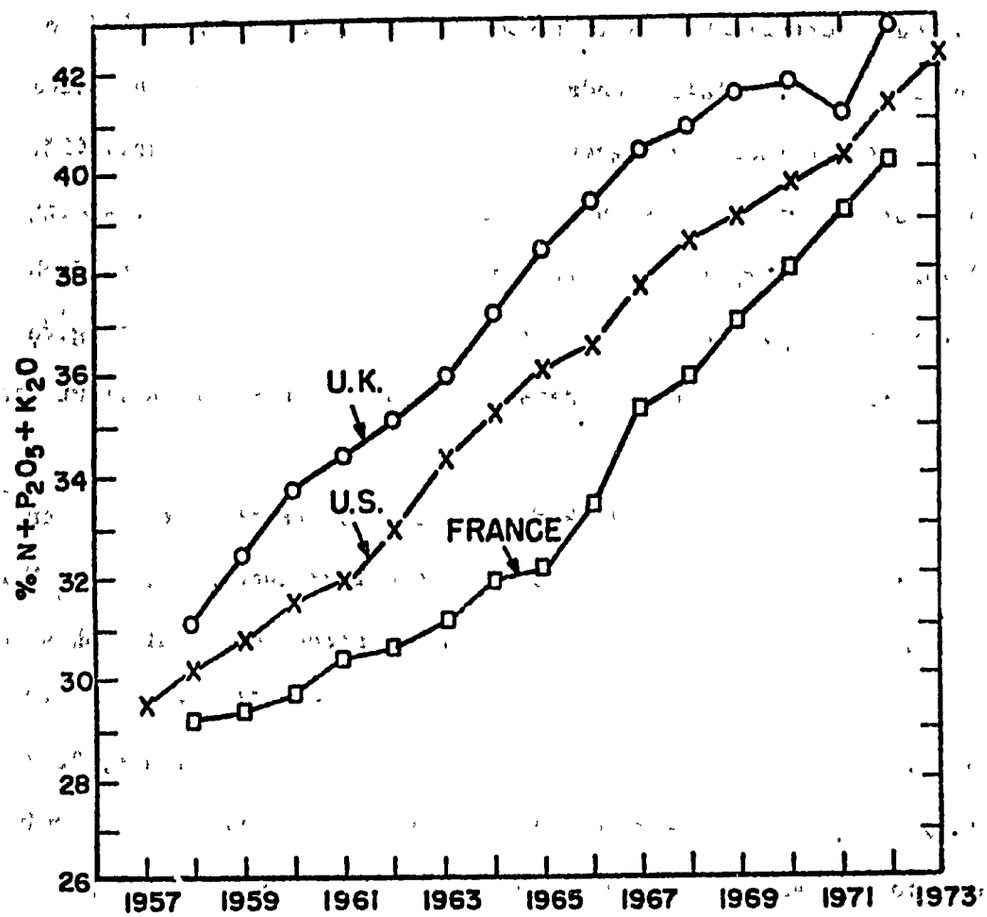
Increased Concentration of Fertilizer

Another important trend has been towards an increase in the concentration of the plant nutrients in the fertilizers. This has come about due to the increased popularity of NP and NPK fertilizers. Figure 5 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 as costs of bagging, storage, handling, and transportation often account for more than half of the cost of fertilizer delivered to the farmer. Consequently, 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 12-31-16 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

Figure 5



TRENDS IN CONCENTRATION OF COMPOUND FERTILIZERS

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.

With this than as a background I would next like to discuss specific types of fertilizers, as to their properties, likely potential in certain markets, and agronomic suitability for major food crops.

Fertilizer Products Having Broad Immediate As Well As Long-Term Potential

Urea, high-analysis compound fertilizers, and ammonium phosphate are experiencing and will continue to experience the greatest acceptance and offer the greatest growth potential in Asia of all the new fertilizers on the market today. These projections are based in part on trends of use by product that have occurred in the past 10-15 years, and on new fertilizer capacity scheduled to be built in Asia in the next 3-5 years.

Although special local situations may dictate otherwise, the materials in decreasing order of immediate potential in Asia are as follows:

Urea

Potential--Urea is the highest N-containing solid fertilizer material commercially available. Its high analysis permits considerable savings in shipping and distribution costs. Because of this, plus the fact that solid fertilizers have better growth potential in Asia than liquids due mainly to the simplicity of shipping and handling dry materials in areas of small land holdings and the lack of widespread availability of sophisticated equipment, urea has proven very attractive to a very large number of farmers and fertilizer manufacturers.

The actual dominance of urea on a per country basis is somewhat upon the amount and type of other nitrogen capacity that now exists within the country. For example, urea will not reach a dominant role in nitrogen production in Taiwan until about 1975 since considerable ammonium sulfate capacity now exists within the country and probably will be used for at least the next 5-6 years. The same holds for The Philippines and, to a lesser extent, Japan. On the other hand, Korea, Indonesia, and Pakistan are in the process of building or have just recently built their nitrogen capacity, almost all of it based on production of urea. In these countries and in countries of low total nutrient use, the dominant fertilizer is and will be urea.

Agronomic and Chemical Properties--Some of the specific chemical and physical properties of urea are as follows: 46% N, solid, prilled or crystalline, usually white, formula NH_2CONH_2, molecular weight 60.06, melting point 132.7° C, heat of solution 57.8 cal/g, specific heat 0.320 cal/g 20°C, solubility 119 g/100 ml H_2O at 25°C, specific gravity 1.335 (1).

When properly applied, urea has been shown to be equal or nearly equal to ammonium sulfate as a source of N to a wide range of crops, including maize, wheat, and rice (2). In those instances where response to urea was less than to ammonium sulfate, the differences have been attributed to either the sulfur component of ammonium sulfate or to the improper use of urea. There are instances where urea has proven to be a superior source of N to rice. This has usually occurred on degraded paddy soils. For these reasons, no other single-nutrient fertilizer has captured the attention of agricultural and fertilizer production specialists as has urea. In most areas, it already has become or is rapidly becoming the leading fertilizer used in the developing world.

In spite of this potential and current rate of acceptance, urea has certain inherent problems that must be overcome if it is to continue to enjoy this current flush of growth. This is particularly true in those regions lacking sophisticated capabilities in handling fertilizer and modern methods of tilling soil. The more significant of these problems are: (a) Its hygroscopic nature which often results in poor handling properties--either as straight material or in blends, particularly under hot, humid conditions (figure 6). Unless corrected, this disadvantage could restrict its use to reduce costs by bulk blending, bulk transport, and mechanical bulk spreading; and (b) nitrogen losses through volatilization as ammonia when urea is surface-applied to soils, especially in warm climates. This is a major problem when the product is not incorporated into the soil immediately after application (3, 4, 5). As much as 60% of the N applied as urea may be lost through this mechanism. Even on flooded rice soils urea has occasionally been shown to be vastly inferior to ammonium sulfate as a source of N to the crop (6). The reasons for this, as yet, have not been identified. These problems are real and will be more apparent as fertilizers become more available and farmers have an opportunity to compare various nitrogen sources in supplying the needs of the crop.

Although it has been suggested by some that the biuret content in all urea produced should be less than 0.3%, it is now believed that this is important primarily for citrus crops in situations where urea is applied as a foliar spray. Extensive tests on other crops suggest that biuret levels in foliar-applied urea can approach 0.75% and not be harmful, and up to 3% biuret is acceptable if the urea is applied to the soil (7, 8, 9) preferably away from the seed.

Figure 6

CRITICAL HUMIDITIES OF FERTILIZER SALTS AND MIXTURES AT 30° C.

(Values are percent relative humidity)

Note: To obtain vapor pressure (mm. Hg at 30° C.) of saturated solution of salt or mixture, multiply critical humidity by 31.8.

	Calcium nitrate	Ammonium nitrate	Sodium nitrate	Urea	Ammonium chloride	Ammonium sulfate	Diammonium phosphate	Potassium chloride	Potassium nitrate	Monoammonium phosphate	Monocalcium phosphate	Potassium sulfate
Calcium nitrate	46.7											
Ammonium nitrate	23.5	59.4										
Sodium nitrate	37.7	46.3	72.4									
Urea	-	18.1	45.6	75.2								
Ammonium chloride	-	51.4	51.9	57.9	77.2							
Ammonium sulfate	-	62.3	-	56.4	71.3	79.2						
Diammonium phosphate	-	59	-	62	-	72	82.5					
Potassium chloride	<22.0	67.9	66.9	60.3	73.5	71.3	70	84.0				
Potassium nitrate	31.4	59.9	64.5	65.2	67.9	69.2	-	78.6	90.5			
Monoammonium phosphate	52.8	58.0	63.8	65.2	-	75.8	78	72.8	59.8	91.6		
Monocalcium phosphate	46.2	52.8	68.1	65.1	73.9	87.7	79	-	87.8	88.8	93.6	
Potassium sulfate	76.1	69.2	73.3	71.5	71.3	81.4	77	-	87.8	79.0	-	96.3

TVA, Applied Research Branch - 1965

Values for mixtures containing diammonium phosphate are approximate values obtained by TVA. Other data are from literature.

Ammonium

Grades available (11-48-0, 18-46-0, 11-55-0, 16-20-0, 16-48-0, 13-29-0).

Potential--It is difficult to forecast the role ammonium phosphates will play in the total phosphate market in Asia. Although their popularity has increased greatly in recent years and, on a world basis they have replaced normal superphosphate as the number one phosphate fertilizer, this growth has occurred primarily in the developed countries where bulk blending has become very popular.

Prediction are for ammoniated phosphates to command a major share of the phosphate market in the developing countries in Aisa by 1976. However, the true direction in growth of ammoniated phosphates in these countries is dependent upon whether bulk blends or complex (N-P-K) fertilizers become popular. This in turn is dependent upon the type of phosphate capacity that already exists within a country. Where little or no phosphate capacity exists, ammonium phosphates have proven very popular--first because their high analysis and good handling qualities make them easy to import and second, as consumption increases, this may lead to the building of large, efficient monoammonium and diammonium phosphate (MAP, DAP) facilities within the country. This provides a basic ingredient essential to the start or continuation of a blending industry.

Where blending has been accepted, such as in the United States, a phenomenal increase in 18-46-0 and 0-46-0 has been observed. Where substantial superphosphate capacity already exists within a country, it may well be used directly in small N-P-K granulation plants. Under those circumstances, the potential for ammonium phosphates will be quite limited.

Agronomic and Chemical Properties--The term "ammoniated phosphates" encompasses a wide variety of fertilizers produced by the ammoniation of phosphoric acid, often in admixture with other materials. A brief description of the properties of at least three types of ammoniated phosphates appears below:

Product	Analysis	Formula	Molecular weight	Color	Specific gravity	Solubility (cold water)
Monoammonium phosphate	11-48-0	$NH_4N_2PO_4$	115.0	white-gray	1.803	58.2 g/100 ml
Diammonium phosphate	18-46-0	$(NH_4)_2HPO_4$	132.06	white-gray	1.619	22.7 g/100 ml
Ammonium sulfate phosphate	16-20-0	-	-	-	-	-

Ammonium phosphates--because of their binutrient content, low hygroscopicity (figure 6), overall high analysis, excellent handling qualities, 100% water solubility of nitrogen, and near 100% solubility of phosphate--offer considerable advantages not only in savings accured in transport and application but also agronomically because of their quick-acting effect on crops.

Ammonium phosphates are particularly suited for direct application in situations where substantial amounts of basal or band-applied phosphorus and small amounts of nitrogen are required. As more sophisticated application equipment is developed, they will be banded rather than broadcast at time of planting for such crops as wheat, maize, and sorghum. Where conditions permit, these materials will more and more be supplied to rice soils during seedbed preparation. Since all of the nitrogen in the ammonium phosphates is in the ammonium form, they are particularly well suited for rice (2).

In contrast to urea, there are few physical or chemical problems associated with the use of ammoniated phosphate in the humid tropics. They have good handling characteristics, can be shipped in bulk in hot, humid regions with little or no difficulty, are compatible with a wide range of other fertilizers, and can be safely applied to the surface of the soil with less danger of either N or P loss. There is at least one problem, however, usually associated with diammonium phosphate; when banded at high rates in contact with or close to the seed under dry conditions, it can release free ammonia in sufficient quantities to retard seed germination or young seedling growth (13). This can be easily avoided through proper placement of fertilizer either by hand or with special banding equipment to ensure that at no time it is closer than 1-2 inches to the side and below the seed.

Chemically- or Physically-Combined High-Analysis N-P-K Fertilizers

Potential--Next to straight urea and one or more of the ammonium phosphates, complete high-analysis N-P-K grades (30+ units of plant food) of fertilizer are just beginning and in the near future will receive major consumer acceptance in Asia.

This, however, will not occur at nearly the rate of acceptance for either of the other products discussed because under current cropping practices, the need for a complete N-P-K fertilizer is not as widespread. The frequency of potash deficiency, particularly for rice, is less than one-tenth that for nitrogen and one-third that observed for phosphates. But with intensification of farming, including use of new and higher-yielding varieties, responses to potash will become more frequent, particularly on the organic sandy and laterite soils; thus N-P-K compounds or mixtures will be in demand. As already discussed in the section on ammonium phosphates,

the acceptance of physically mixed N-P-K grades is dependent upon the potential of bulk blends. Where bulk blends have good potential, physically-mixed N-P-K grades which include ammonium phosphates will probably increase in demand. In regions where bulk blends do not have great potential, such as in much of Asia, the chemically-combined compound fertilizer will grow in acceptance.

Regardless of whether as a blend or compound, N-P-K grades will be of high analysis. Products are now available to make complete fertilizers in either form with at least 40 units of plant food.

Chemical and Agronomic Properties--The products are usually granular solid, color variable but generally grayish if chemically combined variable in blends. They usually contain in excess of 30 units of plant food and are available in a number of ratios and chemical or physical combinations of two or three major nutrients. They are 100% water-soluble N and 50%-100% water-soluble P depending upon the choice of phosphate materials and production processes. The materials most frequently used in N-P-K grades (physical and/or chemical) are urea, ammonium phosphates, muriate of potash, ammonia, or phosphoric acid. Less common but still substantial for use in N-P-K grades are such products as ammonium sulfate, triple superphosphate, sulfate of potash, and on occasion phosphate rock. The agronomic properties of these N-P-K grades are based upon the form of the individual plant nutrient present.

Triple Superphosphate (0-46-0)

Potential--Triple superphosphate is a high-analysis phosphatic fertilizer that has become significantly more important in the last 20 years.

Its use in Asia has increased substantially over the past few years. The fact that ammonium phosphates are experiencing good acceptance in some cases precludes any additional growth as a major source of phosphorus at the consumer level.

The most economical production of triple superphosphate occurs when a supply of phosphate rock is nearby and the phosphoric acid is produced in large and continuously-operating plants.

Chemical and Agronomic Properties--Nonhygroscopic (figure 6), 46% P_2O_5, is usually granular. The phosphorus is almost entirely water soluble and is readily available to most crops under a wide range of conditions. Its low sulfur content (3% or less) relative to that of normal superphosphate is easily overcome by including sulfur-containing material somewhere else in the fertilization program. This fertilizer is free flowing in either run-of-pile or granular form and lends itself readily to ammoniation. This is a particularly important characteristic for those countries that must import phosphate but have their own ammonia facilities. Finally, it is a relatively low cost source of P_2O_5, and its high analysis permits additional economies in handling, shipping, distribution. In spite of all these apparent advantages, most if not all, are equalled or surpassed by ammonium phosphates, particularly DAP and MAP. This coupled with its incompatibility with DAP or urea in blends limits its future growth potential as a material to be used directly by the farmer.

Potash Fertilizers

Potential--Potash ranks third in importance of major nutrients consumed in the developing countries. The relative importance of this nutrient in relation to nitrogen and phosphorus varies significantly among the various

countries under consideration and has already been discussed in some detail under the N-P-K section. Rice, the dominant crop in Asia, historically has responded much more readily to nitrogen and phosphorus than to potassium. Although this relative emphasis has changed in Japan, Korea, and Taiwan and is now changing in India and a few other countries, the major emphasis for some time to come will be on nitrogen and phosphorus and to a lesser extent potash. This will be true mainly where rice is the dominant crop grown in the area. In cases for wheat, maize, and vegetables, potash is frequently equal in importance to phosphate as a primary fertilizer.

Based on the relative small demand for potash by a crop such as rice, the author is of the opinion that the majority of the potash needs by the farmer in Asia will be satisfied via chemically- or physically-combined N-P-K fertilizers. Very few straight potash materials as such will be sold directly at the retail market. Thus, increased use in potash for the area will be very closely related to the growth of N-P-K grades.

Muriate of Potash--Commercial agricultural muriate of potash products contain from 96% to 99% KCl, equivalent to approximately 60% to 62.5% K_2O. Muriate of potash products made from the flotation recovery processes are usually of varying pink to red hues, reflecting the presence of small quantities of colored impurities. Products made by solution and recrystallization methods are white in color, the principal impurity being colorless NaCl.

The potash is 100% water soluble, readily available to the crop, and accounts for over 90% of all the potassium consumed in the world. KCl is readily acceptable as a source of K for most crops which are not affected by the chloride associated with the product.

Because of its nonsulfate composition, muriate of potash is preferred over either sulfate of potash-magnesia or potassium sulfate on degraded rice paddy soils.

Sulfate of Potash--Commercial agricultural sulfate of potash contains from 92% to 98.5% K_2SO_4, equivalent to about 50% to 53.2% K_2O. It also contains over 17% S as the sulfate; thus, combined sulfate of potash represents over 67 units of plant food. The potassium and sulfur are readily available to the crop and this material is used widely on vegetables, tobacco, and other crops where low chloride levels are desired. Because of its sulfur content, it is not recommended for use on degraded paddy soils grown to rice. This product constitutes about 6% of the current sales of all potash.

Sulfate of Potash-Magnesia--It contains from 21% to 26% K_2O, 7% to 11% Mg and 18% to 23% S depending upon the process used to produce the product. All three nutrients are readily available to the crop. It is used primarily in N-P-K grades where magnesium and/or sulfur are needed and contains approximately 55 units of plant food.

Potassium Nitrate--Potassium nitrate contains almost 14% N and 46% K_2O making it a fairly high analysis product. The agronomic value of the product is well-known with both the potash and nitrogen water soluble and readily available to the crop. It is used mainly on high-value specialty crops and not well suited for rice because all of the N is in the nitrate form.

New Potential for Old Products

Without exception, all of the new fertilizers just discussed are higher in N, P, or K than their predecessors and all are either void or extremely low in sulfur and certain other essential nutrients. Because

of this and the proven beneficial effects of sulfur, particularly on wheat, maize, sorghum, and certain pulses, it would seem appropriate to reassess the potential of some of the so-called low-analysis fertilizers. Two of these are ammonium sulfate and ordinary superphosphate.

Ammonium Sulfate (21-0-0)

Potential--Because of its low nitrogen content (21%, all ammonium nitrogen), the downward trend in use of ammonium sulfate was predictable. In most fertilizer research tests, and in many government fertilizer education programs, it has been replaced by other nitrogen sources, usually urea. Under the circumstances then, now, and in most instances in the future, this decision is justified; per pound of N, urea is most frequently a more economical choice. Nevertheless, the relative competitive situation for ammonium sulfate is changing. It is important to note that the majority of ammonium sulfate produced today is as a byproduct usually of the steel or caprolactum industries. Therefore the real cost of ammonium sulfate from this source is negligible. The loss of domestic and export N markets to urea has been substantial (14). This, coupled with increased emphasis on pollution control, has led from time to time to very substantial supply of ammonium sulfate in recent years. Although shortages of all nitrogenous products now exist, prospects are good for a continued and at times an even more abundant supply of ammonium sulfate in the coming years.

Although urea will remain the dominant source of N in the developing nations, the pricing of ammonium sulfate will be sufficiently attractive for the next several years to warrant its reconsideration as a significant source of nitrogen. Consideration must also be given to its 22% sulfur level. Although the exact reason is not known, ammonium sulfate has shown

a slight but consistent superiority over urea as a source of N for rice. Vegetable producers the world over have shown some favor to ammonium sulfate, presumably because of its sulfur content.

Chemical and Agronomic Properties--Ammonium sulfate can be satisfactorily supplied to rice either as a basal application or as a topdressing. When applied to paddy rice fields, changes in leaf color will often be evident with 3 or 4 days.

There are instances where ammonium sulfate is inferior to urea or ammonium chloride as a source of N to rice (15). This is related to the presence of the sulfate radical in its overall makeup. The sulfate radical, when in the reduced layer of the paddy, forms hydrogen sulfide which is harmful to rice plants. This is not a problem on ordinary paddy fields for the hydrogen sulfide will become water-insoluble iron sulfide by combining with the iron usually present in abundant quantities. Degraded paddy fields contain very little iron; thus, in this system there is no mechanism available to counter the yield-reducing toxicity effects of hydrogen sulfide.

Some of the properties of ammonium sulfate are as follows: 21% N, crystalline, size various with production process, color usually white but can be grayish if from byproduct steel process, formula $(NH_4)_2SO_4$, molecular weight 1.769, melting point 512.2°C, heat of dilution, 6.35 cal/kg from 42% to 1.8% solution, density 20°/4° C--solid 1.769, specific gravity--sat. solns. 1.2412 at 20° C. loose bulk density 60 lb/cu ft angle of repose 28° (18).

Ordinary Superphosphate (0-20-0)

Potential--Like ammonium sulfate, until recently ordinary superphosphate was by far the leading phosphate fertilizer in most of the developing countries of the world. This has changed, the decline being caused mainly

by the acceptance of concentrated phosphates, so that it now comprises less than 20% of the world's phosphate and even less in the developing areas of Asia. The primary reasons for this decline were high production and transportation costs both directly related to its low P_2O_5 content (11).

Despite these negative factors, the rate of decline in normal superphosphate is expected to decrease. Depending upon availability of alternate sources of sulfur in fertilizers, such as ammonium sulfate, ordinary superphosphate could actually grow in acceptance in certain regions. Like ammonium sulfate, it contains a significant amount of sulfur. As sulfur needs become more apparent and as granulation of N-P-K fertilizers become more common, the use of ordinary superphosphate should continue to be significant particularly in compound fertilizers unless, of course, an alternate and cheap source of sulfur is available.

Phosphate Rock for Direct Application

The current phosphate shortage and subsequent escalation in price of finished phosphates as well as raw materials has prompted several countries to conduct a major review of the feasibility of applying phosphate rock directly to the soil rather than going through the relatively expensive route of converting the PR to a concentrated phosphate such as DAP, TSP, or simply phosphoric acid.

While shortage of intermediates has been the driving force to merit renewed interest in this area, there have been major breakthroughs in research that clearly suggest that in certain situations it may not be necessary to upgrade phosphate raw materials to high analysis products. This may be the start of a long-term trend.

For example, it is now generally accepted that phosphate rocks when used as a direct application vary greatly in their effectiveness as a phosphate source to the crop (16). This effectiveness appears to be directly related to specific properties of the rock which are easily identifiable and can be readily measured in most modern laboratories equipped with X-ray and/or electron microscope units.

Methodology has recently been developed at TVA where, through the use of chemical and physical characterization of a representative sample for specific properties, the agronomic effectiveness of a particular rock source can be predicted without going through extensive agronomic field trials.

This principle was proven in a greenhouse at TVA and in the rice fields of Thailand by testing several U.S. sources as a DA phosphate application (figure 7). The results showed that North Carolina and north Florida rock were nearly as effective as TSP in increasing rice yields. TVA researchers have extended this work to classify several rocks as to their probable effectiveness (figure 8). For example, it is now presumed that all rocks have 60% or more of their P_2O_5 as citrate soluble and in a number of cases nearly equal the effectiveness of orthophosphates as a source of P to the crop. Some of the rocks falling into this classification appear in figure 4. Note a number of sources from Tunisia, Morocco, Israel, Jordan, etc., have very favorable properties in this regard. The Peruvian source would be very similar to that found for north Florida rock.

TVA has further translated this information into a form that can be translated into economic terms (figure 9).

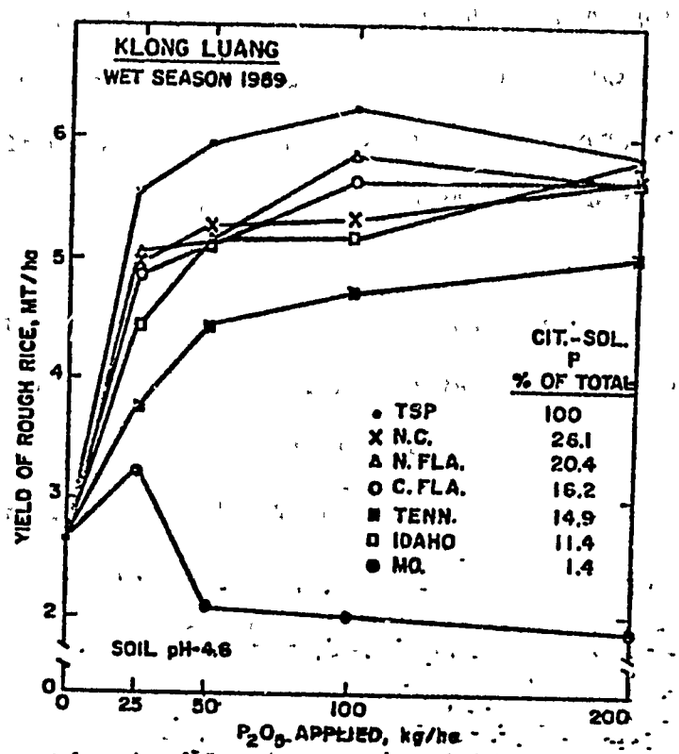


Figure 7. Effect of Various Phosphorus Sources on the Yield of Rough Rice--Thailand

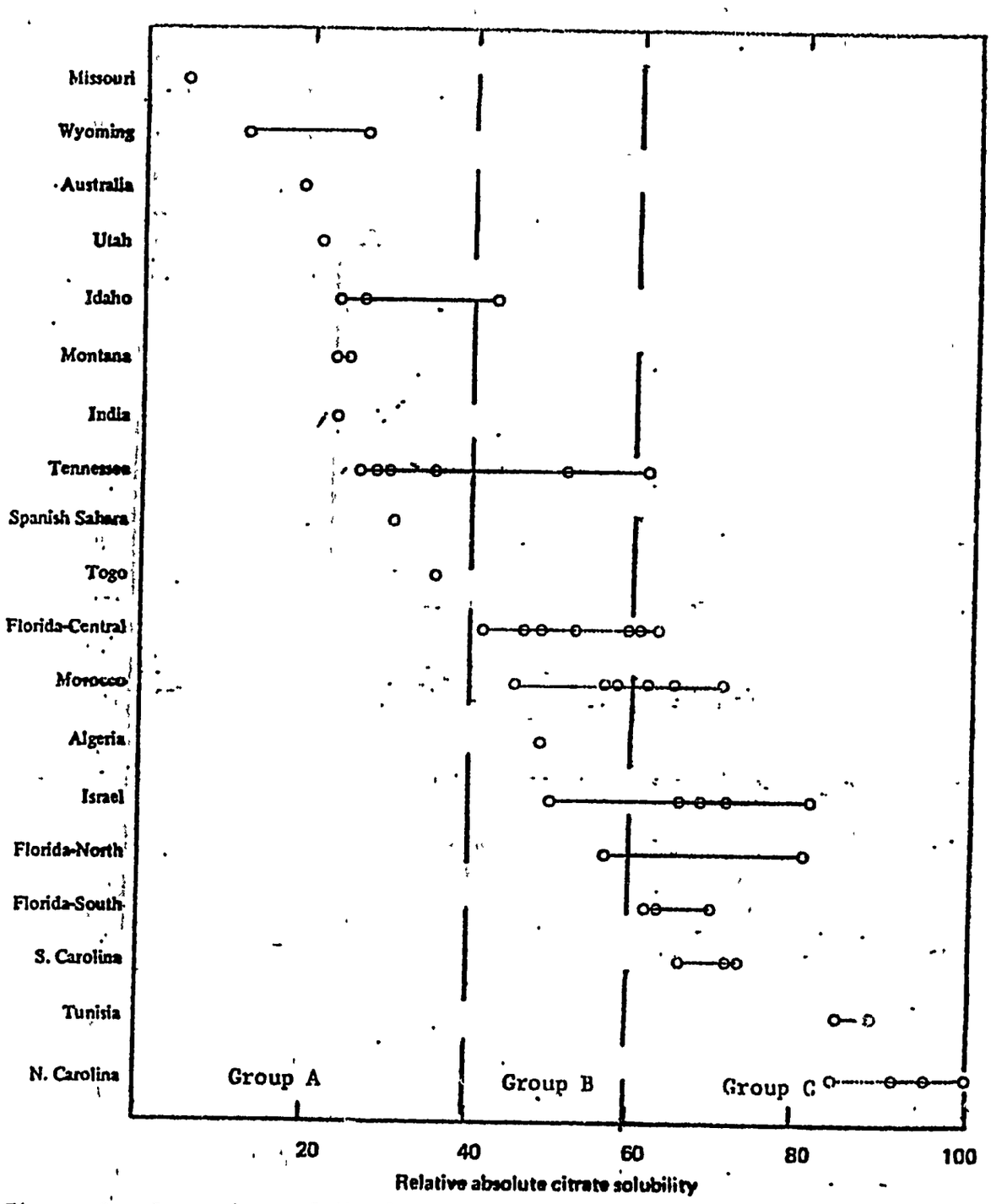


Figure 8. Comparison of Absolute Citrate Solubilities of Phosphate Rocks (ACS Value of MR-467 from North Carolina taken as 100)

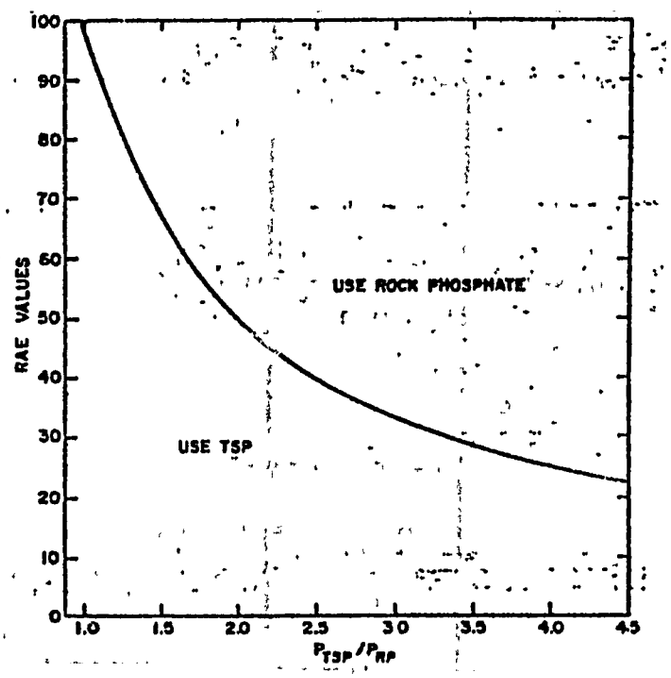


Figure 9. Relationship Between Relative Agronomic Values (RAE) and the Price Ratios Between TSP and Rock Phosphate

Calculations were made to determine the conditions under which TSP and rock phosphates would compete as P sources. Figure 9 shows an indifference curve which should aid in the decision-making process of choosing P sources. For example, where the price ratio of TSP:RP is 2.0 and the RAE values are 60 or greater, rock phosphate might be used. At the same price, TSP should be used if the rock phosphate had an RAE value of less than 50. This curve should not be taken too literally; however, it does illustrate a method for reducing RAE of sources and relative prices to a single curve. With more refined data, such a method may become more generally useful.

These developments are proving a real boon in helping scientists and country leaders alike determine the merits of exploitation of new and/or small indigenous, previously uneconomical, phosphate rock deposits. Recent shortages of supply and rapid escalation in prices have virtually assured that a much larger portion of the phosphate market potential in the LDC's than recently thought will go the direct application route of phosphate rock. Major areas where this is already practiced include Brazil, Malaysia, Indonesia, and Sri Lanka.

Fertilizers Currently Available But Of Limited Availability or Declining in Importance

There are other fertilizers that are or soon will be available to the farmers but represent a more limited potential, often only in special areas. No attempt is made to list them in order of importance for their acceptance will depend upon a specific set of conditions.

Ammonium Chloride (26-0-0)

Potential--Like ammonium sulfate, ammonium chloride is a byproduct of the alkali industry. It is of interest primarily in Japan and/or countries receiving imports from Japan. This product accounted for slightly over 8% of the total output of ammonia fertilizers produced in Japan during 1968. Introduced in Japan as a measure of coping with the heavy competition from alkali imports, the popularity of ammonium chloride as a fertilizer, even in Japan, has declined in recent years.

Consumption of ammonium chloride in Japan has been stagnant since about 1963; the industry is now exporting about 50% of its production. Demand for industrial use is increasing and therefore should lead to continued decline in its use as a fertilizer.

Chemical and Agronomic Properties--Ammonium chloride is slightly more readily soluble in water than ammonium sulfate, but higher than the latter in hygroscopicity (figure 6). It is usually sold in the granular form.

All the nitrogen in ammonium chloride is in the ammonium form and therefore will, in most cases, react similarly to other ammonium fertilizers in satisfying the nitrogen needs of the crop. However, there are some exceptions to this. Ammonium chloride does not contain sulfur. Although, in the case of ordinary paddy fields, no difference is observed in the fertilizer effect between ammonium chloride and ammonium sulfate, it is superior to ammonium sulfate as a fertilizer to degraded paddy fields (15). The reasons for this have already been covered in the discussion dealing with ammonium sulfate. Some researchers feel the chloride present helps present plant disease in rice.

Ammonium chloride has been found to be inferior to ammonium sulfate when applied to extremely phosphorus-deficient soils.

Some of the chemical properties of ammonium chloride are as follows: 26% N, color white, molecular weight 53.5, density of $20^{o}/5^{o}$ C 1.526, solubility 37.2 gm in 100 gm H_2O at 20° C, 45.8 gm in 100 gm H_2O at 40° C (18).

Calcium Cyanamide (21-0-0)

Potential--Like ammonium chloride, the production and consumption of calcium cyanamide (sometimes called lime nitrogen) as a fertilizer is not a major factor in Asia and is on the decline. Small but locally significant quantities are still produced in Japan, Taiwan, and South Korea.

Chemical and Agronomic Properties--Calcium cyanamide is extremely hygroscopic and therefore must be handled very carefully in the tropics.

Unlike the strong acidifying effects of ammonium sulfate and ammonium chloride, calcium cyanamide is actually basic in reaction, thus, does not lower the soil pH.

When applied to soils, calcium cyanamide is converted into ammonium carbonate as described by the following series of equations (15).

1. $CaCN_2 + 2H_2O \qquad CN^{\cdot}NH_2 + Ca(OH)_2$
2. $CN^{\cdot}NH_2 + H_2O \qquad CO(NH_2)_2$
3. $CO(NH_2) + 2H_2O \qquad (NH_4)_2CO_3$

The speed at which this series proceeds is dependent upon the rate of equation 2. When this reaction is slower than the rate for equation 1, under certain soil conditions polymerization of two molecules of $CN^{\cdot}NH_2$ will occur forming $C_2N_2N_2H_4$. It is known that this dicyanodiamide slows the process of nitrification, thereby increasing the efficiency of fertilizer use by reducing loss of nitrogen either through leaching or the denitrification process.

Calcium cyanamide, because of it being a non-sulfate containing fertilizer, is superior to ammonium sulfate when applied to degraded paddy fields. When applied to ordinary paddy fields, its fertilizer effect is similar to that of ammonium sulfate and urea. Because it also has herbicidal effects, it should not be applied as a topdressing.

Ammonium Nitrate

(26%-33½% N; formula NH_4NO_3; molecular weight 80.05; melting point 170.4° C; density 20°/4° C 1.725; solubility 0° C 118 g/100 g H_2O, 100° C 843 g/100 g H_2O; white crystalline or prilled; specific gravity 1.29) (1).

Prior to the major breakthrough that occurred in the production of urea, ammonium nitrate showed promise in replacing ammonium sulfate as the major source of nitrogen in certain developing regions, particularly in Latin America. Although most of this was attributed to its slightly higher N content (21% N for ammonium sulfate versus 33½% for ammonium nitrate) and tendency to be less acid forming than an equivalent amount of ammonium sulfate, this product has certain distinct disadvantages which in the author's opinion limit its use particularly in the hot, humid developing countries where rice is a major crop. The major disadvantages are as follows:

1. The extreme hydroscopicity of ammonium nitrate and its resultant incompatibility with urea in blends and mixes, even in the same plant, severely restrict its suitability in bulk transport, blending, or general use in the humid tropics (figure 8a). Even in temperate regions, the hygroscopic property becomes a problem when the temperature exceeds 25° C.

2. The explosive tendency of ammonium nitrate when mishandled has in a number of countries prompted laws requiring that it be diluted with other products to reduce this hazard. As a result, the N content of the finished product has been lowered to 24%-27% thus eliminating some of the cost savings that could be generated by shipping the 33½% N product.

3. Fifty percent of the nitrogen is in the nitrate form. Many rice researchers and educators feel that most of the N should be supplied to the rice crop in the ammoniacal form; if nitrate nitrogen is used, it should be applied usually in the later stages of growth. Research work has shown ammonium nitrate to be inferior to either urea or ammonium sulfate as a source of N on rice (2). Thus, a vast rice market in Asia appears to be closed to this product. For these reasons, we see ammonium nitrate as having very limited potential in the hot, humid areas of the tropics and in general declining in overall importance.

In spite of these limitations, ammonium nitrate will probably be available in large quantities primarily because of advantages in production. This will be more apparent as the nitrogen industry in many of the developing countries begins to mature and producers look for new markets.

Recent process improvements have made the metric phosphate process more versatile and have removed some of the earlier objections to these products. It is now possible to produce in large, efficient plants, high-analysis grades such as 20-30 and 23-23 with over 80 percent of the P_2O_5 water soluble (16a). Even so, it may still prove unacceptable to many as a source of nitrogen for rice. Therefore, one concludes that nitric phosphates will not be widely used in many of the developing countries.

Fused Magnesium Phosphate (FMP) (0-18-0)

Fused magnesium phosphate is a byproduct of the steel industry. It is used extensively in Japan, South Korea, Taiwan, and to a lesser extent in the developing countries of Asia. Its relative position of importance as a phosphate fertilizer is on the decline. However, because of its affiliation with the steel industry, it will remain a significant factor as a fertilizer--particularly in Japan and/or countries buying Japanese fertilizers. For these reasons, it is given considerable discussion here.

The chemical structure of fused magnesium phosphate is not clear but is theorized to be "$3MgO \cdot CaO \cdot P_2O_5 \cdot 3CaSiO_2$." As shown by the formula, it contains along with phosphorus substantial amounts of magnesium, calcium oxide, and silicic acid. None of the phosphate is water soluble; however, nearly all of the phosphate is soluble in 2% citric acid.

FMP is incompatible with physical mixtures containing ammonium fertilizers. When applied to ordinary paddy fields, it is almost equal to ordinary or triple superphosphate as a source of P to rice. Because of its lack of sulfate and presence of silica, magnesium, and lime, it is recommended for use on degraded paddy, very acid soils or allitic soils.

FMP is slightly inferior to superphosphates when applied to cold soils growing rice. This difference decreases as soil temperature increases; therefore, FMP is considred to be a very satisfactory source of P on many rice soils of the tropics (15).

Nitric Phosphates (Nitrophosphates)

Solid, more hygroscopic than urea or ammoniated phosphates, typical analysis 29-29-0, 26-26-0, 20-20-0, 14-14-0, water solubility ranges from less than 10% to more than 80%, depending upon the process. Nitrate nitrogen comprises 30%-50% of the total N, again depending upon the process.

In contrast to the dominant role of ammoniated phosphates in the U.S. phosphate industry, nitric phosphates (called nitrophosphates in Europe) have been almost equally dominant in Europe. By the late 1960's European plants accounted for over 5 million mt, a major portion of the phosphate produced in Europe (11).

Nitric phosphates have a low sulfur requirement and as a result recently gained in popularity when sulfur was expensive or in short supply. Several plants to produce nitric phosphates were built in developed and developing countries as a result of the tight sulfur supply situation. With sulfur now in more plentiful supply, however, this route has lost much of its attractiveness.

Nitric phosphates do not offer a great potential for growth in Asia for at least two basic reasons. First, and dominant in rice-growing Asia, is the fact that from 30%-50% of the total nitrogen in nitric phosphates is in the nitrate form, a form not recommended by many rice specialists. Those rice specialists who do feel there is a place for nitrates restrict use of fertilizers containing nitrate nitrogen to one of the later topdressings. The second drawback to the use of nitric phosphates is the limited water solubility of phosphorus. Depending upon the researcher, the acceptable range of water-soluble phosphorus for use on upland crops appears to be from 35% to 80%. Early processes resulted in a nitric phosphate water solubility of usually under 50% and frequently below the 35% minimum (19, 20, 21, 22).

Nitrogen Solutions (Including Aqua Ammonia)

(20-0-0, 28-0-0, 32-0-0, 37-0-0, 41-0-0, and 44-0-0) The rapid expansion in the number of NH_3 plants that has occurred both in the developed

and developing world has prompted many companies to produce a variety of nitrogen compounds as a means of disposing of nitrogen production and satisfying the various agronomic and marketing needs. Not only does this provide additional market outlets for nitrogen, but the cost of storing some of these nitrogen materials is considerably less than for storing NH_3, which requires pressurized vessels or refrigeration.

One group of new nitrogen materials is those classed as nitrogen solutions. They have had wide acceptance in the United States and Europe and are just now being introduced into Japan as well as certain developing nations. For purposes of discussion and to afford clarity in the following paragraphs, a brief statement is made as to the properties and classes of materials.

Nitrogen solutions are classed according to composition, as follows: (a) aqua ammonia; (b) solutions containing ammonia and ammonium nitrate; (c) solutions containing ammonia and urea; (d) solutions containing ammonia, ammonium nitrate, and urea; and (e) solutions containing ammonium nitrate alone or with urea but without ammonia (23).

Aqua Ammonia--Usually 20% N, the production of aqua ammonia involves the addition of anhydrous ammonia to water, a relatively simple operation that can be carried out independently of an ammonia synthesis plant, thereby saving the expense of transporting water. The operation requires facilities for proportioning the flows of water and ammonia, cooling freshly formed aqua ammonia to remove the heat of absorption, and measuring the concentration of aqua ammonia.

Cast-iron or mild-steel equipment is suitable for handling aqua ammonia. Storage and applicator tanks should be designed for a working pressure of at least 7 kilograms per square centimeter (kg/cm^2). Equipment for handling aqua ammonia is not necessarily suitable for handling other nitrogen solutions, which are generally more corrosive.

Aqua ammonia is used primarily as a direct-application fertilizer. A considerable amount of experience and success with this product has been gained in the United States, Europe, and Japan. When used properly, it is an effective source of N (ammonium form) for a wide variety of crops. Application should be subsurface; otherwise, gaseous loss will occur. Aqua ammonia can be prepared in the field by injecting anhydrous ammonia into irrigation water.

Ammonia-Ammonium Nitrate Solutions. (37-0-0, 41-0-0, and 44-0-0.) Solutions containing ammonia and ammonium nitrate are produced by injecting ammonia into ammonium nitrate solutions. Although such solutions are usually produced at an ammonia plant, they can also be produced from transported ammonia.

Ammonia-ammonium nitrate solutions are used both for manufacture of mixed fertilizers and for direct application to the soil. Ammonia-ammonium nitrate solutions cannot be economically handled in ordinary steel equipment because of corrosion. Equipment made of aluminum or stainless steel is satisfactory

Ammonia-Urea, Ammonia-Ammonium Nitrate-Urea Solutions. (37-0-0, 41-0-0, and 44-0-0.) Aqueous urea-ammonia solutions and ammonia-ammonium nitrate-urea solutions are designed for use by the manufacturer of mixed fertilizers, the latter type solution usually being added to improve condition of finished product. A tracing of the development of this type of solution in the United States may help illustrate the manner in which it could develop in many of the countries of Asia.

The original use of nitrogen solutions was in the manufacture of solid mixed fertilizers in the United States. Some of the solutions found their way into the direct field application market. A large potential market for nitrogen solutions as direct-application materials soon became evident--a situation promoted by the growing market for liquid mixed fertilizers, anhydrous ammonia and aqua ammonia. Manufacturers of solid mixed fertilizers recognized this potential and found that some of their ammoniating solutions purchased for manufacturing could also be sold locally as liquid fertilizer. The ammoniating solutions could be diluted with water as desired to lower the gauge pressure and salting out temperature. This permitted the solutions to be handled in nonpressure applicators, but the presence of small amounts of free ammonia in all these solutions resulted in losses of ammonia to the atmosphere during application unless the solutions were injected beneath the soil surface. Thus, surface application of this product was not entirely suitable. Furthermore, the presence of ammonia increased the corrosiveness of the solutions.

Non-Ammoniacal Solutions of Ammonium Nitrate and Urea--(16%-32% N, typical grades 28-0-0 and 32-0-0.) This type of nitrogen solution offers its greatest potential in many of the developing countries.

To satisfy the market for nonpressure nitrogen solutions suitable for surface application, aqueous solutions containing ammonium nitrate alone or with urea or other sales are produced.

As with ammoniacal solutions, the manufacture of nonammoniacals is usually integrated with an ammonium nitrate plant. These solutions are not as corrosive as ammoniacal solutions and can be handled in plain steel equipment if corrosion inhibitors are added.

These products have the same agronomic effectiveness as similar amounts of dry urea or ammonium nitrate. This may prove to be a very effective way to market ammonium nitrate in the tropics in area where nitrate fertilizers have wide acceptance.

Anhydrous Ammonia

(82-1/5% N gas at atmospheric pressure; liquid when compressed and cooled; colorless; molecular weight 17.03; critical temperature 1.33° C; critical pressure 1,657 psig; latent heat vaporization at 28° F 589 BTU/lb; liquid density at 60° F 38.50 lb/ft^3; vapor density at 1 atm, 60° F 0.0456 lb/ft^3; vapor specific gravity (1 atm, 60° F, air = 1), 0.597; vapor volume (1 atm, 60° F) 22.0 ft^3/lb; boiling point at 1 atm -28° F; freezing point at 1 atm -107.9° F) (1).

Anhydrous ammonia is by far the highest analysis N product commercially available anywhere in the world. Because of its high analysis, it can be shipped great distances to its point of use at competitive prices. Anhydrous ammonia has one major disadvantage--high vapor pressure at ordinary temperatures. It must be transported and stored in pressure containers, generally with a minimum working pressure of 265 psig. Unless injected into irrigation water, anhydrous ammonia must be injected as a liquid into the soil with special equipment where, beneath the soil surface, it vaporizes, reacts with the soil water, clay or organic fractions, changes to the ammonium form and is retained by the system.

When properly used, anhydrous ammonia is equal to any other form of ammonium nitrogen and is occasionally superior to urea or nitrate forms, but does require special management or its agronomic performance can be affected (2). Ammonia applied either as pre- or post-plant should never be placed in close proximity to the seed or young roots; otherwise, as in the case with diammonium phosphate, germination or growth can be retarded. Depending upon the amount injected, losses of ammonia can result if the ammonia is injected at too shallow a depth in soils low in moisture, clay

content or organic matter or when tracks left by the injector knife fail to close because of insufficient or excessive moisture. In general, anhydrous ammonia requires special equipment for handling.

Prospects for Use of Nitrogen Solutions and Ammonia in Developing Countries

It is generally accepted that dry fertilizers offer the greatest potential in the developing countries of the world. Many believe the immediate potential for ammonia and nitrogen solutions is quite limited.

These assumptions are probably correct based primarily on the general acceptance of dry fertilizers. Their simplicity of handling, compared to the more sophisticated system required for liquid materials, makes them more readily accepted in a country which lacks mechanization. However, to stop here would be an oversimplification of the situation and would not reflect the true potential for nitrogen solutions and ammonia.

Although dry fertilizers, particularly urea, ammoniated phosphates, and complete N-P-K compounds will be the dominant force in the developing country market for some time, ammonia and nitrogen solutions, particularly aqua ammonia and nonpressure, could very well make substantial advances in the next few years. This will occur for at least four reasons. These are: (1) Labor shortages are developing in certain regions, thus placing a premium on increasing efficiency of handling agricultural inputs, (2) adaptation to nonpressure aqua ammonia or nonpressure solutions requires only a very limited amount of sophisticated equipment, (3) because of the tendency for ammonia producers to look for additional markets for excess

ammonia, they will actively push to develop these markets, and (4) increasing evidence indicating the seriousness of N losses from surface-applied urea will pressure producers to look toward alternate ways of marketing this product and alleviate losses.

Under these four conditions, prospects are good for acceptance of one or more of these materials as agriculture becomes mechanized. The major potential for nitrogen solutions exists mainly in large estate areas that are the major earners of foreign exchange and which produce rubber, oil palm, sugarcane, or where these holdings are old, must be rejunvenated, and are converted to such crops as rice, maize, or wheat. Potential also exists in certain areas of smaller land holdings. Of particular promise are areas where farmers are willing to pool equipment and cooperatively farm their land. Under these circumstances, nitrogen solutions can offer both labor saving and low cost per unit N advantages. An additional potential, its success dependent upon government policy and development of regional projects, is aerial application of nitrogen solutions. There are vast areas of India, Pakistan, and Indonesia where much of the rice and wheat is grown under uncertain moisture conditions. In these areas, farmers often use only a very minimum of fertilizer. Where optimum rainfall occurs, usually too late to effectively apply fertilizer via the soil, perhaps foliar application may prove effective.

Ammonium Polyphosphate

The term "ammonium polyphosphate" is used in fertilizer parlance to denote materials containing condensed phosphtes, and these are produced as solutions or as solids by ammoniation of superphosphoric acid. Typical compositions of the three most popular polyphosphate materials are given on the next page.

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

*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 tetrammonium 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 (26) 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 (27) 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 (28) 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 (29) reported that polyphosphate was superior to ammonium orthophosphate or two zinc-deficient calcareous soils.

Soubies and Baratier (30) 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 (31) 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 fertilier in either liquid or solid form.

Solid ammonium polyphosphate (15-62-0 or 12-57-0) of the materials in this family offers the greatest potential for use in developing countries. This is because (a) it is a high-analysis, binutrient fertilizer (77 units of plant food) second only to anhydrous ammonia in plant food content, and

(b) it can be shipped in the solid form to intermediate points where it in turn can be readily converted to a liquid (11-37-0) if and when the situation should warrant.

For these reasons, solid APP has good potential in the same regions offering good opportunities for nitrogen solutions and bulk blends. The solid APP (imported) together with the locally-produced nitrogen solution could serve as the nucleus of developing a low-cost liquid industry. It could also serve as a high-analysis, binutrient component of a bulk blend.

Urea-Ammonium Polyphosphate. (Solid; 30-30-0, 39-13-0, 19-19-19 or varying grades; all nitrogen in urea or ammonium form; phosphate 100% water solubility and 50% in the nonortho form.) Agronomically, this product is as good as MAP or DAP. This coupled with its high analysis, simplicity of production and low production costs makes it a product with good potential in Latin America, Asia, and Africa.

Suspension Fertilizers (Fluid; 12-40-0, 14-44-0, or other grades; requires superphosphoric acid. Nitrogen in ammonium form, 50% of phosphate in condensed (nonortho) form, all phosphorus 100% water solubility.) Only in very special cases will suspension fertilizers have a place in Asia; the major limitations being a readily available source of super acid and the need for highly-specialized equipment. Nevertheless, the next ten years will see the appearance of this product in areas of Asia where large, uniform fields exist, mechanization of equipment is possible and the desire exists to save labor through the applications of high-analysis N-P-K micronutrient-pesticide combinations all possible with suspensions. However, this is a very sophisticated, service-oriented market; the frequency of its occurence in most of the developing world is rather limited at the present time.

Special Developments With Respect to Urea Based Products

It has already been stated that urea will be the primary nitrogen fertilizer for many years to come, inspite of certain limitations on product performance.

As a result, considerable research is now underway to improve urea, either its handling properties, nutrient efficiency, or both. The following is a brief description of just a few of these efforts.

Granular Urea

Use of urea* in bulk blends should become increasingly attractive as we move away from the small prilled urea to larger particle sizes more compatible with other bulk blend materials. TVA is making a major effort to improve the technology in this area. Cominco in Canada has produced granular urea using a pan granulator; we understand that at least three other U.S. producers are planning production. Larger granules reduce moisture pickup and caking; also, the granules can be made more durable than prills. Urea has its limitations. Unfortunately, urea cannot be used with or near nitrate-containing materials because mixture of the two extracts water from the atmosphere. Also, urea is not compatible with triple or ordinary superphosphates because of a chemical reaction that causes stickiness. Work is now underway to overcome these problems.

Sulfur-coated urea,* a controlled-release nitrogen product developed by TVA and soon to be produced in a prototype plant, appears to hold a lot of promise and may come into limited commercial production by the late 1970's. The main objective in developing this product is to provide a more uniform supply of nitrogen to the crop than is obtained via a single application of conventional water-soluble nitrogen sources. This reduces leaching

losses and should improve nitrogen recovery by the crop. A secondary objective is to enhance the compatibility of urea based products with nitrates and TSP.

The process basically involves spraying preheated urea with molten sulfur in a rotating drum. A wax sealant is applied on top of the sulfur coating to seal pinholes and cracks that would affect the controlled release properties, and a coating dust is added to reduce stickiness of the product. The rate of release can be controlled by varying the thickness of the sulfur coating. Total coatings by weight normally are varied from 14% to 21%, producing grades ranging from 40-0-0-9S to 36-0-0-16S. Costs for coating add about 30% more per unit of nitrogen than uncoated urea. The greatest economic potential appears to be for (1) use on sugarcane, forages, and turf grasses; (2) use on soils in which leaching losses of nitrogen can be a problem during the growing season; and (3) for fall or winter application. SCU does not hold much promise for corn, small grains, and short-season crops which require a relatively large amount of nitrogen during a rather brief period of growth.

SCU should be useful in bulk blending because of the larger granule sizes and because the sulfur coating prevents undesirable chemical reactions with superphosphate. It has greater crushing strength and resistance to abrasion and is not as hygroscopic as uncoated urea. Light coatings with sulfur only will likely impart some of the desired characteristics and at less cost, but the slow-release value would be minimal. A thinly coated material, however, might find a real place in bulk blending and for direct application.

Summary--Relative Effectiveness of Various Fertilizers

(Special Emphasis on Rice)

Much has been written as to the effectiveness of various fertilizers in supplying the nutritional needs of the crop. Researchers are not in complete agreement with regard to the effectiveness of each product. The following is an attempt to summarize some of the areas of agreement and identify certain aspects that are still contested.

Nitrogen Fertilizers

Ammonium N appears to be the preferred form of N to the rice crop. Fertilizers containing nitrate nitrogen have been consistently shown to be less effective than most ammonium forms as a source of N to rice. To illustrate that clear-cut agreement does not exist regarding the relative performance of products within these two categories, the author calls attention to efficiency ratings published by De Geus (34), Wahhab, Bhatti (35), and Lin (36). These appear in table 7.

The author is of the opinion that these inconsistencies will always occur but to varying degrees. One final note about nitrogen sources for rice. Products containing sulfur can be detrimental to the growth of rice when grown on degraded paddy.

Phosphorus

Less controversy exists about the relative efficiencies of phosphatic fertilizers in meeting the phosphorus needs of the rice crop.

The rice crop does not demand a highly water-soluble source of phosphorus to achieve maximum growth. This is true, even on very phosphate-deficient soils, probably because soil phosphorus tends to be more available in the flooded (reduced) than upland (oxidized) state. These

relationships are particularly true for the tropics where soil temperatures are almost always quite high. In addition, many of the soils have a high phosphate-fixing capacity which minimizes the value of high-water solubility.

For these reasons, fertilizers having fairly high citrate solubility (including certain phosphate rocks and fused magnesium phosphate) are equal or superior to fertilizers containing highly water-soluble forms of phosphorus.

Phosphate sources containing substantial amounts of sulfate are not recommended for use on degraded rice paddy.

Potash

Muriate of potash is the main source of potash for rice. Because of its chloride, nonsulfate content, it can be used on all rice soils including degraded paddy. Where sulfur is needed or chlorides are harmful, potassium sulfate and sulfate of potash magnesia are satisfactory sources of K.

Table 7. Relative Efficiency of Various Nitrogen Fertilizers Applied to Rice

Product	Researcher (33)	(34)	(35)
	Relative Rating		
Ammonium sulfate	100	100	100
Urea	82	110	97
Ammonium chloride	-	-	99
Calcium cyanamide	64	76	-
Ammonium nitrate	92	78	88
Sodium nitrate	40	-	-
Ammoniated phosphate	86	-	-
Potassium nitrate	44	54	-

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