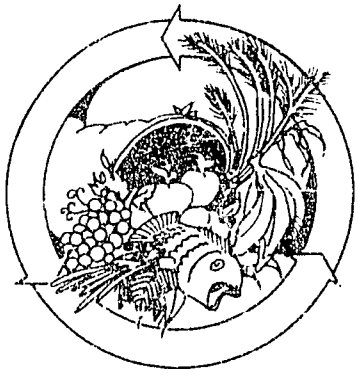
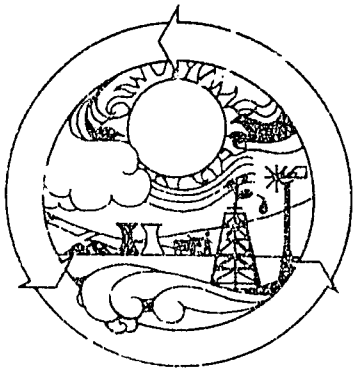
East-West Resource Systems Institute
East-West Center, Honolulu, Hawaii



FERTILIZER RAW MATERIAL RESOURCES, NEEDS AND COMMERCE IN ASIA AND THE PACIFIC



Proceedings of the
Fertilizer Flows Conference
August 27–31, 1979
Honolulu, Hawaii

Edited by
Richard Sheldon,
Saleem Ahmed
and Yueh-Heng Yang

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PREFACE

The need to increase per capita food consumption in the world has stimulated increased resource inputs of many kinds to the food production systems of the world. This has included arable land, water, pesticides, and improved biologic strains of food plants, as well as the object of this study, fertilizer. Many nations have no internal sources of fertilizer and cannot attain maximum food production without importing fertilizers. Thus, fertilizer flows between the nations of the world are essential to make up for imbalances of raw material resources distribution and of the different stages of development of fertilizer production systems of the nations. It seems clear that a full understanding of the factors that relate to fertilizer flows both within and between countries would be helpful in stimulating this flow and in alleviating shortages.

A program of international study of fertilizer availability and use in Asia and the Pacific was initiated in 1974 by the Food Institute of the East-West Center and continued in 1977 by the Resource Systems Institute, which replaced the Food Institute. These studies initially included studies of efficiency of nitrogen use, intercropping relative to fertilizer use and effectiveness of organic fertilizers. At a later date, socio-economic studies of fertilizer use, fertilizer marketing studies, and fertilizer raw material resource studies were added. Many international workshops aimed at specific aspects of these fertilizer studies were held at the East-West Center between 1974 and 1979, and a final Fertilizer Flows Conference was held in August of 1979 to integrate these individual studies into a broad view of the fertilizer supply and demand systems of the Asia and Pacific region. The Proceedings volume presents the formal papers, discussions and recommendations of the final Fertilizer Flows Conference.

The Conference was broken into three sections dealing with resources, need, and commerce to address the questions affecting long term availability and utilization of fertilizer. Are raw materials for manufacturing fertilizer available in this region? What are the long term needs of fertilizer? What are the commercial systems handling fertilizer flows and their potentials for change?

The fertilizer resource section had two objectives. The first was to develop understanding of the quantity, quality and distribution of fertilizer raw material resources in the Asia and Pacific region. The major conclusion on this issue was that fertilizer raw material resources in Asia and the Pacific are adequate to meet future needs of the region, but that much of the resource is yet to be discovered and much is not economic relative to the present fertilizer manufacturing technology. To realize these future resources, the Conference recommended 1) that existing fertilizer resource data be collected and exchanged within the region, 2) that geologic research on the origin of fertilizer minerals be strengthened, 3) that geologic and geophysical mapping within the region be increased, 4) that undiscovered fertilizer raw material resources within the region be assessed, and finally 5) that the

technology of exploration for fertilizer minerals be strengthened.

The second objective of the resources section was to examine alternate technology of fertilizer production on small farms using local resources. The major conclusion was that alternate systems of fertilizer supply are feasible in developing regions, and specifically that the nitrogen-phosphorus fertilizer generator may prove to be effective at the local level. The Conference recommended 1) that alternate methods for supplying fertilizers to small farms be explored, 2) that research on the nitrogen-phosphorus fertilizer generator be continued to develop a technology using renewable energy to produce nitrogen and phosphorus fertilizer from local small mines, 3) that the mini-Haber Bosch nitrogen generator plant be further investigated for use on offshore and small onshore natural gas fields, and 4) that research be strengthened on utilization of organic materials as fertilizer, including biogas and biomass.

The fertilizer needs section had its first objective of assessing the long term needs for the Asia and Pacific region and the world in general. It was concluded that depending on the method of analysis used, meeting optimum world fertilizer need require increases over present production of 100-340 percent nitrogen fertilizer, 240-500 percent of phosphorus fertilizer, and 40-500 percent for potassium fertilizer and that to bring world soils presently under cultivation up to at least a moderate fertility level would require about 870 million metric tons of P_2O_5 over a 20 year period or about 45 million tons per year. This compares to the present annual consumption of about 30 million tons. The Conference recommended that 1) techniques, particularly satellite techniques, be developed for more accurately assessing arable lands and for monitoring changes in land use, and 2) that a methodology be developed to make estimates of national fertilizer needs more crop specific.

The second objective of the fertilizer needs section was to assess methods to conserve fertilizer by reducing waste in their use. It was concluded that nitrogen fertilizer can be conserved by more efficient use (particularly by use of urea supergranules), that intercropping contributes to more efficient fertilizer use, that combined use of organic and chemical fertilizers is more efficient than either alone, and that more efficient forms of fertilizer can be developed for use in tropical countries. The Conference recommended 1) that research on urea supergranules should be continued and socio-economic factors of their use should be studies, 2) that research be expanded on the agronomic and socio-economic aspects of cropping systems, and 3) that interdisciplinary research on development of fertilizers more effective in tropical areas be strengthened.

The fertilizer commerce section had the objective of developing further understanding of fertilizer commerce of the Asia and Pacific region. It was concluded that the present fertilizer system is meeting present demand in the region, that the fertilizer consumption is only about 20-30 percent of the optimum fertilizer needs of the region, that fertilizer marketing strategies can play a vital role in not only making fertilizers available to farmers but also in enhancing the efficiency of fertilizer use, and that government policies that encourage development and use of fertilizers are vital to improvement of the fertilizer-food system. The Conference recommended 1) that constraints and disincentives

to fertilizer use be identified at both the national policy and village levels, 2) that government policies regarding fertilizer pricing, subsidy and taxation be analyzed and their effect on fertilizer use be evaluated, and 3) that research be strengthened on farmer decision making regarding fertilizer use, particularly with respect to bringing about a more balanced use of fertilizers.

The background of the participants in the Fertilizer Flows Conference is important to know if one is to assess the reliability and credibility of the Conference. Participants were from the fields of geology, soil science, agronomy, environmental science, agricultural chemistry, agricultural engineering, agroclimatology, geography, computer science, agricultural economics, fertilizer marketing and human nutrition. Of the 85 participants, 48 came from 14 developing countries, 19 came from 3 developed countries and 18 came from international institutes or organizations. Seventy of the participants are from public or private research organizations and 15 were in development organizations or industry. Looked at another way, 29 participants are from national organizations, 18 are from international organizations, 22 are from universities and 16 are from industry. A list of participants is shown in the Appendix.

It seems fair to characterize this conference as a meeting of fertilizer research scientists from international and national research organizations and research oriented arms of industry. Few if any participants were from the policy making levels of national governments, although many have served as scientific advisors to policy makers. Perspectives on fertilizer problems have come from developing, developed and centrally planned economies. The validity of this contribution is drawn from the apolitical exchange of scientific ideas of a diverse group representative of all facets of the fertilizer supply and demand system.

There was a general feeling among the group that the technical problems of fertilizer supply and use that seem so intractable in the short term can be surmounted by careful and adequate research efforts in the long term. Many present problems of imperfect, inadequate or inappropriate fertilizer technology would fall before such research. The governments of all countries of the world should see to it that this research is planned and funded, and the opportunities for national development thereby created be seized.

Richard Sheldon
Saleem Ahmed
Yueh-Heng Yang

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the many organizations whose contributions made this Conference possible. All donated the time of their research scientists freely and many also contributed the travel expenses of their scientists. These organizations included 15 different universities, 31 national government institutes, 5 international institutes, and 14 commercial companies. The U.S. Geological Survey in particular should be singled out in their contributions which included financial support for publication and distribution of the Proceedings, as well as their collaboration in the activity through the services of conference co-coordinator, Richard P. Sheldon.

The Conference would not have reached its full potential without the far-seeing guidance of Harrison Brown, director of the Resource Systems Institute. Research Associate Y. H. Yang, and W. C. Burnett and H. K. Lakshman Rao, research fellows of the Resource Systems Institute gave essential help in planning and conducting the Conference. Nazir Ahmad, Adelaida Alcantara, Mohammad Ashraf, and Tamrong Chomaitong, research interns of the Resource Systems Institute gave valuable assistance before and during the Conference, and a number of degree participants of the East-West Center were very helpful, including Antonio Alcantara, Jagdish Bhati, Seung Keun Jong, Annabelle Lee, Kwang Suck Lee, Kazi S. Memon, Devaiah Muruvanda, Fazal Rahimi, Nasir Saidy, and George Silva.

To all of these people and organizations, the Conference coordinators owe a large debt of gratitude.

OPENING ADDRESS

PROBLEMS AND OPPORTUNITIES IN MEETING FOOD NEEDS IN THE YEAR 2000 AND BEYOND*

RALPH W. CUMMINGS**

LADIES AND GENTLEMEN:

It is indeed a privilege to be with you today as you begin your deliberations in the workshops on production systems, fertilizer marketing, and fertilizer raw materials resources. The problems you are addressing assume added importance at this time: (1) when the numbers of people in the world are increasing so rapidly with consequent increased food requirements; (2) when we must be deeply concerned with the sources and supply of energy needed to support our developing economies and our food production and distribution efforts; (3) when inflation in costs is causing disruptions and strains in the supply, and availability, and the abilities of farmers to purchase and utilize fertilizers and other inputs so necessary to the higher levels of production that will be required; and (4) when the future availability of sources of hydrogen and energy (from fossil fuels) for the manufacture of nitrogen fertilizer is so uncertain. It is imperative that we bend our efforts assiduously to the task of finding ways of improving the efficiency with which the fertilizers and other yield-increasing or yield-protecting chemicals we use are converted into usable food products. Indeed, supplies are, and will continue to be, tight--whether in total or in terms of availability to the farmer who is the ultimate user. We know that the present efficiency in use by crop plants of the fertilizers applied, especially in developing country agriculture, is very low. Some of the reasons--volatilization and leaching of nitrogen, soil fixation of phosphorus, crude methods of application and placement, etc.--are well known. If we can find ways of overcoming or partially overcoming these inefficiencies, this would be equivalent in its effect to substantially increasing fertilizer supplies and would thus have an important impact on the incentives and profitability of their use. I am intrigued by the acronym you have assigned to one of your major projects under review at these meetings: INPUTS or Increasing Productivity Under Tight Supplies. I think it is quite appropriate.

But at this point, I would like to say a few words about a subject which is behind our efforts and the deliberations of these workshops. Namely, hunger, present and prospective. It is one of the great overriding problems of our time and is destined to assume even greater

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*This paper was published in its entirety in the Proceedings of Final Inputs Review Meeting (Ahmed, Gunasena and Yang, 1980, pp. 29-36). But only the first part, which was the general treatment of the problems of meeting future food needs, is published in this proceedings volume.

**Dr. Ralph Cummings is Emeritus Professor, North Carolina State University, and Chairman, Technical Advisory Committee, Consultative Group on International Agricultural Research.

importance during the remainder of this century. The production of the necessary food for sustenance and nutritional sufficiency for people, including the poorer segment of the world's people, and the development of the opportunities for them to generate the income which will give them access to it are among the great challenges which face us today. You and I have been and are deeply concerned with problems related to generation and application of the scientific technology necessary for meeting this challenge.

At our levels of income and privilege, we may not have to experience personally the real meaning of hunger, but I hope this will neither dull our appreciation of its importance nor diminish our resolve both to understand the problem and to use our talents to the fullest extent possible to help in lessening the pain of those who must face the problem grimly.

Prior to going to lunch today, I suspect that we may feel just a little hungry; but this is nothing more than a signal that we are ready to enjoy our next meal. We have the confidence that we shall be able to eat not only enough food, but also food of a sufficient variety and quality to satisfy our appetites and even more important, to provide the balanced nutritional needs of our bodies.

The average American gets about 20% of his caloric energy from cereal grains variously processed and about 37% from animal products (meat, milk, eggs). To this we add about 12% from sugar, about 18% from fats and oils (cooking fats, salad dressings, seasonings, etc.), and about 5% from various vegetables. Potatoes may contribute another 3%; and pulses (beans, peas, etc.), about 4%. We may also supplement even this variety with some vitamin and mineral concentrates.

We are a privileged group. We have the necessary income to compete in the market for higher cost foods. And there are enough supplies on our grocery shelves to meet market demands. We may complain about the high prices, but we do not really have to go without food.

But this is not true for a large number of humankind around the world. There are large areas at the other extreme in which more than 80% of the food energy comes from cereal grains and starchy roots and less than 3% comes from animal products (meat, milk, eggs). This does not leave much room for variety in the diet. Think for a moment of having little choice from day to day but a gruel or dough or flat bread made from millet, cooked with a few leaves or gourds harvested from the bush or fence row, perhaps spiced with chili peppers and at times a small serving of cowpeas or native beans. In some areas, cassava might take the place of millet. Compound this with the fact that the storehouse from the last crop does not permit more than one or two meals per day without the risk of running out and facing starvation before the next harvest. And yet, large numbers of people in the lower income end of the spectrum are faced with just this situation. Droughts, crop failures, or partial failures become personal and family disasters. Such people know the real meaning of hunger.

Our own diet, with a large component of animal products, requires the equivalent of about 0.9 tons of grain per person. In contrast, peoples and societies which subsist largely on a grain diet consume only about 0.2 tons of grain per capita. It is a well established fact that, as incomes improve, people tend to shift their preferences from coarse grains to the

more elite grains of greater prestige, seek more variety in their diets, and consume more animal products. This tendency increases the per capita requirement for grains and puts more pressure on overall food supplies and reserves.

During the past four years, we have had a continuing period of better than average or normal weather and growing conditions in the grain-producing areas of the world generally. High yielding varieties and high yielding production technology have been extended, and food grain production has exceeded market offtake sufficiently to enable us to build back some of the food reserves which had been depleted to such dangerously low levels in the early 1970's. Wholesale grain prices have declined. And grain surpluses have accumulated in the few countries still able to produce enough to enable them to enter the export market. But every indication to date would lead one to the conclusion that this is a temporary situation and that the specter of hunger is still very real today in many parts of the world and with the poorer segment of the population in many others. This year's wheat harvest in Russia is down and both Russia and China are making substantial purchases of food and feed grains on the international market. There is a prospect that we may see a substantial draw down of our reserve grain stocks within the coming year.

The seemingly inexorable continued growth in the numbers of people, especially in the developing countries, is the factor which compounds the problem. We have in prospect a manageable rate of population growth in the U.S., Canada, Western Europe, and Japan. Unconfirmed reports from China sound encouraging. But in most of the rest of the world, population growth is still more than 2% per year, and in over 30 countries annual population growth exceeds 3%. A 2% annual rate of population increase would double the population of a country in 35 years and a 3% growth rate would double it in 23 years. Demographers predict that the world's population, now above four billion, will rise to around six billion by the end of the century. With no changes in average dietary intakes, this would require a 50% increase in staple food supplies. If the purchasing power of any substantial numbers of the less privileged people should improve, their choice of food would respond correspondingly and the requirement or demand would be even greater.

Improved disease control over the last two generations has enhanced the chances of survival dramatically, especially among infants and children; and thus larger numbers of people have been reaching reproductive age. While birth rates have begun to decline with this greater survival expectancy and with improvements in education, they have not declined nearly as rapidly as have the death rates. However, the increase in numbers of people is occurring faster in those areas in which population pressure on the land is already high.

In all the developing countries taken together, we can expect that there will be four people by 1985 for each three who were present in 1975. And by the year 2000, this gain will increase to five. In several countries, the increase will be up to six or more for each three people in 1975.

The world trade in food grains has been undergoing a drastic change during the past few years. One country after another has passed

from the position of food self-sufficiency or surplus to that of a net importer. And many of the more highly industrialized nations now import more than one-half their food grain requirements.

The number of remaining countries able to export grain in quantities sufficient to make a significant impact on world trade can now be numbered on the fingers of one hand--the U.S., Canada, Australia, Argentina, and Thailand. And even here, the volume moving in world trade represents only a small proportion, less than 10% of world production. And while this is still a very significant amount, the dependence of so many nations on these imports underlines the precarious nature of the balance. The reserve stocks which have been replenished during the last four years could be wiped out by one or two years of drought, such as was experienced in the middle 1960's and again in the early 1970's. And while production technology has been developed to a very high level in the larger volume exporting countries (and total production therein could no doubt be increased still farther), the amount of such increase would at best be marginal in terms of percentage of the total world production and requirements. And even if substantially more could be produced in these countries, the logistics of moving it to areas of need and their ability to purchase and distribute it would present formidable problems indeed.

If widespread hardship, hunger, and starvation are to be avoided in the next two decades, there is no substitute for very substantial increases in the level of yields and total food production <u>within the present food-deficit countries around the world</u>.

In the U.S., we have about 0.9 hectare of arable land per person in the population. In the developing countries, on the average, each hectare of arable land must now support three people. By the end of the century, this number will be five (per hectare). In some of the more crowded countries of the developing world, each hectare of arable land may have to support twenty or more people by the end of the century (two examples are Egypt and Korea).

And the greatly increased use of fertilizers, together with substantially improved efficiency in the use of such fertilizers, will inevitably be a very major requisite and ingredient. New processes and new fertilizer products may be needed to achieve the needed efficiency in returns. Whatever the processes and products chosen, fertilizer production and consumption must be a very significant growth area in the developing countries around the world.

The past decade has witnessed the birth of the "green revolution", which has already had a profound effect on irrigated wheat and rice production around the world, on the outlook of agricultural science, and on the hopes and optimism of people around the world that we do have more room in which to maneuver in order to meet the mounting pressure of population on food. Its secondary effects on the society in many nations have probably been as great or greater than its direct ones.

I am sure that most of you are aware of the two scientific and technological breakthroughs which made the initiation of this revolution possible and of the institutional developments which have taken place in its promotion and in attempts to extend it. Nevertheless, I think it may be useful to review these briefly.

First, with rice. This is the major staple food crop in Asia--from parts of Pakistan and India on the west to the Philippines, Japan, and China on the east. Rice accounts for 25% of the world's cereal grain production and is used almost entirely for direct human consumption. Ninety per cent of the world's rice is grown in South and East Asia. Here, the population is increasing rapidly. The balance between total food production and food needs has always been precarious; but by the middle of this century, it was evident that a crisis might be imminent.

The International Rice Research Institute (IRRI) was created in 1960. Prior to that time, rice varieties and rice culture in the developing world had been developed for poor soils and consequently provided very modest yields. In fact, consistently high yields just did not seem possible. Virtually all of the rice varieties were tall growing and had relatively weak stalks. If more than very moderate amounts of fertilizers were applied, the rice grew even taller and the stalks were unable to support heavy grain heads. Therefore, when the monsoon rains and winds came, they toppled over and were unable to mature the grain. Higher rates of fertilization would be more likely to decrease, rather than increase, grain yields. The best one could hope for was about three to three and one-half tons of paddy, in husk, per hectare; and the average was closer to one-third of this figure.

The International Rice Research Institute was able to identify a Chinese variety with drastically different plant type, cross it with an Indonesian variety having good grain quality, and by 1966, release IR8, a variety which was short in height, had very strong stalks which could hold up heavy grain heads, tillered profusely, and was able to give good grain yield response to very heavy fertilization. Yields of as much as ten tons per acre were attained in a four-month growing period. It was quickly realized that here was a breakthrough to entirely new production levels which, when fully exploited, could revolutionize rice production in the tropics. Subsequent developments, by IRRI and national programs, have greatly improved on IR8, by incorporating a broad base of disease and insect resistance, grain qualities desired by consumers in different regions, and other characteristics. IRRI does not now release varieties; but varieties and technology growing out of these developments have moved around the world. These new high yielding varieties are now planted on more than 25 million hectares and, with the higher fertilization rates and improved production technology that they have made possible, have been a major factor in alleviating or preventing unduly severe hunger in the Asian region during the past decade.

A parallel development took place with wheat during the same period. Yield ceilings with wheat had been limited by the same phenomenon as with rice--tall plants, weak stalks, with inability to support heavy heads of grain. The genes for short, strong wheat stalks came from the Norin 10 variety obtained from Japan just after the end of World War II. This was crossed with spring wheat varieties in the northwest area of the U.S with spectacular results. It subsequently went to CIMMYT (International Wheat and Maize Improvement Center) in Mexico and from there to India, Pakistan, Turkey, and other points in the Middle East and Africa. India doubled its wheat yields in five years and is now producing almost three times as much wheat as it did in the early 1960's.

These two developments launched the "green revolution". In spite of questions raised in certain quarters, this revolution has not stagnated. It is still rolling on. More and better varieties and more dependable proven technology is being extended to rice and wheat farmers with a widening range of impact in the years ahead.

In the developing nations, cereal grains, roots, and tubers provide the bulk of the caloric composition of the human diet. These are supplemented by grain legume seeds, a variety of vegetables, cooking fats and oils, sugar, and limited quantities of animal products. Wheat and rice together account for approximately one-half of the world's production of cereal grain. The green revolution had its first impact on the portion of rice production in South and East Asia in which water levels could be controlled. There is still ample room for improvement in this sector. It is being extended to less favorable environments, including to rainfed areas with intermittent changes in water availability during the growing season, to upland and deep water environments, and to rice grown on problem soils.

The initial impact with wheat came in the irrigated regions of Mexico, India, and Pakistan. It is being extended to many other regions including East and North Africa, West Asia, and other parts of Latin America.

But if we are to avoid very serious hunger and widespread starvation and suffering during the next generation, this revolution must be extended with these crops to all parts of the world, to other segments of agriculture, and to all the other items of food production making up the diets of peoples around the world.

The Consultative Group on International Agricultural Research, consisting of over 35 international bodies and governments, is one of the creations of this decade which is dedicated to this end. It now supports 13 international agricultural research centers and agencies on four continents and directs their attention to the search for means of improving production of the world's major food commodities including not only rice and wheat, but also many others such as maize, sorghum, millet, pulses (cowpeas, chickpeas, pigeonpeas, beans, lentils, etc.), groundnuts, potatoes, cassava, other root crops, vegetables, and tropical livestock. Its Technical Advisory Committee (AC) is continuously re-examining its program and priorities to help assure that its investment in this effort is made in a way that will give the greatest hope of meeting the total world food needs and of providing the less privileged members of society with continuing access to food. The Consultative Group recognizes that the solution to these problems will have to be found within the nations, one by one, in which the people live and that each nation must develop its own capabilities to deal with the problems of its people in producing and distributing food and in gainful employment of its people to live with dignity, self-reliance, and self-respect.

In addition, this group also decided to assist national governments in the developing countries to strengthen their own national agricultural research systems and thereby to improve their capability in order to take advantage of all relevant developments in agricultural science, whether emanating from the various international agricultural research centers,

other national programs, or locally and then put this knowledge to work in the solution of their own problems.

The world is now annually using over 80 million tons of plant nutrients (nitrogen, phosphoric acid, and potash) in support of crop production. In order to meet the food needs anticipated by the year 2000, this will have to be increased more than that amount by three-fold or at least effectively so. Less than one-fourth of the present fertilizer consumption is in the developing countries and more than three-fourths in the more affluent countries.

By the year 2000, fertilizer utilization in the developing countries needs to be increased at least five-fold. Hopefully, some of this may be achieved by improved efficiency in utilization of nutrients supplied by present fertilizers through improvements in application or by substitution of new materials which can deliver nutrients to crops in a more timely and effective manner and which may be less susceptible to leaching or volatilization losses. But a very large portion will have to come from increased quantities. Massive investments will be required in:

- o Fertilizer manufacturing facilities--for conventional and more efficient products
- o Irrigation and drainage facilities
- o Equipment for on-farm operations (for much of the world, this will have to be simple, low-cost equipment suitable for small farm operations but providing for the precision of operation necessary for high yields and efficient utilization of inputs)
- o Storage and distribution
- o Marketing
- o Supporting services
- o Research to improve:
  - -Fertilizers--type, physical properties, efficiency in utilization, etc.
  - -Production technology
  - -Genetic yielding ability and pest and disease resistance of crop plants
  - -Technology delivery and application

The talent assembled in this meeting will have the imagination and ingenuity to focus on problems which have real potential and which could advance our understanding and our service to mankind.

PART 1

FERTILIZER RAW MATERIAL RESOURCES

DYNAMICS OF DEVELOPMENT OF FERTILIZER MINERAL RESOURCES

RICHARD P. SHELDON*

INTRODUCTION

The development of fertilizer mineral resources is a multi-stage system which includes conception, assessment, discovery, delineation, extraction, and processing of deposits. The implementation of this multi-stage system is carried out by mineral scientists and engineers of different disciplines working for different organizations from the university, government, and industrial sectors of society.

The mineral supply system is driven by the pressures of mineral demand and is guided by the opportunities created by technologic change to use minerals. Thus, the mineral resource supply system operates in an environment of changing economics and technology.

Finally, the mineral supply and demand system is controlled by the national policies operating within each country. The levels of effort in all phases of the system are directly or indirectly determined by government policies in the areas of: scientific and engineering research and development, education, taxation and subsidies, mining, manufacturing, environmental laws and regulations, import and export laws, and tariffs and regulations.

The amount of fertilizer that is applied to the farms of a country is the end result of this melange of human activity. If the system is to be improved, it must be understood. This paper is an attempt to describe the general workings of the fertilizer mineral supply system and the external factors that influence it.

RESOURCE DEFINITIONS

Mineral resources are created by human activities in response to human needs from the rocks that make up the earth. McKelvey (1972) remarked, "Defining resources as materials usable by man, a little reflection reveals that whereas it is God who creates minerals and rocks, it is man who creates resources." McKelvey then formulated a system of classification of mineral resources which, with minor variations, is used presently throughout much of the world. In it, mineral resource deposits are defined by two factors: (1) the amount of knowledge (or certainty) about mineral deposits and (2) their value to man (or the feasibility of economic recovery) (Figure 1). Thus, resources can be considered as identified or undiscovered under present levels of knowledge and as economic or subeconomic under present levels of price and technology. These four classes can be subdivided for more complete analysis.

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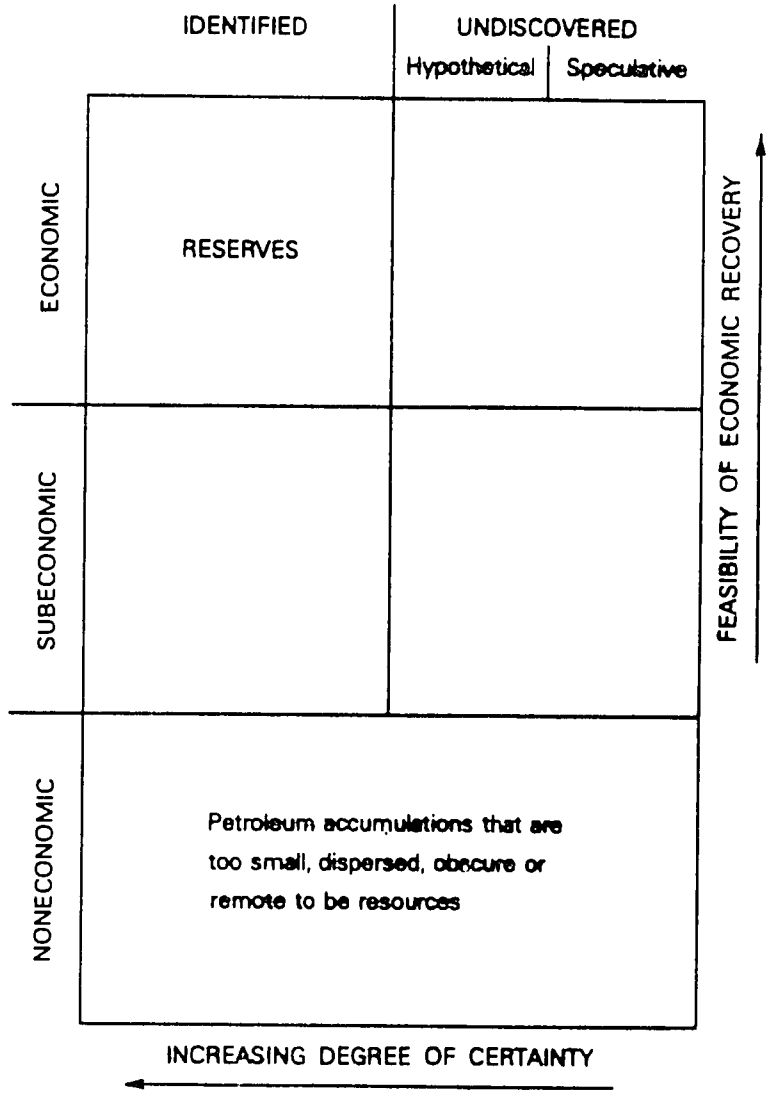

Fig 1. General classification of mineral resource (McKelvey, 1972)

The category of identified-economic resources is classified as reserves. These have been divided into three subcategories: inferred, indicated, and measured--in order of increasing accuracy and precision of estimates of their quantity. When a deposit is first discovered, the extent of the deposit must be inferred largely from geologic interpolations and limited extrapolations about data points. A program of deposit exploration better delineates the extent of the deposit and enables the reserves to be classified as indicated and finally, when knowledge is complete, as measured. It is useful in this paper to deal with the class of inferred reserves and the combined classes of indicated and measured reserves. Also, for this analysis, it is helpful to use the hypothetical and speculative classes of the undiscovered category that were defined by Brobst and Pratt (1973). Hypothetical undiscovered deposits are those about whose existence the geologist feels fairly confident, that is to say his hypotheses about them are strong. On the contrary, the geologist can speculate about additional undiscovered deposits that are only poorly understood, and these deposits are categorized as speculative resources.

Exploration geologists know that deposits exist that are unconceived and probably unconceivable given the present knowledge base. The evidence for such deposits is the occasional complete surprise discoveries, such as the Precambrian stromatolitic phosphorite of western India. Before the discovery of the phosphorite in the late 1960s by routine geochemical surveying techniques, the existence of such a type of deposit was unsuspected, and only a few years earlier most geologists believed that no sedimentary Precambrian phosphorites existed except for mineralogic curiosities.

RESOURCE SUPPLY SYSTEM

By human thought and activity, mineral deposits are conceived, speculated about, hypothesized, prospected for, discovered, and delineated. Thus, the classification of deposits tends to move from one category to the next, from right to left, as shown by the arrows on the diagram (Figure 2), and as production increases, reserves are depleted. Technologic and economic change cause deposits to move vertically in the classification, generally in an upward direction as shown in Figure 2, as production shifts to higher cost deposits or technologic change makes subeconomic resources economically viable. However, both price/cost ratio change and technologic change can result in reserves becoming subeconomic, for example, by lower prices, higher costs, or shifts from one type of deposit if a new technology makes another type less expensive. If we consider only the category of undiscovered resources (Figure 3), the conception of new resources through advances of knowledge allows increases of speculative resources. Resource assessment by means of geologic, geochemical, and geophysical surveying, as well as geostatistical analysis of mineral data, allows increases in hypothetical resources from speculative resources. Finally, prospecting resulting in discovery or identification deposits that are economic to mine adds to inferred reserves.

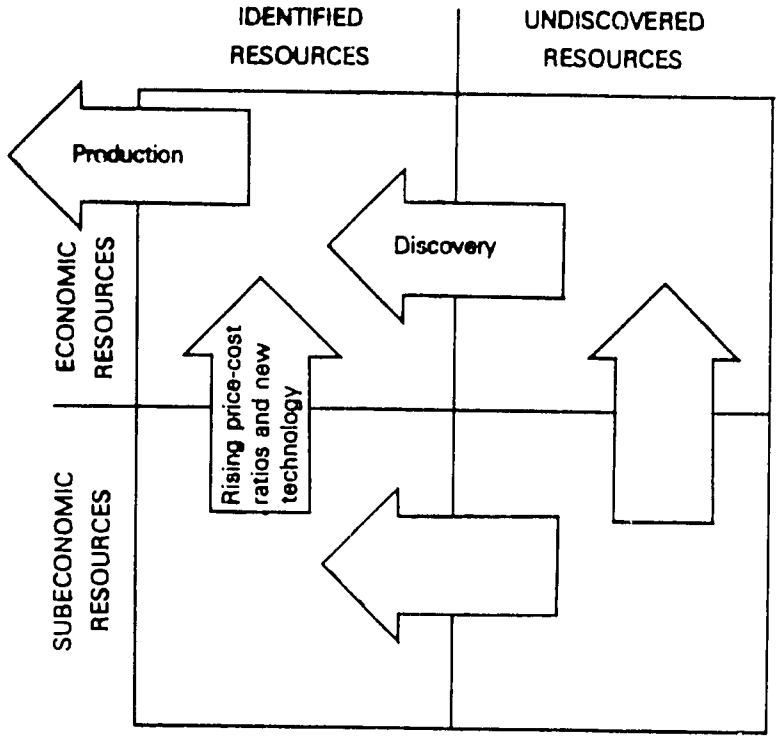

Fig 2. Simplified model of mineral supply system

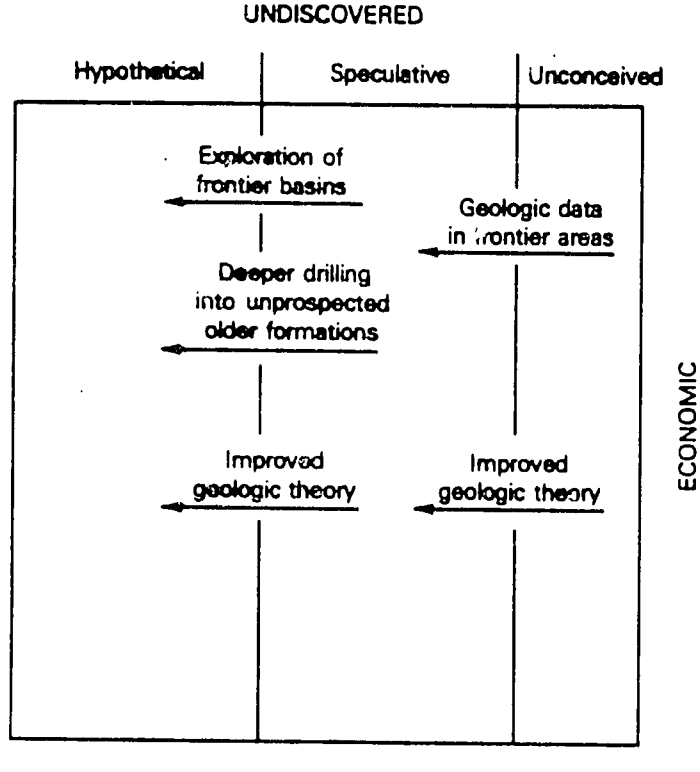

Fig 3. Dynamics within the undiscovered economic resource category

Research to improve the efficiency of all of these activities can greatly speed up this flow of mineral deposits from one resource category to another. Thus, an advance in basic geological science, such as the upwelling theory of origin of phosphorite deposits of Kazakov (1937), can have a profound effect on magnitude of speculative resources. An advance in geophysical techniques of surveying mineral deposits, such as the LANDSAT remote-sensing technology, can have a profound effect on the ability of geologists to assess mineral resources in poorly known areas. The development of a prospecting technique, such as the geochemical mapping of bromine-chlorine ratios in salt deposits for prospecting of potash, can greatly increase geologists' ability to discover potash deposits.

The development of a better mining technique can make deeply buried deposits economic to mine, such as the Saskatchewan and Manitoba potash deposits. The development of new beneficiation techniques can allow poor quality ore to be mined economically. Finally, the development of a new manufacturing process can greatly change the quality requirements for raw material. Clearly, research activities at every stage of the mineral supply system are vital to a healthy system that is responsive to the changing politico-economic climate.

The phases of activity in the mineral supply system and the category of mineral resource developed during each phase are shown in Figure 4. This analysis clearly shows that reserves are increased not only by prospecting activity but also by research in deposit exploration, extraction, and processing techniques. These phases of the mineral supply system are shown in the McKelvey diagram in Figure 5.

The universities, government research organizations, private institutes, and industry play different, but generally distinct, roles in the mineral supply system. These phases of responsibility (shown in Figure 4 and in Figure 6) vary from one country to another depending on the degree of political and economic socialization of the country, but a general pattern of organizational responsibility is common to all countries. Basic research in geology, mineralogy, geochemistry, geophysics, oceanography, climatology, and the like is conducted primarily by university and university-affiliated research institutes and some privately endowed institutes. In some countries, such as the United States, much basic research is also carried out by government or government-contracted research organizations. Regional resource assessment is generally left almost exclusively to government research organizations, mainly because of the expense and nonprofit-making nature of such regional studies. Prospecting branches of industry commonly carry out local resource assessment activities on a proprietary basis as well as regional low-cost reconnaissance. The discovery, delineation, extraction, and processing phases are the responsibility of industry; however, research and development on the techniques of discovery, delineation, extraction, and processing is shared between government organizations and industry in most countries.

Major phases	Detailed phases	Activity	Mineral resource category developed		Prime responsibility
RESEARCH	CONCEPTION	Research in geologic processes, i.e. plate tectonics, formation of mineral deposits, etc.	UNDISCOVERED RESOURCES	SPECULATIVE	Universities, Government, research organizations, private institutes
	ASSESSMENT	Geologic, geophysical, and geochemical mapping, geostatistical analysis		HYPOTHETICAL	Government Industry
EXPLORATION	DISCOVERY	Prospecting	RESERVES	INFERRED	Industry
		Research on prospecting techniques			Government and Industry
	DELINEATION	Exploration		INDICATED AND MEASURED	Industry
		Research on exploration techniques			Industry and Government
EXPLOITATION	EXTRACTION	Mining and land reclamation	Produced raw material		Industry
		Research and development on extraction	Reserves		Industry and Government
	PROCESSING	Beneficiation reduction and refining	Produced refined material		Industry
		Research and development on processing	Reserves		Industry and Government

Fig 4. Phases of mineral supply system

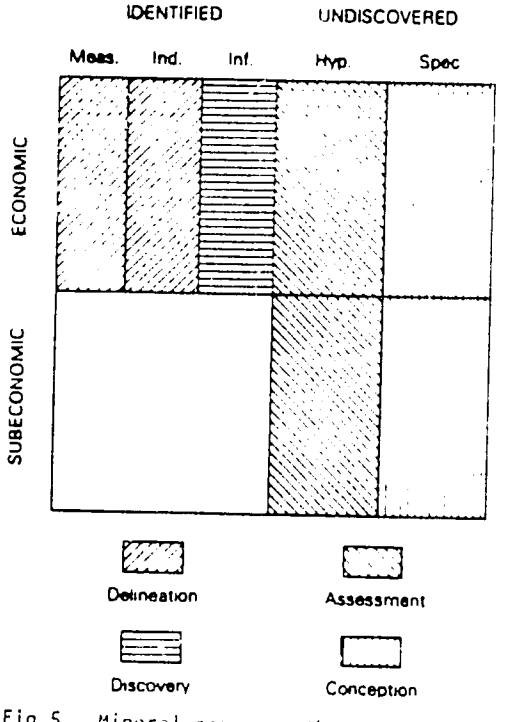

Fig 5. Mineral resource diagram showing phases of mineral supply system

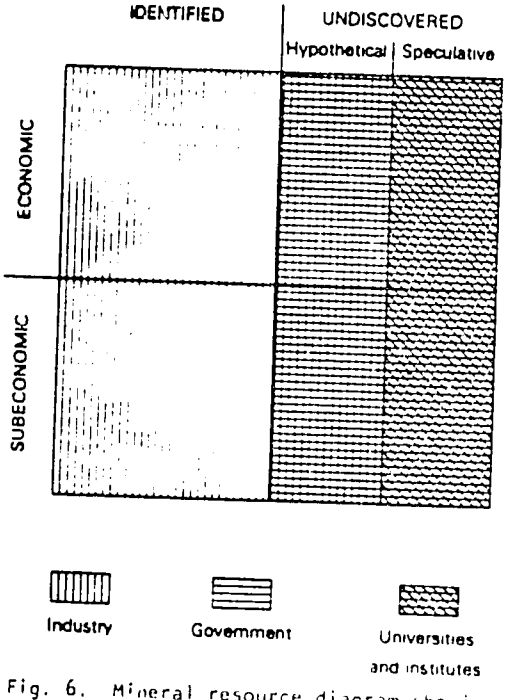

Fig. 6. Mineral resource diagram showing sector responsibilities for phases in mineral supply system

RESOURCE DEMAND SYSTEM

The resource demand system is also multiphased and complex. Analysis of it is beyond the scope of this paper, but interactions between the mineral-resource supply and mineral resource demand systems must be recognized. Of course, the economic demand for fertilizer raw materials provides driving pressure to the fertilizer mineral resource system. In addition, technologic change in the fertilizer manufacturing process produces change in both quantity and quality of the raw material demand and therefore is the guiding force of the fertilizer supply system. A slow evolution of fertilizer raw-material quality requirements has taken place during the era of low-cost petroleum in response to the lowest cost technology of the supply and demand systems, and approached an equilibrium based on low energy cost by the early 1970s. The recent increase in energy costs has upset this equilibrium because production of all of the fertilizer raw materials is energy intensive. In nitrogen fertilizer, for instance, the hydrogen of natural gas is a raw material itself for the ammonia product. A strong pressure is building to devise and use a less energy-intensive fertilizer manufacturing technology. This will probably have a large effect on the quality requirements of the raw materials. The nitrogen-phosphorus fertilizer generator technology described in a paper by R. W. Treharne in this conference is an example of such a technologic change. If successful, this technology will demand less pure phosphate rock, and many presently subeconomic phosphate rock deposits would become economic (Sheldon and Treharne, 1978).

POLITICO-ECONOMIC FACTORS IN MINERAL RESOURCES SUPPLY

Clark and Drew (Clark, 1977) devised a conceptual model of a mineral supply system, using petroleum as the example. This composite model (shown in Figure 7) consists of a geologic-occurrence model which is the basis for an economic-search model, which in turn is the basis for an economic-production model. The value of this model is that it shows conceptually the relationship between the economics and the geology of mineral supply. Two major factors external to the model are world supply price and government policies, which affect substitutions in the case of petroleum. The point of impact of these factors on the system in their model is on exploration.

It was pointed out earlier that the economics of supply and demand gives the driving force to the supply system and technologic change gives the guiding force. Governmental policy determines the overall economic environment of mineral supply and controls the complete process, whether by neglect, a policy of total control, or something in between. When one considers that government policies are the main controlling factor in the levels of research of all kinds, as well as the main contributing factor in subsidy, taxation, economics, and foreign trade, clearly the primary factor in fertilizer raw-material availability in a country is the overall government policy.

CONCLUSIONS

The fertilizer minerals are made available in a country by a well-functioning supply system. If the supply falls short, the supply system

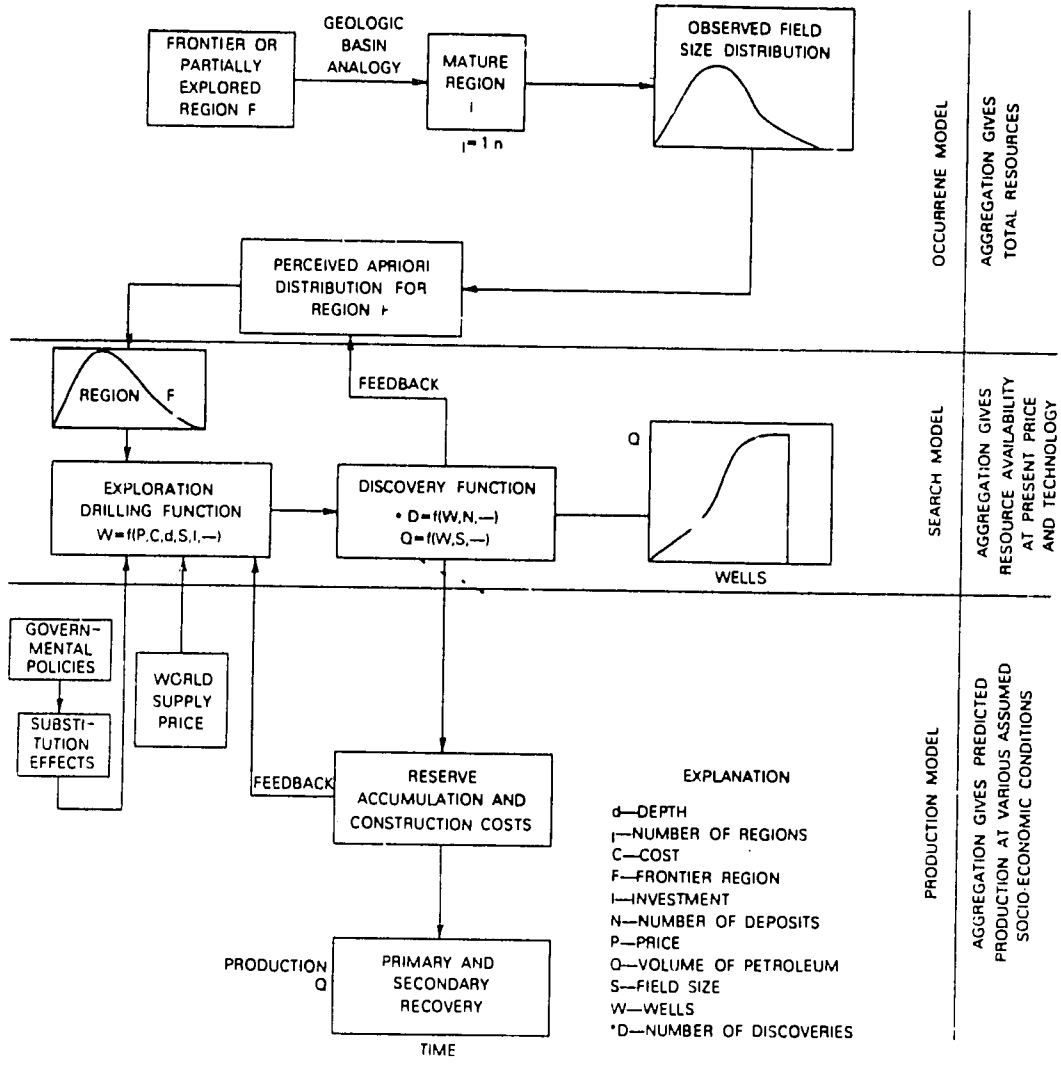

Fig 7. Clark-Drew Conceptual Model of petroleum supply system (Clark, 1977)

is sensitive to stimulation at a number of its phases. However, the importance of the early research phases of the system are generally not recognized. These phases are the responsibility of the university, public and private research sectors of society, which are largely funded or subsidized by government. The lack of recognition by governments of the importance of these research phases makes the timely development of their fertilizer mineral resources difficult. For example, many, if not most, developing countries and several developed countries are not mapped geologically at a sufficently large scale for prospecting. Without adequate geologic maps, prospecting activity, which is always high risk, is too risky for industry to undertake, thereby keeping undiscovered fertilizer mineral deposits undiscovered. Knowledge of the geologic history of many countries is sketchy. The number of trained earth scientists in many countries is too small to make rapid changes in these situations. Knowledge of geologic processes determined by basic research in one country can easily be transferred to another country, but regional geologic knowledge generated by resource-assessment activity is country specific and must thus be carried out in each country.

In conclusion, the availability of domestic fertilizer raw materials is a function of the foresight of the research programs in the specific countries carried out or financed by the country governments. Timely programs to take advantage of these development opportunities will do much to improve the availability of fertilizer raw materials to the countries of the world.

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PHOSPHATE ROCK DEPOSITS AND POTENTIAL OF ASIA AND AUSTRALIA: WORKSHOP REPORT

P. Cook. I would like to introduce you to one or two of the aspects of phosphate geology, which those of you who are nongeologists may not be familiar with and which you may find useful in understanding the concepts that we are presenting. If the geologists could bear with me, the first point is that there are three basic types of phosphate deposits, igneous, sedimentary, and the guano-type deposits. The guano-type deposits will be dealt with in the next panel discussion, and so I won't consider those at all. The igneous phosphate is from a high-temperature igneous rock--granite is another igneous rock, for example, that you're all familiar with. The igneous-phosphate deposits occur in a particular type of igneous rock called carbonatites, and something like 20 percent of the world's phosphate comes from this source. The dominant type of phosphate deposit is the sedimentary rock, which is often called phosphorite. All of these deposits basically consist of carbonate fluorapatite, composed of calcium, phosphorus oxide, fluorine, carbon oxide, and very small amounts of many other elements.

Phosphorites for the most part are composed of pellets. The form of these pellets not only gives us some indication of how they formed, but it's also quite important in terms of how we beneficiate these rocks. Discovered deposits are scattered around the world but there are a number of countries in Southeast Asia in particular that have no known deposits. So there's by no means an equal distribution of phosphate deposits as far as we know.

When we go into new areas and look for undiscovered deposits we do have a few pointers. There seem to be certain times when phosphate deposits were deposited in various parts of the world, so that there are these preferred periods in earth's history for the occurrence of phosphate deposits. For example, in old rocks from about 500 million to 600 million years old quite a number of deposits are found in the Asian region.

Another thing that we use which Dick Sheldon pointed out a number of years ago, is the latitude at which ancient phosphates were deposited. This we call the paleolatitude. Phosphate deposits were formed at particular paleolatitudes, and so if we can reconstruct the paleolatitudes of a region we can say whether or not the deposit possibly formed at this time and in this region.

Particular types of sediments are deposited with phosphates. We can use these particular rock assemblages for exploration, and from these we can develop particular models of rock assemblages. From such patterns of similarities we can say whether or not we think there may or may not be deposits in particular areas and in particular ages of rocks.

So you can come up with a series of requirements for finding phosphate deposits. Every geologist would produce a different set of requirements in detail, but there are a number of points that they would have in common.

Turning now to the results of the proceedings during the past week on the sources of phosphate rock, the panel discussions were chaired by Maurice Slansky of BRG in Paris, with Dhiraj Banerjee of India and

Arthur Notholt of the United Kingdom as Recorders. We addressed the question of identifying areas which may contain deposits of phosphate, and also the likelihood that we will need to develop new techniques to find and exploit these as yet undiscovered deposits.

Our finding is the feeling that there's no overall shortage of phosphate in the region. However, this provides no grounds for complacency, because presently there is an inequitable distribution of deposits, with large areas in Asia with few or small or no deposits and many individual countries lacking adequate supplies of phosphate rock. This necessitates their importing phosphate rock. We do believe there are grounds for optimism about the chances of finding future new small deposits for local use and also for finding a number of larger deposits suitable for exploitation on a national basis. In particular it was felt the older rocks, which include the Lower Paleozoic rocks 400 million to 600 million years old and the Precambrian rocks more than 600 million years old, offer the highest hopes for the Asian-Australian region in particular. To some extent igneous apatite bodies offer additional hope.

Consequently we feel that work programs in these countries should be concentrated on those areas where these types of deposits are most likely to be found. The point was made that whilst the deposits we're talking about are old, our knowledge of them is fairly new, and we're going to have to acquire a lot of new information on these deposits because of it. The first way you identify areas that possibly contain phosphate is by going to the geologic map, and if you don't have a geologic map, you have to make one first off. We need to know more fundamental information, too, such as that regarding the geography of ancient continents, how the land and the sea were distributed, how the plates moved, as these have a great influence on where phosphate deposits formed and what types of phosphate deposits formed. We need to know the precise age of phosphogenic sequences in order to identify the age of rocks that potentially contain phosphate. We need to develop models of deposition of phosphate to aid exploration. There are probably some advanced exploration techniques that also would be useful, such as geochemical prospecting, which in local areas may be quite valuable, and remote sensing techniques.

On the exploitation side, the ancient deposits tend to be rather hard and somewhat more difficult to exploit than the better-known younger deposits. Thus we are going to have to develop new techniques for exploitation, in other words, new techniques for mining, new methods of chemical treatment, new methods of grinding. In addition, it was felt that there's a need for the fertilizer manufacturers to be somewhat more flexible in their phosphate rock specifications. By and large they're geared for the high quality rock that you get from Morocco, Florida or Nauru, and it was felt that there's a very real need for manufacturers to be less demanding in their specifications for phosphate rock so that some of the new lower quality sources could indeed be used.

Finally, it was felt that there was a need for a more simple technology for using some phosphate rocks. The virtues of direct application of phosphate rock were extolled. And particularly it was felt that there was great scope for small-scale adaptive technology which will need to be suited to the new types of ores likely to become available. And in this

regard it was also pointed out that there was a need for a more sympathetic and flexible approach by the international funding agencies towards small-scale, low-cost adaptive technology operations.

So that very briefly summarizes the findings of the two panels that looked at the question of phosphate rock resources in the Asia-Pacific region, and with those remarks I would like to now throw it open to first of all the rest of the panel to just see if there are any particular things they'd like to highlight, and then to the audience in general.

DISCUSSION

D. E. De S. Jayawardena, panel member. I would like to specifically mention about igneous phosphate. This type of phosphate rock is sometimes considered to be uneconomic because of the low reactivity and the low solubility, but taken as a whole, these rocks are exploited not only for phosphate but for other types of minerals, like rare earth minerals. These rocks are also good for some unconventional forms of fertilizers, where they are thermally fused with other materials. One of the best materials for fusion is serpentinite which when combined with apatite could manufacture fused magnesium phosphate, which is as good as soluble phosphate in tropical countries, where you don't have much wastage of material, because it remains in the soil. We discussed direct application, and how effective it is. Monitoring the uptake of P_2O_5 by introducing radioactive tracers is actively being pursued now by IAEA, and we in Sri Lanka have a program of monitoring the uptake of P_2O_5 in our apatitic phosphate. The next topic is the availability of other types of phosphate technology, especially in this area of world crisis. I think that research in developing solar energy for manufacturing of phosphate fertilizer on a very small scale is something that we should pursue.

Asrarullah. There are carbonatites and carbonatites. Not all are high grade with respect to phosphate. We have discovered in Pakistan a carbonatite body that contains about 8 percent of P_2O_5 and it is in the process of being developed. We have estimated about 3 million tons of P_2O_5 in that carbonatite. High-grade carbonatite bodies do occur, but there are certain countries where only the low-grade carbonatites are present, yet they must be used for national purposes. I would like to emphasize also that other low-grade forms of phosphatic bodies, such as phosphatic limestone and shale occurs in Pakistan in different formations. It is very heartening that a cell process exists in which low-grade ores can be converted into direct forms of phosphate. That should be encouraged as soon as possible.

D. M. Banerjee. The immediate problem of developing countries is that we need some new techniques to use low-grade phosphate ores. We have some high-grade ores, but what concerns us is how to utilize the low-grade ore in a proper manner.

H. P. M. Gunasena. I want a little bit more information on using solar energy by the farmers for processing phosphate. What exactly are you talking about, and what is the resource?

R. P. Sheldon. We will be having a talk this afternoon by Treharne regarding this.

H. S. Subramoney. There is a considerable amount of work that has been done on direct application of various types of phosphate rock, not using radioactive techniques but just plain yield figures. By and large the information now available indicates that where you don't have high soil acidity, direct application is not beneficial, at least at the rates that farmers are capable of applying. If you are capable of making the farmers use larger dosages like half a ton or a ton of powdered rock phosphate, probably yes. But normally in most of the countries they use much smaller dosages, and at that rate insoluble phosphates have not been found useful.

D. E. De S. Jayawardena. Yes, I agree with you regarding the direct application. The basic fact is that soil acidity is very important, and we in Sri Lanka have been trying some of the igneous phosphates, grinding them to about 100 mesh and applying it to the soil, and we believe some of the people in the Tea Research Institute in Sri Lanka have got very good results and they are quite happy with our rock phosphate. They say it is better than even the imported Jordanian phosphate, but of course long-term tests are required; field trials are required for this.

V. Kumar. I refer my question to the chairman who pointed out that the fertilizer manufacturers have to be more flexible in accepting different types of phosphate. I think it is more appropriate to have the supply from the suppliers to be of a specific order because the plants are made to a particular specification and it is very difficult to accept a different type of specification for a particular plant. So my friend Dhiraj Banerjee mentioned that we have to find some technique where the low-grade rocks can be used successfully and that could be the answer for some of the developing nations.

Peter Cook. God made the phosphate rock and he made it the way it is and there is not much we can do about that. So I think there is greater opportunity for the manufacturers to have flexibility than there is for the geologist to have flexibility. We can do a certain amount of high grading of the ores, selective mining and things like this, but there is a limit to how far you can go with this sort of thing and after that I guess that the manufacturer has to take it or leave it, and in some cases they leave it. Which perhaps is unfortunate from the national point of view in some circumstances.

V. Kumar. Why do I raise this tactical question? We have supplies from Jordan for phosphate input, and the plant runs perfectly well. New plants are made for specific standards and will not accept a low grade even from within the country. It would take a long time to establish new plants and to start functioning.

M. A. Mian. My question is to Mr. Asrarullah. The fertilizer complex is going to be established at Hazara. I would like to know, will they be using Hazara rock phosphate which is very hard, low-grade, and what fertilizer would they be producing?

Asrarullah. Hazara phosphate rock is being mined for that very purpose, and beneficiation and processing is being experimented with. The plant will be using ore from the Karkul area. It will be producing superphosphate.

R. Choudhuri. I have a question about the utilization of the low, medium or marginal grade of ore. Just now Peter (Cook) pointed out that in the natural endowment the ore is as it has been created, and at the same time the plants are built up on the basis of certain specific ores. Now here a sensitive issue is involved: economic process, conservation, utilization. I think there is a point where these interests can converge. What I'm talking about is born out of practical experience. I cite an example without mentioning it specifically. The accepted limit of SiO_2 is no more than 6 percent. We know today plants which are utilizing as high as 12 percent. Superphosphate is utilized as high as 14 percent. So within a national context and in the present situation, all possibilities must be taken into consideration in the context of development. There is a need for flexibility from the manufacturers also to take into consideration those problems instead of being rigid. I do not deny there are an enormous amount of processing troubles, particularly in the specific silicon process, but there is an enormous scope for dovetailing the marginal grade of ore in the national interest in a particular context.

S. Ahmed. For the benefit of us nongeologists, looking at the theory of igneous or sedimentary phosphate rocks, could you identify potential areas in the Asia-Pacific region where there are more chances of economic findings being discovered?

D. E. De S. Jayawardena. Yes, we identified areas as far as phosphorites were concerned. Most of the areas were in India and Australia and some in Pakistan. We found that as far as the igneous phosphates there is a high potential for discovering new deposits in several areas, especially in the Asian and Australian region.

S. Ahmed. Any particular countries?

Asrarullah. Regarding Pakistan, discovery of carbonatites actually came about by delimiting the province of igneous rocks undersaturated with respect to silica. In Pakistan, in the northern frontier province, earlier we had found an outcrop of carbonatite. Later on we tried to find more undersaturated syenitic igneous bodies, and as a result of that search we stumbled against this one pure carbonatite body which has a higher percentage of apatite. So delimitation of a certain petrologic province is needed and where they have been found, the chances of discovering carbonatite are there. Regarding phosphorites, as far as the Cambrian sedimentary province we are expanding the search to further areas where actually structural complexity may be less and sedimentary possibilities may be greater.

D. M. Banerjee. Peter (Cook) has shown you a slide in which he has given you an idea of the occurrence of phosphorite seas, with different phosphorite seas limited to specific areas at different times. Now that straightaway goes to the fact that you need a geological map with which you can find areas which belong to a certain geological period. Once you have identified such an area, then comes the second step, that is, identify the

lithologies which are favorable for phosphate sedimentation or precipitation. That means you require a good geological map identifying the geological age and the lithologies favorable for phosphate sedimentation. The third step seems to be an academic exercise, but has an important bearing, that is to identify the paleolatitudes--where this particular part of the continent was in particular parts of the geological periods. Once you have done this you can send exploration parties to prospect for deposits.

P. Cook. If I could be a little more specific, we would say that there are good chances of finding Cambrian phosphate deposits in Pakistan; reasonable chances for Cambrian deposits in India; good chances of finding Precambrian deposits in India; some chance of finding Cambrian deposits in Nepal--Bangladesh has difficulties because the rocks are so young, so there is less there than in other places; and so we can do this sort of thing for each country and again it harps back to the fact that we are specifying a particular age and then just looking at a geologic map and seeing which countries have rocks of the right age and the right lithological assemblage.

J. Ando. Concerning the phosphate of Asia, I understand that China has a very large deposit, but I do not know any details. Fortunately this morning we have Dr. Yeh as co-chairman. I would appreciate it if Dr. Yeh would please give an explanation of these phosphate deposits in China.

L. Yeh. There are lots of phosphate deposits in China that are Precambrian and Cambrian. The Cambrian amd Precambrian deposits usually are quite large in the southwestern part of China. We have two horizons in the Precambrian, and they lie largely in the southern part of China also, and the much older Proterozoic phosphorite is just in the eastern part somewhere near the Chening Range or the lower valley. So far in northern China only phosphorite that is not industrial has been found.

J. M. Tater. Could you give us any idea regarding the known phosphate rock reserves in Asia and Oceania at this time?

P. Cook. They are large. Proven resources in Australia have been stated at about 5 billion tons of phosphate rock by the Bureau of Mineral Resources; the reserves for China have been stated at 5 billion tons of phosphate rock; the reserves in India are 120 million tons; Hazara 25 million tons; Sri Lanka is 50 million tons. We are talking on the order of 10 billion tons of phosphate rock in the Asia and Australia region overall.

PHOSPHATE ROCK DEPOSITS AND POTENTIAL OF OCEANIA: WORKSHOP REPORT

J. Eade. This panel considered phosphate rock deposits and the potential phosphate in Oceania. We've just heard about phosphate deposits in Australia and Asia, and the Oceania area by comparison is quite different. The previous area, Australia and Asia, was mainly land with very little water area and their phosphate deposits are very old; the Oceania area is largely water with very small land areas, and their phosphates are very young. The known deposits and the potential for phosphate in the Australian and Asian regions as we've already heard is very great. On the other hand, I'm afraid to say that in Oceania the potential is nowhere near that category.

But let's have a look at the situation in Oceania. The area we're talking about is the Pacific basin with islands and submerged islands or seamounts, and including the volcanic arc areas of Asia and the southwest Pacific. First of all we can talk about the guano-derived deposits. These known deposits are high-grade and of fairly large size, but now they're largely mined out. In Nauru it seems there is perhaps about ten years' supply of phosphate left. Ocean Island is virtually worked out, and we understand that the mining operation there is in the process of closing down. Not in Oceania strictly, but the same type of deposit, we have the Christmas Island (Indian Ocean) phosphate deposit. Again, we understand the high-grade deposit there is virtually worked out and will be finished in 1983, according to the current estimate.

Other guano-derived deposits that are known to exist in Oceania are very small cemented phosphate deposits on low-lying islands throughout the Pacific. These are in the order of a few thousand tons and they're generally of low-grade quality. Also in the region are phosphatic clay deposits. These are deposits in soils, and some of them of moderate size, some smaller deposits. These have associated aluminum and iron which at the present time makes them difficult to use. Examples of the last two deposits will be given to you in a little bit more detail by Howard Plummer and Josh Tracey on my right here.

Of the seafloor deposits in the region, the largest is the Chatham Rise deposit of New Zealand, which is currently being investigated by the New Zealand government. There are one or two other signs that there may be phosphorite deposits on the seafloor in other regions of Oceania, particularly the volcanic arc regions of the southwest Pacific. This is an area where CCOP-SOPAC is particularly concerned and is doing some exploration for seafloor phosphate.

Other known phosphate in Oceania is on the tops of seamounts--for example, the mid-Pacific mountains. And a lot of information has recently come to light in a Russian publication on this deposit.

Regarding the potential for finding new deposits in Oceania, in the high limestone islands, e.g., the Nauru-type deposits, the size of these deposits is generally low- to medium-size; the probability of finding more is small, but if such deposits can be found, the quality of these deposits can be very high. Regarding the potential for finding new deposits in the low limestone islands, the size is very small, the

probability of finding new deposits is medium, and the quality is quite low. Other deposits are found on volcanic islands, and once again the potential for finding new deposits is similar to that for the low limestone islands, where the probability of finding new deposits is medium, but the size and quality are both low.

The potential for finding new deposits on the sea floor on rises and ridges is as follows: the probability of finding new deposits we felt was perhaps medium to high; and the size of these deposits would be low to medium and the quality low to medium.

For seamounts the size is low to medium, the quality is low, but the probability of finding more of these deposits is quite high.

I'll now pass over to Josh Tracey.

J. Tracey. The low islands, the islets on reefs and atolls of Oceania have a century ago produced on the order of perhaps a million tons of dried guano or phosphatic guano. These were derived principally from the low arid islands in the equatorial dry belt of the Pacific Ocean. Away from these are many atolls, for example, in the Marshall Islands, the Gilbert Islands, Kiribati, and the Ellis Islands, Tuvalu, and others, on which the islets which may range in size from a few hectares to a few hundred hectares--many of them contain low calcareous sand and gravel deposits which are cemented by apatite. The size of individual deposits on these islands may range from only a few tons or tens of tons to a few thousands of tons. If these can be processed in some way locally they would be available to help out the agriculture of these local islands which is very restricted because of the pure calcareous soil there.

The high islands which contain the very large deposits--such as Nauru and Ocean--are anomalously uplifted islands. There is therefore a possibility that these many atolls and low islands which in general have subsided through the past several millions of years may contain large deposits of phosphate at depth. The prospecting for these would be a bit hazardous because it could only be done by drilling.

J. Eade. Thank you. Now Howard Plummer will give us a bit more information on the phosphatic soils that are known to occur.

H. Plummer. I'd like to elaborate a little on the phosphatic soils classification within Oceania. We've heard about the high island types, Nauru and Ocean Island, which have very good quality. They do not contain deleterious elements such as iron and alumina. Another class or subclass which is in the same general geographic area, but which contains deleterious compounds, alumina and iron, amounting to 15 to 30 percent aluminum oxide and 15 or more percent Fe_2O_3. Some think that these high aluminas and iron diluents in the phosphate are due to volcanism. I've yet to be convinced of this. However, it is a fact that most of the island occurrences with high aluminum and iron do have associated volcanism nearby.

Going to some examples of the deposits we were talking about about a half a million tons of phosphorite containing 30 percent P_2O_5 occurs on Bellona in the Solomon Islands. It contains high alumina. In addition

there are four and a half million tons of about 22 percent P_2O_5. This compares with, say, 38 to 40 percent P_2O_5 of Nauru and Ocean Island type deposits with negligible alumina. The Bellona deposits probably cannot be worked at this time.

In Fiji we've recently done some work to get more knowledge of the deposits which have been known for some time but were not known in sufficient detail. There has been recently proved on one of the islands almost half a million tons of 17 percent P_2O_5. They also generally contain about one million, up to ten million tons of an intermediate grade between 20 and 30 percent P_2O_5, and with high aluminum content.

On Christmas Island in the Indian Ocean, the reserves are running out by 1983, but that refers only to the high-grade, higher quality material. There are substantial reserves of aluminous phosphate on Christmas Island which awaits new technology. These deposits are usually associated with higher grade oolite layers, and the oolites themselves are very high grade. They're composed mainly of high calcium phosphate. It's the matrix or the clays associated with the oolites which contain the high alumina. So if you can separate this clay from the oolites--which is, of course, a costly process--you can upgrade the deposit.

Another way in which some people have tried to make these aluminous deposits useful is by direct application. However, I believe there's a necessity to crush the rock and to dress it to acid soils. They're not of use in alkaline soils. You must have the acid soils in a tropical environment.

So perhaps the end point of my talk should be that we need for this class of phosphorite new technology to make use of these small deposits. They're not going to be mined for exportation, but they may be of use in the actual regions or islands in which they are a part. Thank you, Mr. Chairman.

J. Eade. Thank you, Howard. Bill Burnett is now going to give us a bit more information on the seafloor deposits, and then tell us about the recommendations of the panel. Bill was the reporter for the panel on Oceania and Asian islands phosphate.

B. Burnett. Thank you, Jim. What everyone is interested in is whether or not phosphate deposits from the ocean floor can ever be a resource that we can exploit. That is not an easy question to answer, but I think one should follow New Zealand's activities in the years ahead. The undersea phosphorite deposits on the Chatham Rise off the east coast of New Zealand, is probably today our most promising prospect for ocean mining of phosphorite.

First of all, the deposit is fairly substantial. It's been estimated that it contains at least one hundred million tons of phosphate rock. The deposit on the Chatham Rise is also fairly shallow, on the order of a few hundreds of meters, and perhaps more importantly, there is a readily available market in the area.

New Zealand and Australia import virtually all of their phosphate rock from the oceanic islands of Nauru and Christmas Island in the

Indian Ocean. These islands will not be supplying phosphate rock much longer in the future, so perhaps if we watch the experience of New Zealand in the years ahead it can tell us something about how other deep sea or shallow sea, rather, phosphate deposits may fare.

The panel came up with three general recommendations on how we might better discover and develop phosphate occurrences in the Pacific and oceanic regions, which I'll outline to you now and offer one or two specific examples of each recommendation.

Recommendation #1. The panel believes that an improvement of the basic geologic knowledge of the area is critical to helping exploration.

Recommendation #2. Relevant models of phosphate sedimentation should be developed and applied to the region.

Recommendation #3. The development of new technologies will be necessary to move these deposits from the subeconomic class to the economic class. Indeed, most of the deposits in the area would be considered subeconomic.

As an example of improvement in basic geologic knowledge, the first recommendation, we've heard from the other panel members that deposits that are found on Nauru Island, for example, which has provided some of the best phosphate ore in the Pacific region--these kinds of deposits are found on islands that have been uplifted. They're also found, interestingly enough, often on what's called the leading edge of a tectonic plate. Perhaps one can use those clues to search for other deposits as Joshua Tracey has already outlined. In addition, there's been some recent work done on dating, in terms of absolute years, the ages of various island phosphate deposits in the Pacific. Preliminary results suggest there may be a trend in these ages, and following this trend may offer some clues as to where future deposits could perhaps be found.

A last example shows how geologic knowledge may provide theory in which we as scientists can go out and search for more deposits. Richard Sheldon has suggested and partially documented that many seamounts from the north Pacific that are known to have phosphate deposits, when you examine their ages and reconstruct where these seamounts geographically occurred at the time the phosphate was formed, all seem to occur close to the equator in the zone of equatorial upwelling. Again, a new theory may develop from this that suggests that phosphate deposits found on seamounts may only form in certain provinces, therefore if you can delineate these provinces in past geologic epochs you may have another exploration tool.

Our next recommendation was to develop and apply various types of models of phosphate sedimentation. Peter Cook and Dhiraj Banerjee outlined this approach quite well for the Asian mainland and in India, and it applies in a slightly different sense in Oceania. The scientific approach is more or less the same. You have to examine the type of deposit you want to look for, you have to find out what kind of information is available, and then you have to apply some type of hierarchical approach to the models that can be applied.

As Mr. Banerjee outlined, this could include the model identification for the type of deposit you're looking for, paleolatitude determinations, stratigraphic intervals of interest, etc.--I won't go through all of them now. As a specific example, the panel recognized that in Indonesia there are known occurrences of strata of certain geologic ages, namely Miocene and Permian, which are known from other areas to contain phosphatic materials. It was recommended that would be a reasonable place to start in a search for phosphate in Indonesia.

Finally, the panel recommended development of new technology where that's possible. Some specific examples, the development and refinement of the Kettering nitrogen-phosphorus "fertilizer generator" may help in developing some of the submarginal deposits found on small islands, for example, in the Pacific Ocean. Other possible improvements may include development of inexpensive power, wind power, solar power, etc., for use by fertilizer production. And another example, extraction of potentially valuable byproducts from phosphate rock--uranium, for example, is being extracted in some parts of the world already. Perhaps the rare earth elements that are enriched in phosphatic materials can be extracted for economic use. Also development of technologies may remove potentially harmful elements. This has turned out to be a problem on some oceanic phosphate materials, as cadmium is known to be a problem in some rock, and arsenic may also be high.

In conclusion I would emphasize the point that the panel agreed that the application of sound scientific theory will be necessary for either further discovery or further development of fertilizer raw materials.

DISCUSSION

H. Le Sieur. You speak of marginal deposits of most of these islands. What kind of P_2O_5 contents are you talking about? What are the typical analyses of impurities such as alumina and iron?

J. Eade. This depends on the type of deposit you are talking about. For the phosphatic clays, there are 4½ million tons of phosphatic clay on Bellona with P_2O_5 content ranging from 15 to 25 percent, the average is about 22 percent. This is the largest deposit, although I am not including Christmas Island in this because I am not too sure of the figures there.

H. Plummer. I have an example from Fiji Island, Tuvuca deposit, R_2O_5 (R equalling phosphorus and aluminum) is equal to 31 to 42 percent, Fe_2O_3--13 to 19 percent, silica 5 to 10 percent, loss on ignition 17 to 20 percent. That is about the order of things in many of these deposits.

B. Burnett. Many of the island deposits are subeconomic, not because of the grade of the rock, but because of the size. Many of them have good quality rock but the overall size of the ore itself is limited, and that makes the deposit subeconomic, at least on a commercial basis.

H. Le Sieur. What is the extent of impurities in some of these deposits? They are submarginal in terms of quantity, therefore they are perhaps not useful for superphosphate manufacture from that standpoint, but another limitation in superphosphate manufacture is the presence of impurities and I am asking, what is the extent of Al_2O_3, Fe_2O_3 in these deposits?

J. Tracey. It was reported that Nauru ore is no longer shipped to Japan. Japanese will not accept ore from Nauru because it has something on the order of 150 parts per million of cadmium in it.

B. Burnett. The aluminum and iron content is highest on the volcanic islands which have phosphatic clay. The coralline islands would normally not have very high quantities of iron and aluminum impurities, although they could have substantial amounts of calcium carbonate which causes other problems.

J. Eade. That is not entirely true. Bellona phosphate, for example, formed in an area where volcanism was taking place. It is an active volcanic island arc situation, and subsequent to uplift there were sufficient volcanic materials deposited on the islands to form bauxitic soils and the aluminum content is as high as 40 percent on Reynolds, just alongside of Bellona. Bauxite is being looked at as a possibility for mining.

POTASH DEPOSITS AND POTENTIAL OF ASIA AND THE PACIFIC: WORKSHOP REPORT

D. Workman. I'll just make a few introductory remarks about the general situation in respect to potash in the region, and then I'll call on Mr. Thawat Japakasetr on my right to tell us something about the very interesting and promising discoveries of potash in Thailand. Keith Rogers can answer any questions there may be on the potash potential of the Australia region. Apart from the Indian subcontinent, India and Pakistan, and possibly China, that represents all of the immediately foreseeable prospecting possibilities for this commodity.

Like phosphorus, potash presents a very unbalanced world picture of supply and demand. In fact it is in an even more exaggerated state than phosphorus. About 97 to 98 percent of all of the potash produced in the world comes from a handful of countries in Europe and North America. Four countries, including Canada, the Soviet Union, and the two Germanies, possess more than 95 percent of the present known world resources of potash. Nearly all the countries of the world, something like 140 countries, are on record as using some potash in their fertilizer input, but five countries account for about 60 percent of the total. These of course are countries with developed agriculture, the United States, the Soviet Union, the countries in western Europe and Japan.

At the present time, there is something like 25 million tons of potash consumed in the world. I use the term "potash" to mean the potassium oxide equivalent of the potassium contained in the various salts which go into the fertilizers. There is something of an overcapacity situation, that is to say, the suppliers are in a position to meet excess demand if it exists. About 60 percent of that total goes into international trade, so there is a very large international trade in potash, something like 15 million tons a year at the present time.

Looking ahead to 1985, it is forecast that the production will increase to around 33 million tons a year, and this will approximately equal the demand at that time. So the gap between capacity and demand is expected to narrow. There may be a small shortfall in potash by the year 1985 due to lack of operating efficiency in the potash mines, so that supply and demand by that year are expected to be about equal.

These figures allow for a doubling of Asian (excluding Japan), consumption, to just under two million tons a year, which is expected to be a little less than 6 percent of the world's total of potash consumption by the year 1985. Both in absolute terms and in relation to the use of nitrogen and phosphorus for fertilizers, the potash is and can be expected to remain for some time little used in the Asian-Pacific region. This is partly because of lack of availability because of high price and high cost of shipment from the available sources and partly because with the high preponderance of relatively unsophisticated agricultural practices, to an extent more than nitrogen and phosphorus it's been possible to get by so far without it.

For example, in the case of rice grown in the fertile delta regions of Asia there's little application of potash. Replenishment of nutrients by natural siltation in the deltas is usually sufficient with ordinary

varieties of rice and with single cropping to maintain the fertility of the soil. But in the case of the use of high-yield varieties of rice and of double cropping, the use of potash is becoming more necessary, particularly on some of the less fertile soils in the region. Under many soil and climatic conditions found in the region, yields and quality of other food and fiber crops will never be optimized without a major increase in the use of potash fertilizers.

So the critical question facing Asia now is that of potash supply. Where do potash deposits occur? The great bulk of potash produced comes from a group of rocks known as evaporites, which result from the evaporation of seawater in restricted coastal basins and the consequent deposition of precipitates of the salts contained in the water. Because potash salts are relatively less insoluble than the salts of elements like calcium, magnesium and sodium, potassium salts are precipitated among the last stages of the evaporite cycle. Consequently, in many cases where the cycle of evaporation is arrested, potassium deposits do not occur, and so not all evaporite deposits contain potassium. On the other hand, potassium deposits don't always occur at the top of the evaporite sequence because most sequences contain more than one cycle, and cycles lower down in the succession may contain potassium. This is the kind of prospecting target we're looking for.

In the Asia region potash deposits have been located in Thailand and Laos, and are now in the stage of evaluation. India and Pakistan, Australia, China, also have evaporite basins, and have a potential for containing potash deposits, There are one or two other countries with small indications of evaporites mainly from boreholes, but it is not yet known whether these contain much potential. In the era of a great amount of exploration drilling for petroleum much has become known about evaporite deposits in this part of the world, and petroleum prospecting has given a major boost to the task of looking for potash.

Potash minerals are few in number as far as fertilizer raw materials are concerned. Mainly we're concerned with the potassium chloride mineral, sylvite . Sylvite is applied directly to the soil. Carnallite is another important mineral. I mention that because of the resources so far found in Thailand consist of carnallite, which is a less favorite mineral; however, if it occurs in the vast quantities that are found in Thailand with or without sylvite , it can be regarded as a major resource. It's also true in Thailand that sylvite has been found in very many, I think a dozen, localities and the Thai government is now engaged very actively in locating exploitable deposits of sylvite, in addition to the carnallite already found.

The production of potash in Asia east of the Dead Sea is insignificant. A problem facing any country wishing to establish a potash mining industry is the high capital cost required, and the need to establish firm export markets for its produce in order to justify the investment. There's only room for a few and possibly only one major supplier in this region in the foreseeable future. Once such a supplier gets going, the need for potassium exploration in other countries will decrease.

Potassium production nowadays around the world is becoming more and more an affair of government. This is true in the west as well as in the centrally planned economies, and it will be true in Asia in the future. One can see that the demand for potassium can be met in many countries by government to government barter arrangements. If one country can establish the market, it will be in a very strong position to dictate the terms for potassium trade in the region for a very long time. In Thailand there are huge deposits of potash which are being evaluated by the government, and I will now hand over the microphone to Mr. Thawat Japakasetr, to tell you about this program.

T. Japakasetr The development of the potash deposit that we have found in Thailand is in the exploration stage. We discovered it about six years ago. The first hole we drilled hit potash. In a four year period we have drilled 63 holes and we have found the potash minerals carnallite and sylvite.

The potash is found only at shallow depth compared with other countries. The shallowest sylvite bed is 90 meters and the deepest is 427 meters. We are now doing some detailed drilling to delineate the boundary of the sylvite and carnallite ore bodies which we earlier found interesting.

K. Rogers. I'll comment on the Australian situation, briefly because we can't follow that act. Unfortunately in Australia, we have no reserves of potash at all. However, we do have a number of thick sequences of evaporites identified in basins from Late Proterozoic through Devonian. Most of this work has resulted from petroleum search exploration and possibly some of the potash sequences have been missed in that work.

NITROGEN FERTILIZER RAW MATERIAL DEPOSITS AND POTENTIAL OF ASIA AND THE PACIFIC: WORKSHOP REPORT

Asrarullah (Chairman of the session). This session deals with nitrogen fertilizers raw materials, that is, natural gas for production of fertilizers. The usefulness of natural gas I don't have to dwell upon. So far as Pakistan and India are concerned it has really proved a boon. Pakistan at the moment is meeting 45 percent of her energy requirements through gas. If this natural gas was not found we would be in a real stew because we are producing only 13 percent of our oil requirements. India recently found a bonanza in Bombay embayment, so perhaps very soon they are going to join the gas OPEC of the world.

Pakistan is producing urea fertilizer from gas. We have four large factories that are producing urea and meeting 50 percent of the requirements. I would request the panel, consisting of Mr. A. Chaube, the chairman, Ms. Nicholas, and Dr. F. Hehuwat and Dr. M. Ahmed, to give you the details of what happened at their proceedings.

A. N. Chaube. The gas commodity panel concerned itself with the preparation of an inventory of the reserves of gas that have already been discovered. The panel also had as its goal a taking of the stock of the gas resources of the region in the context of future development opportunity and likely availability.

We should like to steer clear of the quicksands of nomenclature and conceptual differences about the terms existing in the field of reserve and resource. For our purpose here we have used the term reserve to mean proven or demonstrated reserves which can be recovered with contemporary technology. The term resources, however, is not so easy to define to a general audience of the kind that we have here. This term has inherent in it the feel of the explorationist who gives his best estimate after taking into account the sum total of all factors which constitute the prospect of a geology province or basin. Essentially, resources are fairly conceptual numbers which must be concretized in future exploration and technology development into the class of reserves.

Another factor of importance is that there are generally no conscious exploration programs for natural gas as such. Any gas that is discovered is incidental to oil exploration. It is noted, therefore, that the exploration for the two commodities oil and gas thus follow slightly different paths. On the other hand, once gas has been discovered, further exploration and development is contingent upon generation of market demand and this is intimately interwoven with economic policies and priorities of the governments concerned.

This outlines the factors, the uncertainties which inhibit gas discovery in the first place and, in the event of discovery, further follow-up action on reserve assessment and development. It must be mentioned that gas is found in nature as free gas accumulations, in which case it is called "nonassociated gas". Much gas is also found occurring in solution in oil and is inevitably produced during oil production. This is called "associated gas". Both types are important components of the total resource system.

The figures which I will now be giving to you largely exclude the associated gas because the estimate for this class is generally not available easily. This was identified during our panel discussion as a gap and a very significant gap in our knowledge of the figures on the associated gas reserves and resources.

The important reserves existing as of today are located in Indonesia, Australia, Malaysia, China and Pakistan. The total figure of recoverable reserves is 191 trillion cubic feet. There are other nations which report smaller reserves available.

On Table 1, the total resources that are estimated for the region are shown. The yet-to-be-discovered reserves form the dominant component of these figures.

Important future resources are likely to be discovered in China, India, Australia, Indonesia, Malaysia and Bangladesh. It must be emphasized that the degree of confidence for these figures is much less and reflects only the level of information presently available.

On the consideration of natural gas availability it appears probable that within the region as a whole natural gas as feed stock for fertilizer will continue to be available for the foreseeable future, though considerable irregularities exist in the distribution of this raw material both insofar as the reserves and resources are concerned. In order to convert the resource inventory into producible reserves the present techniques are deemed adequate. As initial input reserves are brought into production, new techniques will be developed, particularly in the field of offshore drilling and production technology. The so-called frontier areas of today will, under demand pressures on the one hand and with the improved technology on the other, become the hot exploration places of tomorrow.

Now I'll throw open this panel to the panelists in case they wish to add anything or in case I have omitted any facts or figures.

E. Nicholas. I think one of the things that we found in the panel was the difficulty in getting from the countries some sort of uniformity in the figures. I think we need some sort of uniform assessment method. Everybody seems to mean something different by all the various terms, and I think we should all follow some kind of uniform system so that we can communicate better in the future.

There was just one other point. In the context of this conference, the commodities we've been considering so far you could consider as feedstock. In the case of natural gas, it's one of the world's primary energy sources. It's used as a feedstock and a fuel, and certainly in Australia nitrogenous fertilizer production makes very minor demands on it as a commodity in that context.

M. Ahmed. As already pointed out by Mr. Chaube, discovery or establishment of possible reserves does not necessarily imply exploitation and utilization. In many countries, like Bangladesh, due to technological and economic handicaps, exploitation and utilization are very limited compared to the resources available.

As indicated by others this morning, perhaps more active involvement of international agencies would be helpful in exploitation and utilization.

F. Hehuwat. As Ms. Nicholas has said natural gas is both an energy resource and a fertilizer resource, and we might come up in certain instances with a clash of interests between the various consumers of the product. That has happened in Indonesia. Admittedly that fertilizer takes up only a small portion, but it depends on the geographical location of the deposits whether the competition is severe or not, and then things like prices and so on will play a role in determining the availability of the raw material.

TABLE 1 - POTENTIAL SOURCES OF NATURAL GAS (West to East)

Pakistan

- Sulaiman-Bugti Hills Fold Belt
- Sibi-Boland re-entrant
- Indus Shelf
  - Paleozoic objectives

India

- Kerala Lakshadweep Basin
- Krishana-Godavari Basin
- Bengal Basin
- Punjab-Ganga Basin
- Andaman Basin
- Bombay Basin
  - Offshore unexplored parts

Nepal

- Muktinath Basin
- Nepalganj Basin
- Kathmandu Basin

Sri Lanka

- Cauvery Basin
- Mannar Basin

Bangladesh

- Ganges Delta
- Bogra Shelf

Indonesia

- Fore-Arc Basins
  - Sibolga, Bengkalu,
  - South Java Sea Basins
- Gulf of Bone, Celebes
- Waropen Basin, Irian Jaya

Oceania

- New Zealand
  - West Cook Strait
  - Great South Basin
- Tonga Platform
- Bligh Water
- East of Viti Levu
- Papua New Guinea
  - Northern Basin(s)
  - Southern Basins
- Solomon Islands (Central)
- New Hebrides (Northern)

Philippines

- Palawan Shelves
- Visayan Basin

China

- Tonkin Basin
- Taiwan-Sinzi Basin

Burma

- Iriwaddy Delta

Thailand

- Khorat Plateau
- Mergui Shelf

Malaysia

- Central Luconia, deep horizons
- Northeast Offshore Sabah
  - (i.e., Sulu Sea)

Kampucha-Vietnam-Thailand

- Gulf of Thailand
- Mekong Basin
- South China Basin

Australia

- Northwest Shelf
- Gippsland Basin
- Cooper Basin
- Amadeus Basin
- *Exmouth Plateau
- *Great Australian Bight Basin

* Deep water areas not included in undiscovered resource assessment (Nicholas 1979)

CONVENTIONAL FERTILIZER MANUFACTURE--PROBLEMS AND TRENDS

JUMPEI ANDO*

ABSTRACT

Chemical fertilizers and their production technology are available in wide varieties. Ammonia and nitrogen fertilizers, such as urea and ammonium nitrate, are produced by relatively simple reactions but the production processes are complex and costly and require a large plant and a high operability for economical production. A modern plant has a production capacity of over 1,000 tons per day and requires an investment cost of about 100 million U.S. dollars. Capital-related cost accounts for about 70 percent of the production cost. On the other hand, production processes of phosphoric acid and phosphatic fertilizers are rather simple although the reactions are complex. Over 70 percent of the production cost is accounted for by feedstock and thus smaller plants can be economical. Different kinds of products including thermal phosphate should be produced depending on the type of ore available and the local situation.

While production technology and product quality will continue to be improved, it seems unlikely that dramatically new types of fertilizers will make their appearance and replace conventional ones. Also discussed are energy requirements, technology transfer, and pollution control in fertilizer production.

AMMONIA AND NITROGEN FERTILIZERS

Ammonia, the major source of nitrogen fertilizers, is synthesized from hydrogen and nitrogen. Until approximately 30 years ago, hydrogen was produced mainly by the reaction of coal with steam or by the electrolysis of water. It has since been mainly produced by using natural gas or oil because production with the fluid fuels is much easier than with coal and, moreover, is less costly than with coal or by electrolysis.

However, because shortages of gas and oil are expected in the near future, the use of coal has already come into focus again. Commercial ammonia plants using coal are in operation in South Africa and are nearing completion in India. A demonstration plant is under construction at the Tennessee Valley Authority, United States (Tennessee Valley Authority, 1978). Further improvements of the technology are desired both for gasification of different types of coals and for better heat recovery and environmental protection.

The major nitrogen fertilizers used to be ammonium sulfate and nitrate; they have now been replaced by urea. Consumption of urea has increased remarkably due to the following advantages. 1. It contains 42 percent N as compared with 34 percent for ammonium nitrate and 21 percent for ammonium sulfate. 2. It is produced from ammonia and carbon dioxide; the latter is a by-product of ammonia production using

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fossil fuel. 3. It is less hygroscopic than ammonium nitrate. 4. It is suitable for paddy rice for which ammonium nitrate is not adequate. 5. It has a low melting point and lends itself to melt granulation, which has become popular.

The investment cost (U.S. basis, in battery limits) for a 1,000 ton/day ammonia plant using steam reforming of natural gas was about US $50 million in 1976 (Young, 1977). As shown in Table 1, the production cost of ammonia is estimated at about $79/ton with natural gas at $0.50 per million Btu and $95 with the gas at $1.00 per million Btu. The investment cost is 15 to 25 percent more for a plant using naphtha and 75 to 100 percent more for one using coal. The production cost is estimated at $105/ton with naphtha (Young, 1977).

TABLE 1-- AMMONIA PRODUCTION COST (US $/TON)

	COST OF NATURAL GAS	
	$0.50/MBtu	$1.00/MBtu
Raw material (natural gas)	10.30	20.60
Fuel	5.30	10.60
Return on investment	60.00	60.00
Other	3.30	3.30
Total	78.90	94.50

Investment costs for a urea plant (1,200 tons/day) and an ammonium nitrate plant (1,100 tons/day), both including an ammonia plant (1,000 tons/day), are compared in Table 2. Including auxiliary and supporting facilities, the investment cost is estimated at $104 million for the urea plant and $113 for the ammonium nitrate plant.

With captive ammonia at $80 per ton, the production cost including return on investment would be about $70/ton of urea (42% N) and $60/ton of ammonium nitrate (34% N). The cost indicates an economic advantage of urea over ammonium nitrate.

The investment cost for the facilities would be 25 to 35 percent higher in developing countries. The investment cost is large and more than 70 percent of the production cost is investment-related. In order to ensure economical production, therefore, the plant must be operated at a high percentage of time, say, 300 to 320 days a year (Young, 1977).

Because of the advantages, urea will remain the leading nitrogen fertilizer in the world,as long as ammonia is produced with fossil fuel with carbon dioxide as a byproduct. Urea has been used in large amounts in paddy rice culture. One disadvantage of urea is the partial loss of nitrogen due to volatilization of NH_3, leaching, etc. Devices to minimize the loss--mudballs in Japan and supergranules by IFDC, USA, etc.--have been developed (Hignett, 1978).

TABLE 2-- INVESTMENT COSTS FOR NITROGEN FERTILIZER PLANTS (PRILLING OR GRANULATION) (US $ MILLION) (2)

	Urea (1,200 tons/day)	Ammonium nitrate (1,100 tons/day)
Ammonia plant (1,000 tons/day)	50.0	50.0
Urea plant	16.5	
Nitric acid plant		13.0
Ammonium nitrate plant		9.0
Auxiliary facilities[a]	16.5	18.0
Supporting facilities[b]	21.0	23.0
Total	104.0	113.0

(a) Include steam, power, water supply, rail spur, etc.

(b) Include roads, civil engineering works, offices, shops, laboratory, etc.

Various control-release nitrogen fertilizers based on urea have been produced. These include formaldehyde (UF), isobutylidene diurea (IBDU), crotonylidene diurea (CDU), and guanyl urea (GU). UF products are used primarily in the United States and Europe, in special fertilizers. IBDU, CDU, and GU are used more in Japan, mainly as a component in formulating special fertilizers. Those control-release fertilizers have superior qualities but are expensive; the cost per unit nitrogen is more than double that of urea. Sulfur-coated urea developed by the Tennessee Valley Authority (TVA) may be more suitable for extensive application.

PHOSPHATE ROCK

Phosphate rock consists principally of fluorapatite $Ca_5(PO_4)_3F$ with different crystal sizes ranging from 0.02 to 10,000 microns depending on their origin and with substitution of a portion of PO_4 with CO_3F (Ando and Matsuno, 1966). The reactivity of the rock is dependent on its crystal size, the manner of coagulation of the crystals, and their chemical composition (Ando and Matsuno, 1966). A portion of Ca is replaced by Mg, Na, etc., for further modification of the reactivity (Lehr, 1968).

Sedimentary rocks found in Florida (United States), Morocco (North Africa), etc., are far more reactive than igneous rocks from Kola (USSR), Araxa (Brazil), etc., and have been generally considered to consist of

tricalcium phosphate. But actually they consist of very fine crystals of fluorapatite ranging from 0.02 to 1 micron, while igneous rocks consist of large crystals of over 100 microns. There are other types of rock such as Lao Cay (Vietnam) which contains large crystals of up to 1,000 microns. This deposit is of sedimentary origin but was later metamorphosed. That is, it underwent a thermal effect. Heating sedimentary rock about 1,000°C remarkably increases the crystal size and reduces the reactivity.

Some of the sedimentary rocks such as Gafsa (Tunisia), North Carolina (United States), and Sechura (Peru) are especially reactive and suitable for direct application. Igneous rock is not reactive enough even after fine grinding to pass a 250 mesh screen (63 microns).

When treated with sulfuric acid, fine crystals of calcium sulfate tend to cover the surface of the rock particles and prevent further reaction (Ando and Matsuno, 1966). CO_2 gas contained in the particles is released by the acidulation to break the sulfate coating and to promote the reaction (Ando and Matsuno, 1966). Igneous rock is less reactive with sulfuric acid partly because of the large crystal size and partly because of the low CO_2 content. Nitric and hydrochloric acids decompose igneous rock fairly rapidly because they do not produce insoluble coatings on the rock particles.

For the production of wet-process phosphoric acid, the size and shape of calcium sulfate crystals are important because they seriously influence filtration and washing. The size and shape as well as the rate of hydration of hemihydrate to dihydrate vary with the amounts of rock ingredients such as F, Al, Fe, Si, and also with special ingredients of igneous rock, such as Sr, La, and Ce.

Although there are numerous phosphate rock deposits around the world, high-grade rock is expected to be in short supply. Technology for utilization of low-grade rocks including aluminum phosphate rock should be developed.

PHOSPHORIC ACID AND PHOSPHATIC FERTILIZERS

Direct application of ground phosphate rock is suitable for acidic soil in a hot climate, particularly for paddy fields, where the rock decomposes fairly rapidly. Ordinary superphosphate is easily produced where sulfuric acid is available and is particularly useful for sulfur deficient soils, but the P_2O_5 content is not high (usually 16-18%). Triple superphosphate has been produced in increasing amounts because it contains about 46% P_2O_5 and lends itself to long-distance transportation. For sulfur-deficient soil, double superphosphate containing about 32% P_2O_5 and 5% S, produced from phosphate rock and a mixture of sulfuric and phosphoric acids, may be a better choice.

Wet-process phosphoric acid has been produced mainly by the dihydrate process in many countries. The process is relatively simple but the

P_2O_5 yield is usually below 95 percent; moreover, the by-product gypsum is useless since it has a high impurity content. The hemihydrate-dihydrate and dihydrate-hemihydrate processes have been developed in order to raise the yield to 98 percent and to make the by-product gypsum useful for wallboard and cement. Those processes have been applied in Japan, Holland, Morocco, Brazil, etc.

The product acid by the above processes has a P_2O_5 concentration of 26 to 32 percent and has to be concentrated to 40 to 54 percent for commercial uses. Recently, hemihydrate processes that produce 40-50% acid directly were commercialized in Europe and Japan, saving energy otherwise required for concentration (Blumrich, Crerar, and Quinton, 1974, Miyamoto, 1975). Wet grinding of phosphate rock has been practiced in the United States to save the energy for drying.

Costs for phosphoric acid production (54% P_2O_5) by the conventional dihydrate process and a combination of wet grinding and hemihydrate process are compared in Tables 3 and 4 (Blouin, 1974). The tables indicate that, with the wet grinding/hemihydrate process, the investment cost is a little higher but the production cost is slightly lower than with the dihydrate process.

TABLE 3-- INVESTMENT COST FOR PLANTS TO PRODUCE 54% P_2O_5 ACID (US $ MILLION, in 1974)*

	400t P_2O_5/DAY	600t P_2O_5/DAY
Conventional process (Battery limits)	10.3	12.8
Auxiliary and support facilities	3.1	3.8
Total	13.4	16.6
Wet grinding, hemihydrate (Battery limits)	10.9	13.6
Auxiliary and support facilities	3.3	4.1
Total	14.2	17.7

* G. M. Blouin, Effects of Increasing Energy Costs on Fertilizer Production Costs and Technology. TVA (Nov. 1974).

TABLE 4-- PRODUCTION COST FOR 54% P_2O_5 ACID ($/TON OF P_2O_5, 1974)*

	CONVENTIONAL		WET-HEMIHYDRATE	
	400 t	600 t	400 t	600 t
Phosphate rock*	118.00	118.00	118.00	118.00
Sulfuric acid	49.50	49.50	49.50	49.50
Utilities	3.51	3.51	2.46	2.46
Capital charges**	12.90	10.30	13.70	11.05
Other	16.91	15.18	19.11	15.46
Total	200.82	196.49	200.77	196.47

* $35/ton
**12.7% of plant investment

For the production of 40-50% P_2O_5 acid, the advantage of the hemihydrate process over the conventional processes is obvious because the concentration step is unneeded. Table 5 compares the investment cost for the production of 45% P_2O_5 acid by the hemihydrate and hemihydrate dihydrate processes (Miyamoto 1975). By the hemihydrate process, grinding of the rock can be eliminated if sandy rock (minus about 2 mm) is available. The total investment cost is thus considerably lowered.

TABLE 5-- COMPARISON OF INVESTMENT COSTS FOR PLANTS TO PRODUCE 45% P_2O_5 ACID*

	HEMIHYDRATE	HEMIHYDRATE-DIHYDRATE
Rock grinding	0	19
Acid production	96	68
Concentration	0	20
Storage tank	4	9
TOTAL	100	116

* M. Miyamoto, Practice on New Nissan Phosphoric Acid Process, ISMA Technical Conference, Sao Paulo (1975).

Table 4 also indicates that more than 80 percent of the production cost is accounted for by feedstock (phosphate rock and sulfuric acid). The situation is strikingly different from that of ammonia and nitrogen fertilizer production shown in Table 1. Therefore, relatively small acid plants, producing 100-200 tons P_2O_5 per day, may be suitable depending on the local situation, although larger plants are more

economical if there is sufficient demand for the acid. The same also applies to phosphatic fertilizers.

In tropical and subtropical countries, there are wide areas with acidic soil rich in Fe_2O_3 and Al_2O_3 which readily fix water-soluble P_2O_5. In such areas, citric-soluble basic phosphates containing soluble SiO_2 such as fused magnesium phosphate and Thomas slag show a superior agronomic response.

Fused magnesium phosphate is produced by fusion of phosphate rock with magnesium silicate ore, such as serpentine and olivine, at 1,400-1,500°C followed by quenching with water to give a sand-like product containing 16-24% P_2O_5. Fused phosphate has been produced in Japan, Korea, South Africa, and Brazil mainly by electric furnaces with a capacity of producing 50-200 tons/day of the product and in China by many small coal-fired furnaces.

Calcined defluorinated phosphate, useful for both fertilizer and cattle feed, has been produced in Japan, the United States, and Israel. Tests have been made on calcination of phosphate rock with magnesium or calcium chloride at 600-800°C to obtain citric-soluble products. The calcination temperature can be reached by burning wood or charcoal, abundant in developing countries.

NPK FERTILIZERS

Fertilizer application in many countries has started with the use of single nutrients such as ordinary superphosphate and ammonium sulfate, followed by low-analysis and then high-analysis compound fertilizers with various grades.

Compound fertilizers are useful in labor saving but cost 20 to 30 percent more than single nutrients because they involve granulation which normally requires grinding of feedstock and drying of product.

On the other hand, fluid fertilizers (liquid and suspension) and bulk blending of granular single fertilizers have increased remarkably in the United States since the mid-1960s and have spread to several countries. Fluid fertilizers require special machines for application and are suited for large-scale farming and where wet process phosphoric acid and a solution of urea or ammonium nitrate are available. Ammonium polyphosphate produced by ammoniation of 50-56% P_2O_5 phosphoric acid is suitable for the production of clear liquid because of its sequestering effect on Al and Fe. It has been produced in many plants in the United States and several plants in other countries.

Bulk blending is suitable where granular nitrogen and phosphatic fertilizers such as urea, ammonium nitrate, triple superphosphate, and diammonium phosphate as well as granular potash come from different sources. Blending of the granules produces various grades of products less expensive than compound fertilizers, which require grinding, granulation, and drying. A major problem with the bulk blending fertilizers

is the segregation of the components. The problem is minimized by using granules of nearly equal size--normally about 3-4 mm. Since prilled urea is too small for blending, granulation of urea has been started in the United States. In many developing countries where humidity is high, the blends must be bagged for distribution and storage, which often lasts for several months (Hignett, 1978).

Among compound fertilizers, those based on urea, ammonium phosphate, and potash have the highest grades (19-19-19, etc.) and have been produced in increasing amounts in several countries. A serious problem for production has been the difficulty in drying the product to a low moisture content (preferably below 0.5%) to prevent caking. Melt granulation using a pipe reactor or pipe-cross reactor developed by TVA is promising because granulation is carried out with a low moisture content so that no drying is needed (Young and Lee, 1975).

In some areas, there is a need or preference for natural organic fertilizers, or fertilizers that contain a substantial proportion of organic matter. Organic matter is preferred in home and garden fertilizers and in those used in greenhouse operations. Main sources are slaughter-house wastes, fish meal, seed meal, and "trimmings" from leather tanning operations (Young, 1977). Use of fertilizers that contain organic nutrients in regular farming is fairly popular in Europe and is becoming popular in Japan. In those countries, heavy fertilizer application is needed to obtain high yields of crops; and moreover, it is becoming difficult to supply sufficient amounts of compost.

ENERGY REQUIREMENT

Most fertilizer production reactions are exothermic and proceed without external heating. Consequently, major energy requirements related to fertilizer are for mining and beneficiation of raw materials such as phosphate rock, potash, and elemental sulfur, as well as for production of hydrogen for ammonia. Concentration of solutions and drying of solid products also require considerable amounts of energy.

It is estimated that in the United States in 1980, 0.66 percent of the nation's total energy consumption will be for fertilizers, of which 75 percent, 11 percent, and 2 percent are for the production of N, P, and K, respectively, and 12 percent for their transportation (Young and Lee, 1975). Most energy for N production is for the production of hydrogen.

Energy requirements for DAP and TSP are compared in Table 6 (Achorn and Kimbrough, 1978). Major requirements are for the production of elemental sulfur by the Frasch method using steam. Mining of pyrite requires less energy but the use of pyrite necessitates a gas cleaning system. Concentration of filter-grade phosphoric acid (30% P_2O_5) to 54 percent acid also requires a considerable amount of energy. The energy may be compensated for by the heat recovered from the sulfuric acid production process. Use of the hemihydrate process for phosphoric acid production, to produce 40-50% P_2O_5 acid, can save the energy for concentration.

TABLE 6 - ESTIMATED ENERGY CONSUMPTION*
(MILLION Btu PER TON OF PRODUCT)

	DAP	TSP
Sulfur	3.5	2.5
Sulfuric acid (100% H_2SO_4)	-2.6	-1.9
Phosphate rock (32% P_2O_5)	0.3	0.3
Product acid (54% P_2O_5)	2.6	1.9
Drying product	0.3	0.6
Total	4.1	3.4

* F.P. Achorn and H.L. Kimbrough, Situation 78, TVA Fertilizer Conference (August 1978).

Conventional granular mixed fertilizers as well as DAP and TSP require considerable energy for product drying. One way to save the energy is to use chemical heat efficiently. TVA has developed a melt granulation process using a pipe reactor or pipe-cross reactor, by which essentially anhydrous melt of ammonium phosphate or ammonium phosphate sulfate is obtained to enable granulation at a very low moisture content without the need for drying.

Thermal phosphates such as fused magnesium and calcined defluorinated phosphates have unique properties suitable to certain types of soils. The phosphates require about 900 kW hr of electricity (8.5 MBtu of thermal energy is needed to produce 900 kW hr of electricity) or about 180 liters of fuel oil (7.2 MBtu) per metric ton of product. Supply of low-cost hydropower or domestic fuel may be needed to make the thermal phosphates competitive with wet process phosphates.

TECHNOLOGY TRANSFER

Technology can be transferred through documents or personal contacts but can be mastered only through experience. In order for developing countries to develop their own new technology, it is necessary that they master conventional technology. They tend to prefer the most advanced technology available, believing this to be the fastest way to promote economic growth (IFDC, 1977). They may also presume this is the best way to raise the technology level of their countries. Such moves, however, often fail to meet their intention for the following reasons:

1. Large modern plants are often highly automated and are capital- rather than labor-intensive and do not help to solve the employment problem (IFDC, 1977). Moreover, an automatic system actually contributes little to the progress of technology in developing countries.

2. Trouble with a small piece of equipment, such as a motor or pump, may cause the shutdown of an entire sophisticated system. After start-up, a considerable period of time may be required before normal operation can be resumed. To ensure continuous smooth operation, "preventive maintenance" service scheduled once or twice a year is essential. There is a general tendency in developing countries to operate a plant as long as it manages to run, or until it is forced to stop by serious damage that is difficult to repair.

3. Production capacity is often much larger than the domestic demand for the product. The low operability of the plant increases the product cost seriously, making it impossible to compete on the international market. The high cost is a disadvantage to the farmers of the country.

In many developing countries, well-educated engineers do not want to work at the plant with operators. Watching what is happening at each step of the entire plant is important in keeping the plant in good condition and in maintaining good product quality and also in improving the process. Experience is important especially in the production of phosphoric acid or phosphatic fertilizers using local rock whose quality may fluctuate considerably, resulting in serious changes in product properties.

Experience is also quite important in the granulation of compound fertilizers using different types of feedstock. Factors affecting the reactions are so complex in those cases that it is impossible without experience to predict optimum operation conditions for the fluctuating compositions of rock and feedstock.

It often happens in developing countries that a well-trained engineer leaves the plant for a better-paying job, even when there is no one else who can maintain the plant in good condition. To avoid such a situation, developing countries have started to ask that qualified engineers of the process supplier or the plant constructor stay at the plant for several years to ensure good operation. Excessive reliance upon developed countries, however, may hinder the progress of technology in developing countries.

Developed countries should not hesitate to transfer technology to developing countries and further assist them in establishing new technology conforming to local conditions. On the other hand, those people in developing countries who have acquired technology should not consider it as a private property. Developing countries should not indiscriminately seek highly advanced technology. There may be fertilizers and production processes most suited to each country according to local raw materials available, soil and climate conditions, and types of farming and crops. For example, powdered or partially digested phosphate rock or mixed fertilizer based on it may be suitable if the rock is reactive and the soil is acidic. Ordinary superphosphate or thermal phosphate may be produced by moderate size plants. Wet-process phosphoric acid and high analysis fertilizers may be produced after the demand for fertilizers has risen and labor cost has increased.

POLLUTION CONTROL IN FERTILIZER PRODUCTION

Major pollutants from fertilizer plants are fluorine from phosphoric acid and phosphate fertilizer plants, dust, and fumes from dryers of mixed fertilizer plants, SO_x (mainly SO_2) from sulfuric acid plants, and NO_x (NO and NO_2) from nitric acid and nitrophosphate plants.

Among these, fluorine is most hazardous and may damage plants and aquatic life. Fluorine is contained in phosphate rock at the rate of 2 to 3 percent and is volatilized in the form of SiF_4 on acidulation of phosphate rock or on concentration of phosphoric acid and in the form of HF by thermal treatment at above 800°C. Both SiF_4 and HF are readily removed by scrubbing and can be recovered in the forms of Na_2SiF_6, HF, AlF_3, KBF_4, etc. Even after recovery, fluorine is present in considerable amounts in wastewater which should be treated with lime to precipitate and separate it in the form of CaF_2 or $Ca_5(PO_4)_3F$.

Dust can be removed by a cyclone or a scrubber but efficient removal of fumes requires an expensive wet electrostatic precipitator. Dust and fumes from high-analysis mixed fertilizer plants can be substantially reduced by using the melt granulation process--for example, the process using a pipe reactor or pipe-across reactor developed by the Tennessee Valley Authority--which dispenses with the drying step.

Tail gas from a sulfuric acid plant by the conventional single contact process contains over 2,000 ppm of SO_2. The use of a double contact process reduces the concentration to 400-500 ppm, which is acceptable in most districts. If desired, gypsum, ammonium sulfate, and other products are obtained from SO_2 in the tail gases. NO_x is present in concentrations of 500-1,500 ppm in waste gases from fertilizer plants and can be removed by scrubbing or catalytic reduction.

SO_2 and NO_x are emitted in huge amounts being contained in combustion gases of fossil fuels. The yearly world emissions are estimated to exceed 40 million tons each for SO_2 and NO_x, which is equivalent to more than half the world consumption of S for sulfuric acid and of N for fertilizer. Commercial plants for SO_2 removal, which number more than 1,000 in Japan, 50 in the United States, and several in Europe, have been operated by-producing gypsum, calcium sulfite, sulfuric acid, elemental sulfur, ammonium sulfate, and so on (Ando, 1978). The number of plants are increasing rapidly in the United States and will increase in Europe and other parts of the world. The major process for NO_x removal so far has been the reduction by ammonia to produce N_2. Over 80 commercial plants for the reduction have been operated in Japan consuming an appreciable amount of ammonia. It might be possible, however, to by-produce nitrogen fertilizer from NO_x (Ando, 1978). Future developments in SO_2 and NO_x removal technology in the world may considerably influence the fertilizer industry.

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NON-CONVENTIONAL MANUFACTURE OF CHEMICAL FERTILIZERS: SMALL-SCALE FERTILIZER PRODUCTION TECHNOLOGY

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ABSTRACT

Nitrogen and phosphorus fertilizer can be produced in small-scale systems designed to provide the fertilizer needs of small farm areas. A review is presented of several types of fertilizer production processes that are adaptable to small-scale fertilizer production technology. Special emphasis is placed on the electric arc process for producing nitrogen fertilizer since this type of process, when driven by a renewable energy source such as wind, water or solar power, does not require the consumption of fossil fuels for the production of nitrogen fertilizer. The electric arc process produces calcium nitrate fertilizer using only air, water, and limestone as raw materials. A system designed and developed for the production of nitrate fertilizer for small farm areas is described.

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INTRODUCTION

For certain types of applications, the production of fertilizer in relatively small-scale systems may be either necessary or desirable. There are several areas in which fertilizer production capability of a few tons per year perhaps can be economically viable. Such areas may include those parts of the world where the high capital investment costs of large-scale manufacturing systems for fertilizer production cannot be justified due to limited market demand for fertilizer in that general area. Other contributing factors that may necessitate consideration of small-scale fertilizer production systems are factors such as: (1) high costs for fertilizer delivered to remote locations or (2) the availability of only limited raw materials or energy sources for fertilizer production or (3) the need for a fertilizer production process more appropriate to the technology readily available in certain parts of the world. Small-scale fertilizer production technology is most applicable to developing countries but, in special cases, also may be applicable to other areas.

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FERTILIZER PROCESSES

Several different types of processes have been developed for the production of nitrogen fertilizer. For purposes of this discussion, three types of processes for the manufacture of fertilizer are considered. The most efficient and, hence, most widely used process for the production of nitrogen fertilizer is the Haber-Bosch process (Waesser, 1926, Safrany, 1974). For small-scale systems, however, the Haber-Bosch process, which produces high-content nitrogen fertilizer in the form of ammonia, may not be economically viable. A distant second, but still commercially significant, fertilizer process used today is known as the cyanamide process (Sidgwick, 1945) since this process produces calcium cyanamide fertilizer. The cyanamide process appears to be more adaptable to small-scale systems than the Haber-Bosch process as described below. Most of this paper, however, will center on a description of a modified version of the electric arc process of Schönherr (1909) for the production of nitrogen fertilizer in calcium nitrate form. An attempt will be made to show that the electric arc, nitrate manufacturing process, now considered to be commercially obsolete, may, in fact, be most readily adaptable to the production of nitrogen fertilizer in small-scale systems.

Haber-Bosch Process

Today, the most economically attractive process for the production of nitrogen fertilizer on a large scale is based on the Haber-Bosch process which combines nitrogen and hydrogen under high pressure and temperature, in the presence of special forms of iron catalysts, to produce ammonia according to the formula:

$$N_2 + 3H_2 = 2NH_3$$

Relatively pure nitrogen, obtained by liquefying and distilling air at cryogenic temperatures is required for this process. Hydrogen for the process is obtained most commonly from natural gas and/or liquid hydrocarbon sources. With the decreasing supply and increasing costs of hydrocarbon fuel stock required for the original Haber-Bosch process, alternate sources for obtaining the necessary hydrogen are either by the electrolysis of water or by the more complex, but generally less costly, process of coal gasification in which coal, air, and steam are reacted to produce hydrogen. The coal gasification process for obtaining pure hydrogen involves many steps, including several steps for the removal of impurities and undesirable by-products of coal from the process. Ammonia fertilizer production, involving the necessity for obtaining hydrogen either by electrolysis or by coal gasification, at the present time, is not economically competitive where less costly natural gas, as a hydrogen source, is available.

Although the Haber-bosch process is the most efficient process known today for the production of nitrogen fertilizer on a large scale, this process requires several relatively complex steps in the manufacture of ammonia as shown in Figure 1a. The complexity of the Haber-Bosch process, requiring advanced technology and relatively high

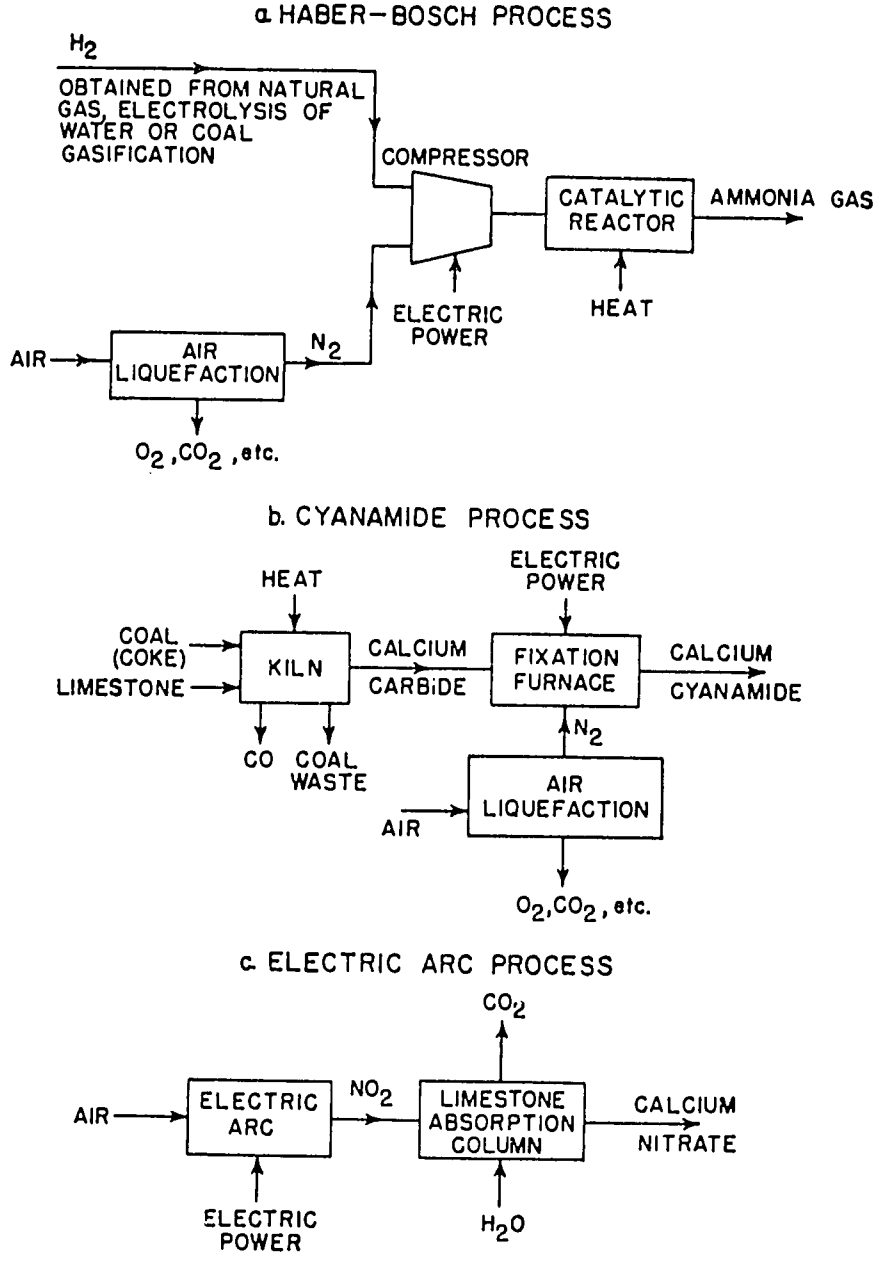

Figure 1 - Flow diagrams of three types of nitrogen fertilizer production processes. Only the most basic steps of each process are illustrated. Complete flow diagrams of each process are considerably more complex than shown.

investment costs, could make the process less attractive economically if scaled down for the production of nitrogen fertilizer on a small scale.

Cyanamide Process

Raw materials for the production of calcium cyanamide fertilizer are, basically, coal, limestone, and nitrogen. The source of power to drive the process normally is electricity. In the cyanamide process, limestone, first, is converted to lime by heating in a kiln to liberate carbon dioxide. Coke is then made from coal by indirect heating of the coal to remove tars and other impurities. The coke should have a low ash content and be essentially a pure source of carbon. The coke (carbon) and lime are then reacted in an electric furnace to form calcium carbide given by the equation:

$$3C + CaO \longrightarrow CaC_2 + CO$$

The next step of the process requires that calcium carbide be reacted with pure nitrogen, obtained by the liquefaction of air, to produce calcium cyanamide by the reaction:

$$CaC_2 + N_2 \longrightarrow Ca\ CN_2 + C$$

This latter step must be conducted under moisture-free conditions since water reacts with calcium carbide to produce explosive acetylene.

Although the cyanamide process also is a relatively complex process requiring several steps, as shown in Figure 1b, the process may be performed in batch type operations using manual labor for some of the steps. Accordingly, the cyanamide process can be adapted to the production of nitrogen fertilizer on a small scale more readily than the Haber-Bosch process.

Electric Arc Process

The electric arc process requires only air, water, and limestone as raw materials plus a source of electric power to drive the reaction (see Figure 1c). The nitrogen fertilizer produced in the arc process, in the form of calcium nitrate, has comparatively low fixed nitrogen content. However, the arc process does not require pure nitrogen and hydrogen as necessary for the Haber-Bosch process. Neither does the arc process require carbon and pure nitrogen sources such as the cyanamide process. Accordingly, the arc process appears to be most readily adaptable to the production of fertilizer on a small scale--particularly if relatively simple, low cost process equipment is desired. Moreover, the arc process can be driven by renewable energy sources such as wind, water, or solar power (Treharne, Moles, Bruce, and McKibben, 1978). Even renewable energy sources that are very intermittent in nature, such as wind power, may be satisfactory to drive the arc process.

The basic equipment required for the electric arc process consists of an electric power source, an electric arc reaction cell, a collection column containing limestone, an air pump, and a fertilizer product collection system, as shown by the flow diagram in Figure 2. Several types of electric arc reaction cells may be used in the arc process.

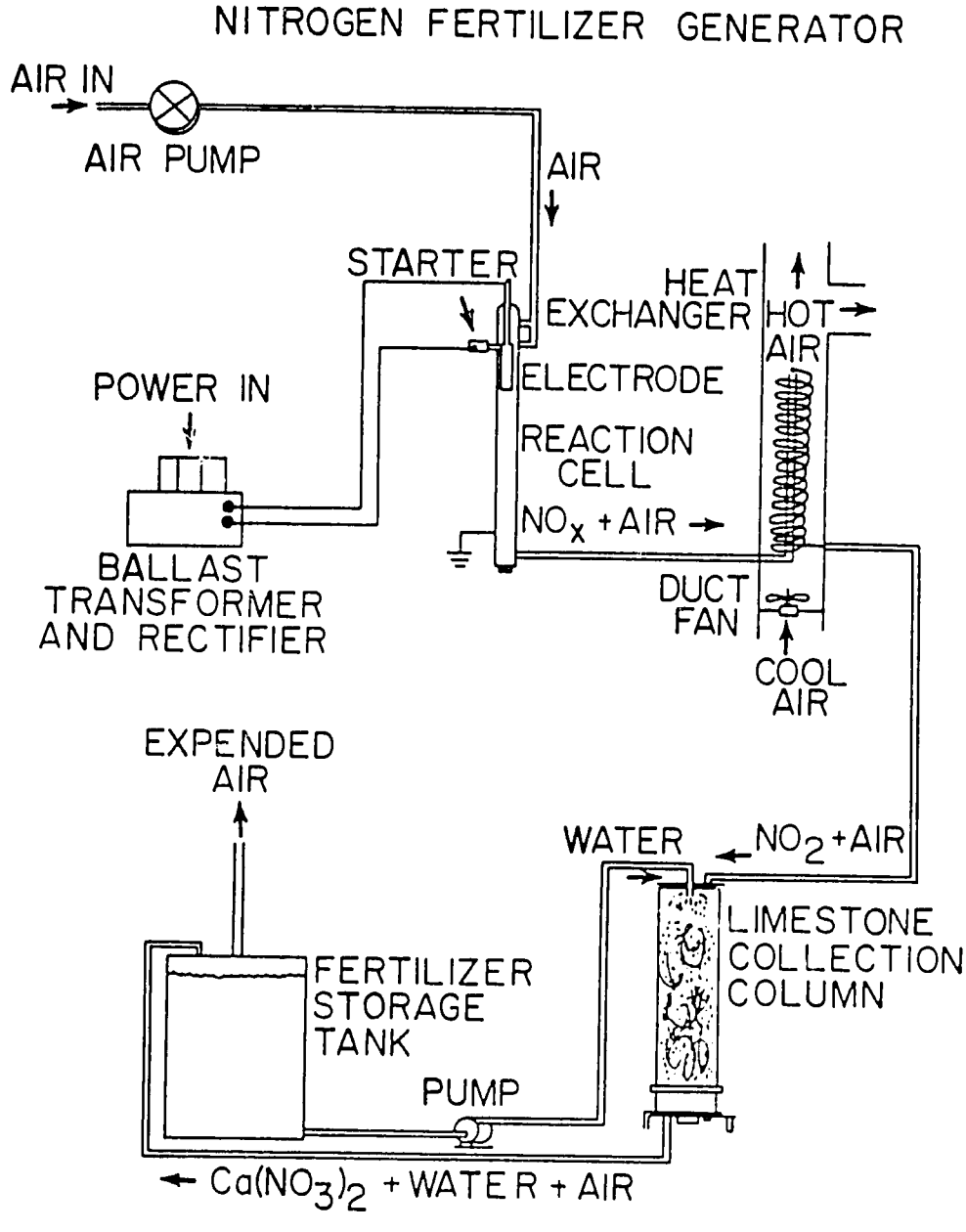

Figure 2 - A complete flow diagram of an electric arc process system developed to produce calcium nitrate fertilizer at a farm site. The process, driven by any electrical power source, requires only air, water and limestone as raw materials.

The reaction cell, shown in flow diagram of Figure 2, is a modified form of a Schonherr furnace in which air is introduced into the cell through tangential ports at one end of the cell. This type of air injection system produces a vortex shaped arc that is capable of producing up to 18 grams of fixed nitrogen per kilowatt-hour of input electrical energy. This corresponds to about 50,000 kilowatt-hours per metric ton of fixed nitrogen. For a nitrate fertilizer generator designed for small farm areas, the reaction cell is constructed from a black iron pipe about one meter long and 8 centimeters in diameter. At one end of the pipe, a second electrode of about 2.5 centimeters diameter and 10 centimeters long is located concentrically. In operation, approximately 1,000 volts, at 3 amperes, is applied between the center electrode and the outer pipe, which is grounded.

The chemistry of the process involves combining the nitrogen and oxygen in the air to produce nitric oxide (NO), which is then air oxidized to nitrogen dioxide (NO_2) and its dimer, nitrogen tetra-oxide (N_2O_4). Energy required for the formation of nitric oxide is about 41.4 kilocalories per mole. However, the second step of the reaction to form the desired nitrogen dioxide is favored by rapid quenching since the reaction is exothermic. The nitrogen dioxide or nitrogen tetra-oxide formed is readily trapped in water to form nitric (HNO_3) and nitrous (HNO_2) acids. The addition of limestone ($CaCO_3$) to the water produces calcium nitrate fertilizer that may be fed directly into irrigation water or, as shown in Figure 2, may be re-circulated back through the absorption column containing limestone to produce the calcium nitrate at a higher concentration in water for application as needed.

SYSTEM COMPARISONS

Table 1 is an attempt to compare the advantages and disadvantages of the Haber-Bosch, cyanamide, and arc processes. For large-scale nitrogen fertilizer production plants, the Haber-Bosch process with its highest efficiency, has virtually no competition as long as relatively inexpensive sources of natural gas are available. In the many areas where coal is more abundant than natural gas, hydrogen for the Haber-Bosch process may be obtained by coal gasification technique or, alternately, the coal may be used more directly, and possibly more economically, by employing the cyanamide process for the production of nitrogen fertilizer. In those areas of the world where neither natural gas nor coal is readily available, the electric arc process warrants serious consideration--particularly for small-scale systems.

None of the nitrogen fertilizer production processes can be considered to be energy efficient. The arc process, however has the lowest efficiency with only about two to four percent of the input electrical energy being converted to chemical energy in the form of fixed nitrogen. The rest of the input energy appears primarily as high grade heat. If the high grade heat can be used to advantage for applications such as space heating, water heating, water desalination, or crop drying, the overall economics of the arc process appear more attractive. Where energy in the form of heat is not required, the heat perhaps also could be used to power a refrigeration unit operating on the expanding gas refrigerator principle. Each of these potential

Table 1: Comparison of Nitrogen Fertilizer Production Processes

Process	Raw Materials	Fertilizer Product and Nitrogen Content	Efficiency of Process (Relative)	Adaptability to Small Scale Systems	Remarks
Haber-Bosch	1) Hydrogen (obtained from natural gas, electrolysis of H_2 or coal gasification) 2) Nitrogen (obtained via air liquefaction)	Ammonia NH_3 82% N	High	Poor	Most widely used commercially. Requires high pressure, temperature and catalysts.
Cyanamide	1) Coal (coke) 2) Nitrogen (obtained via air liquefaction) 3) Limestone	Calcium Cyanamide $CaCN_2$ 20% N	Medium	Fair	Used commercially on small scale. Calcium carbide produced as intermediary step.
Electric Arc	1) Air 2) Limestone (see remarks) 3) Water	Calcium Nitrate $Ca(NO_3)_2 \cdot 4H_2O$ 11.5% N or $Ca(NO_3)_2$ 17% N	Low	Good	Commercially obsolete. Arc processes may also produce phosphate fertilizer by substituting rock phosphate for limestone

applications of the waste heat of the electric arc process is being considered. In Figure 2, the waste heat is shown being extracted by an air-to-air heat exchanger.

ARC PROCESS R & D

It should be emphasized that the electric arc process, as applied to the production of nitrogen fertilizer for localized farm areas, is still in the research and development phase. Considerable basic research remains to be conducted toward increasing the efficiency and improving the performance of the complete, small-scale, nitrogen fertilizer production system that we refer to as a nitrogen fertilizer generator. Nevertheless, at the present time, field-testing of one prototype installation of the nitrogen fertilizer generator is in progress and two other prototype test installations are planned.

The first prototype nitrogen fertilizer generator developed for field testing is shown in Figure 3. This system was designed to be powered by a solar photovoltaic array that currently is being used to supply energy for a solar-powered irrigation system on an experimental farm of the University of Nebraska near Mead, Nebraska (Treharne, Moles, Bruce, McKibben, and Rein, 1979). With this particular nitrogen fertilizer generator system, plans are to produce and store nitrate fertilizer during that part of the year when irrigation is not required and then feed the fertilizer into the irrigation system as needed. Since these field tests have just started, it is premature to present even preliminary results at this time.

The second and third prototypes being planned are a hydro-powered and a wind-powered nitrogen fertilizer generator. Tentative plans are to test a hydro-powered unit on an experimental farm of the University of Nevada near Austin, Nevada. If the economic projections presented previously (Treharne, Moles, Bruce, and McKibben, 1978) are correct, a hydro-powered, nitrogen fertilizer generator may be the closest to approaching economic feasibility in remote areas where fertilizer costs are high and hydro power is available.

In high average wind speed areas, where fertilizer costs are high, a wind-powered version of the nitrogen fertilizer generator also warrants serious consideration. The Agricultural Engineering Department of the University of Hawaii, the Resource Systems Institute of the East-West Center, and The Charles E. Kettering Research Laboratory are currently exploring the possibilities of a nitrogen fertilizer generator powered by wind-power.

NITRATE-PHOSPHATE GENERATOR

By the substitution of rock phosphate or calcium phosphate ($Ca_3(PO_4)_2$) in place of limestone in the nitrogen dioxide absorption column of the arc process system, the same system can produce both nitrate and phosphate fertilizer. The possibility of simultaneous production of both types of fertilizer in the arc process system exists due to the fact that the nitric acid formed in the arc process can react with rock phosphate to produce soluble phosphate fertilizer as well as nitrate fertilizer. It should be noted that the possibility of producing both nitrogen and phosphorous fertilizer is unique to only the arc

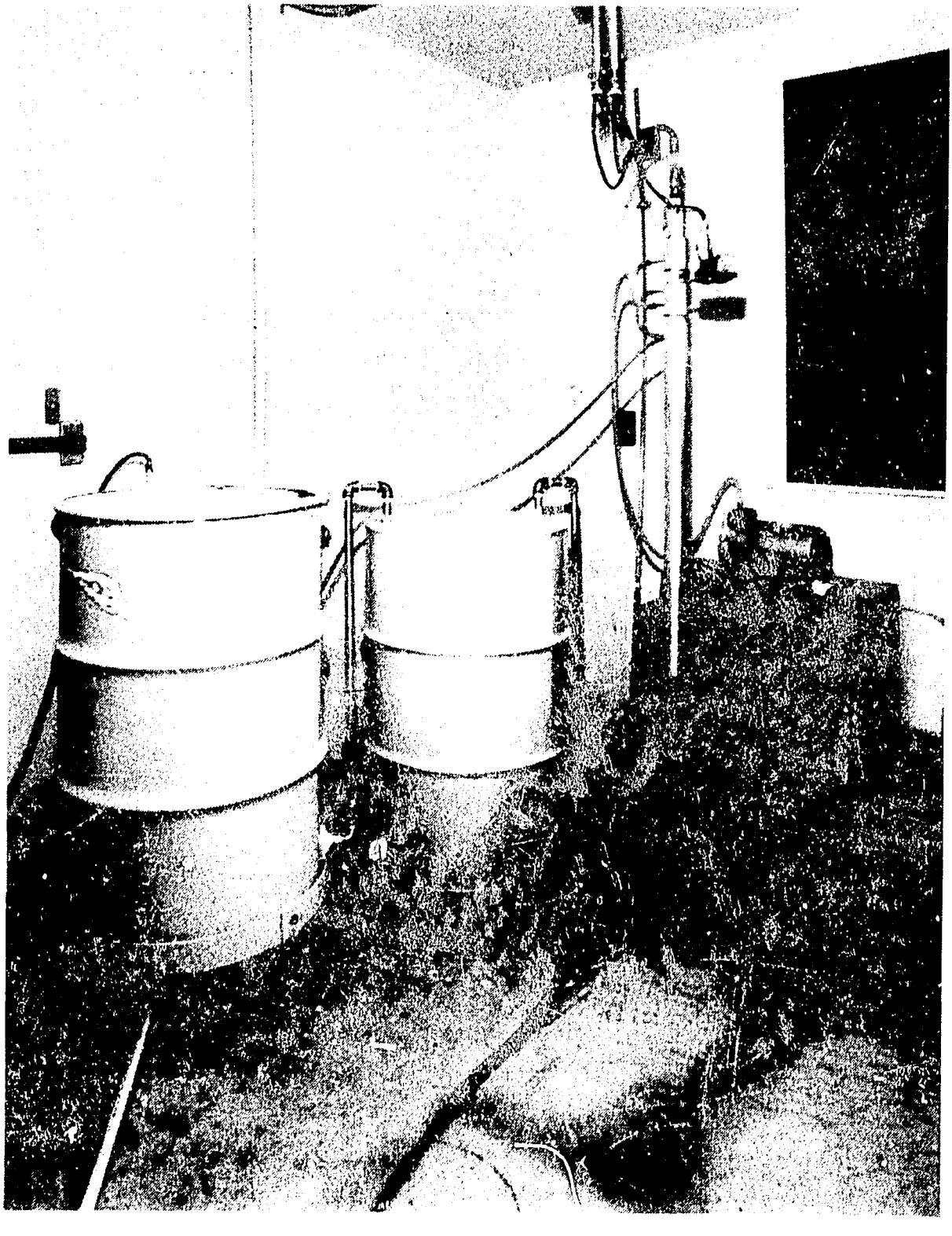

Figure 3 - Photograph of an experimental model, 3 kilowatt capacity, electric arc process system developed to produce up to 3 tons of calcium nitrate fertilizer per year at a farm site.

process system and is another attractive factor favoring the selection of the arc process for small-scale applications. As described previously (Sheldon and Treharne, 1978), there are many areas of the world where low-grade deposits of rock phosphate exist that could be used for the production of both nitrate and phosphate fertilizer. The potentially promising new concept of a relatively simple process to produce both nitrate and phosphate fertilizer in small-scale systems is also currently being investigated in a cooperative research effort of the Resource Systems Institute of the East-West Center, the Agricultural Engineering Department of The University of Hawaii, and the Charles F. Kettering Research Laboratory.

CONCLUSION

The electric arc process for the production of small quantities of nitrogen fertilizer is believed to offer the most promise for meeting fertilizer needs in remote farm areas. The process does not require fossil fuels or costly equipment investment and the electric arc may be powered by renewable energy sources, even of an intermittent nature. The arc process also is believed to be the only process offering the capability of producing both nitrate and phosphate fertilizer in the same process. A small unit capable of producing up to several tons per year of nitrate or combined nitrate and phosphate fertilizer has been developed and is now being field tested.

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FUTURE ENERGY SOURCES FOR FERTILIZER MANUFACTURE: PANEL DISCUSSION

A. N. Chaube. We have five panelists and we will hear from them about future energy resources for fertilizer manufacture. I turn the session over to the panelists now.

T. Siddiqi. I'm going to talk about the global energy reserves rather than individual country reserves. Although this might not be of great help in the case of individual countries, by and large the availability of fertilizers will be on the basis of the global market.

Looking at present day consumption figures, we find that production is roughly of the order of 50 million tons of nitrogen fertilizer a year, and I'm going to speak primarily about nitrogen fertilizers since energy consumption is dependent to a much larger extent in that case. For the sake of the argument I'm going to develop here I'll assume that we'll be talking about a time span of about 30 years and longer and that perhaps consumption figures around that time might be of the order of 100 million tons per year. Let us now look at the proved natural gas reserves worldwide. We find that at least a generally accepted figure is somewhere around 2,500 trillion cubic feet. Let us assume that the fraction of natural gas used for fertilizer will continue to be of the same order, though perhaps it will be a larger number as the years go on and as we find replacement for natural gas by, say, solar heating. But assuming that 5 percent figure, which is a conservative figure I think, we find that there is enough supply of natural gas for the next 40 or 50 years even given the present proved reserves. And most geologists, seem to feel that the situation for natural gas is somewhat better than the situation for oil and that we might be further away from the peak production figures for natural gas.

The reserves figures primarily relate to reserves in terms of median use of natural gas which is for heating the home, and industrial heat, and have not primarily been based on what might be practical for a natural fertilizer system. It might not be unfeasible to think of small ship-based fertilizer factories which could exploit smaller offshore natural gas reserves where it would be very uneconomical to transport them to the shore using large pipelines. Although the reserve supplies of some offshore fields might not be adequate to have a permanent fixture, a movable ship tapping fields of the order of say 200 billion cubic feet might increase the reserves available for fertilizer substantially.

If you include those sorts of reserves then a possible extension of time span might be to about a hundred years' time frame, still using the 5 percent figure for the first 50 years and the other 50 years devoted primarily to use for manufacture of fertilizer, or other chemicals.

Going to oil reserves as we use them today, the feeling is that oil will probably run out before natural gas and so if you think of the longer term projects I suppose it would be unreasonable to assume that too much of the oil in the next few decades will be used for fertilizer. But if we just use the conventionally accepted figure of, say, one ton of oil required for one ton of fertilizer, and assume that 5 percent of

today's proved reserves of 650 billion barrels are used for producing fertilizer, then again we get a figure of somewhere around 50 years.

But chances are that in that time frame, by the time we've run out of natural gas for fertilizer, we will have probably run out of conventional oil-based fertilizers. But there is a lot of additional oil available from heavy oil deposits, oil shale, and tar sands, and this quantity could be about six times as large as that in conventional oil fields. I should be talking more about resources rather than reserves, because oil from shale and tar sands is barely economical right now. Although some oil from such deposits is being produced in Canada, I gather that the companies running the operations are still running them at some economic loss. Perhaps a figure of $35 a barrel of oil might be a good estimate of cost, although we find that our guesstimates on oil from both tar sands and from oil shale have tended to be underestimates, and always keep on increasing. They're always 50 percent more than the going price for oil. But if you assume that it becomes competitive one or two decades from now, the 4 trillion barrels of heavy oil reserves known in just four countries--Venezuela, the Soviet Union, the United States, and Canada--those could keep us going for 300 years if we use only 5 percent of that for fertilizer production.

Finally, a few words about the availability of coal. Using a figure of about 2 tons of coal for one ton of fertilizer, we find present global proved reserves of about 600 billion tons and using only 5 percent of that for fertilizer would mean that we would have enough for fertilizer conversion for the next 400 years. These are only the known reserves of coal rather than the resources, which are larger by an order of magnitude. So, in general, the supply problem does not seem to be very large in terms of proved reserves of hydrocarbons, even without getting to the more difficult processes which involve electrical energy. The primary determining factor will be, as it is in most cases, how much are we going to have to pay as we go from natural gas to the heavy oils, and I believe Kirk Smith is going to be speaking about those.

K. Smith. Let's move on to Mr. Chaube who's going to talk a little bit about regional supplies.

A. N. Chaube. You've had just now a global perspective of the availability of natural gas and later on of oil from Dr. Siddiqi. Now, narrowing our focus on to the Asia-Pacific region, I should like to say that the total proven reserves in the recoverable reserve class for south and southeast Asia and Australasia is of the order of 191 trillion cubic feet. The potential resources about which we had earlier in the day are of the order of 640 trillion cubic feet for this region. I must caution, however, that the degree of certainty on this figure is rather low.

Another factor of importance is that great irregularities exist in the geographic distribution of these reserves and of the resources.

Now, Dr. Siddiqi noted that large additions are possible to the reserves of the marginal fields. This is especially true in the offshore areas where a deposit that is found to be only economically marginal is left out, but it should be possible to develop this with a ship-based fertilizer plant such as he has envisioned.

One point which I would like to add to what he has said on heavy oil resources is that in the field of reservoir engineeering where tremendous strides are being made to recover more of the oil that is underground, fifteen to sixty percent of the resource is left in the ground with conventional production of the reservoirs, and improved recovery techniques of this oil will add significantly to the total reserve figures.

K. Smith. I'd like to talk briefly about some of the general characteristics of fertilizer in terms of energy demand. Here I will consider only nitrogen fertilizer. As you have heard, nitrogen fertilizer only requires about two percent of the world's present commercial energy use. That is two percent for manufacture and another two percent, perhaps, for marketing distribution, transportation, and so forth. Despite its importance to food production, that two or four percent is very much on the margin in terms of global energy supply.

In a world in which energy is becomin' more expensive, the total production and demand of fertilizer does not affect the price of energy very much, nor does it greatly affect the distribution of the different types of energy, liquid, solid, and gaseous fuels. It is not, of course, unimportant, but a fairly small perturbation on the system. But that is somewhat of an advantage for fertilizers in that I think that fertilizers will always be able to pay less for energy than the world market price.

To a first approximation, the world crude oil price determines the price of energy. As it rises, a number of other sources of energy begin to become competitive. They first become competitive not with oil as a liquid fuel but with oil as an energy source for other uses, such as power plants, where the form of the fuel is less critical. For the moment let us consider only the alternative fossil fuels--natural gas and coal. The problem with these fuels, as Dr. Siddiqi has explained, is in transport and handling--not supply. They could easily be substituted for the non-liquid fuel requirements now met by oil if they could be easily transported.

Indeed, the next decade will see these fuels traded in much larger quantities because the increased cost (in money and insecurity) of oil has revealed a whole new economic landscape composed of these alternatives. Thus, even though competitiveness in the liquid fuel market may be some time away even at projected oil prices, the competitiveness for non-liquid fuels is improving rapidly. Nitrogen fertilizer production will be at an advantage in two respects because of this situation. First, since it can be made from oil and coal, it will benefit from the increased world market in these fuels in spite of the restrictions in the liquid fuels market. Secondly, nitrogen is an energy intensive product and can be manufactured at the site of the energy source. It, therefore, acts as a means to extract the energy, concentrate it on site and ship it economically. This, of course, is what we see now in the natural gas production in various countries where there is no market for the natural gas within the country. They make fertilizers and ship them to where the markets are. Iceland produces electricity from hydroelectric power, makes fertilizer out of it and ships that. It would be impossible to ship the electricity. It would be very inefficient for electricity to be used in

most countries for fertilizer manufacture but in Iceland they have an excess of it so they can make an energy intensive product and ship it. Aluminum is another material like fertilizer that has this characteristic.

There is likely to be very little constraint on more or less conventional nitrogen fertilizer manufacture because it can always live on the margin--it can use non-petroleum resources or be used as an energy transport medium. Eventually, the world price of energy will reveal an economically viable topography that includes all sorts of presently exotic technologies like the biological sources of fertilizer or the nitrogen arc process, perhaps along with the ocean thermal plants which use the thermal differences in the ocean to obtain energy. Energy out in the middle of the ocean is not very useful; it is a long way from the market. But if ammonia can be manufactured, it may justify extracting that energy source and then shipping the energy in that high value form.

How expensive is energy? The present world crude oil price of $22 a barrel is equivalent to $4 a million Btu. At a not too much higher price, it is going to pay people to extensively ship natural gas, so that natural gas is going to be less and less available for fertilizer manufacture at low prices. So you can always buy the natural gas at the world crude oil price of $4 or $5 a million Btu, but that would increase the cost of fertilizer dramatically.

Natural gas costing $1.60 a million Btu will produce $100 a metric ton ammonia, depending on the scale of the plant. This is somewhat more than most plants are paying now, but since $4 a million Btu is the world crude oil price, it will not be long before people are paying $4 a million Btu for natural gas.

And as you see, other things start becoming economic at this point. Heavy oil, for example, can come in at this point. Or even coal. Coal is not directly following the world crude oil price. Most of the other fuels are. Coal is still remaining down at $30 a metric ton or less (a little over $1.00 per million Btu. Consequently, if natural gas goes up to $4, coal is competitive. Not only is coal a very large supply of hydrogen for traditional processes, its widespread use would result in a very different distribution of countries who have resources compared with those with oil and gas.

The point is that fertilizer manufacture produces a very energy intensive product which can be easily shipped and, therefore, is able to tap energy reserve resources that are smaller and further away than almost any other kind of manufacturing process.

In addition, fertilizer can be manufactured off peak. That is, when there is a big demand for the energy for something else, the fertilizer plant can be stopped; conversely, when there is excess energy being produced, the energy can be stored in the form of fertilizer. This is true, for example, for hydroelectric power or any other kind of electric system.

These two characteristics of fertilizer are not independent of each other--it is an energy intensive product that potentially can act as an energy storage system. These factors should allow a fertilizer manufacturer to tap lower cost energy resources than the world energy price as a whole. It is going to be some distance behind, but still nevertheless

follow the increasing price of energy in the world. The final demand, and thus the price at the point of distribution, will be affected by the marginal value of food--another subject entirely.

Dr. Ando is going to speak on comparative energetics of different fertilizer manufacture methods.

J. Ando. The study of energy consumption for the fertilizer industry in the United States shows that 70 percent of the energy is for nitrogen fertilizer, and it's mainly for the hydrogen production of ammonia. A little over 20 percent is for phosphate fertilizer, most of which is used for elemental sulfur production. Less than 10 percent is for potash for mining, cleaning and separation, and so on. It is interesting to me that once hydrogen and sulfur and potash are obtained, all other reactions concerned with fertilizer production are exothermic reactions which give heat. For example, the reaction of a hydrogen ion to nitrogen to produce ammonia gives heat and the conversion of ammonia to nitric acid gives heat. The reaction of nitric acid to ammonia to produce ammonium nitrate, the reaction of carbon dioxide to ammonia to form urea, and also the digestion of the phosphate rock and the reduction of compound fertilizer; they all give heat. So if those processes are properly applied, we could recover heat rather than lose it.

Taking the example of DAP production, how much energy is required per ton of product? For production per ton of DAP, 3.5 million BTU (mBTU) is required to obtain elementary sulfur. But to produce sulfuric acid they can recover 2.6 mBTU of heat. The phosphate rock mining and cleaning requires only 0.3 mBTU and the production of acid requires 2.6 mBTU; this is mainly for concentrating the acid and drying the product. If we use the heavy hydrate process the requirements for the production of acid will be less than half of these. Drying the product requires some energy but if we use the TVA types, the key reactor or the pipe reactor, we do not need any drying; we can recover heat. So, in various processes, by good engineering we do not need to add energy except to obtain sulfur for hydrogen.

If we use pyrite instead of this washed sulfur we do not need such a large amount of energy and we can recover energy by burning pyrite. In the production of some phosphates, they have used either electric power or oil. But it is also possible to use charcoal or even wood. For example, in Brazil they do not have oil. They have coal but it's in a distant location and transportation is not easy. So they're trying to develop some more phosphate by burning either wood or charcoal. And this can be done in such a way so that each country may be able to develop a process suitable for each country.

The presentation of Dr. Treharne interested me very much. I'd like to make one comment. In his presentation he said that most of the electric energy is actually converted to heat; only a small portion is used for the reaction. So I think it may be possible that in the world they are going to install a large amount of thermoelectric power by

burning coal. And in burning coal, nitrogen oxide is present as 0.1 percent present in the gas. They are trying to develop a technique to reduce the nitrogen oxide formation in the gas. And for that purpose they lower the combustion temperature just to reduce nitrogen oxide which means thermal reactions go down and we need much more coal for our production. So if the recovery of nitrogen oxide by calcium is obtained and the by-product can be used we can use high temperature burning so that we can obtain this thermal reaction and we can recover nitrogen oxide from the tank gas.

K. Smith. Now Dr. Treharne is going to talk about future sources for hydrogen in raw materials fertilizer manufacture.

R. W. Treharne. First I'd like to respond to Dr. Ando's suggestion which was very good. I see nothing wrong with making nitrogen oxide as a byproduct of burning coal. The process we're developing hopefully can be used where they don't have coal and don't have natural gas. We're talking about perhaps remote locations such as up in the hills of Nepal where it is just as inconceivable to cart in coal as it is to cart in fertilizer.

Now, a few other comments on some good suggestions of the previous members of the panel. Dr. Siddiqi commented that 5 percent of the total natural gas produced goes into the production of ammonia. That's true, but in the United States it's 50 percent of the interruptible natural gas. In other words, of that natural gas which has been used for heating homes, 50 percent of that energy goes into making ammonia. That's why this one plant near my home in Ohio was closed down. It was something that the government thought we could do without. Homes came first, we had to use the natural gas for heating purposes. So it's a little bit misleading to say that only 5 percent of the total natural gas goes into making ammonia. It's more like 50 percent of the interruptible natural gas that is used.

Now, getting back to the original purpose of my discussion here. What do we do when natural gas runs out? Where do we get the hydrogen? Well, there are many ways that one can do it. And here I'm putting in a plug for the Haber-Bosch process. The arc process that we're working on will never put the Haber-Bosch process out of business; no one has to fear that. The Haber-Bosch process of making ammonia could use several sources of hydrogen. Like it does now it could use natural gas for many years to come. After natural gas runs out it can use coal gasification in order to produce hydrogen. After that it could use the electrolysis of water. In fact the Westinghouse Company has a proposal right now to have a floating platform out in the middle of the sea. It will have two electrodes hanging over the platform into the water that will generate electricity (perhaps from wind power or some such force as that) and electrolize the water to make hydrogen. Then they will be able to have a Haber-Bosch plant on this floating platform out in the sea. This is what the Westinghouse proposal suggests may be done. I don't know whether it's been funded to date, but that at least was the proposal.

Still another source of hydrogen is the electrolysis of water. Dr. Bamberger at Oak Ridge National Laboratories, for example, is decomposing water directly with sunlight. Dr. Sam Pietro at the University of Indiana is using a photosynthesis process to make hydrogen.

Still a final way that one may obtain hydrogen through the Haber-Bosch process is by use of biogas. From biogas you get methane, from methane you get hydrogen, and that can be used to drive the Haber-Bosch plant. Well, I think that about sums up my comments on ways that hydrogen can be obtained.

K. Smith. Now, let's open the discussion to anyone else who has any comments on this subject or any comments on any of the speakers' talks.

R. P. Sheldon. A question for Bill Treharne. There was a suggestion by Dr. Siddiqi about shipboard Haber-Bosch plants. And we saw a picture of one of these plants in Ohio, and it was very large and complex, very high temperatures, very high pressures. My question is, is a shipboard Haber-Bosch plant really feasible? I take it, "yes"--you just mentioned that Westinghouse has an experimental project on that. So that's one question. The other one I asked you at lunch. I wasn't entirely certain of your answer. What about mini-plants? Haber-Bosch plants on small gas fields which are too far from market to warrant a pipeline but maybe a plant could be moved in?

R. W. Treharne. As I said before, I don't think the Haber-Bosch process lends itself to miniaturization. It takes very expensive equipment. First you have to have some way to liquify the air to extract the nitrogen. Then you have to get your hydrogen by some sort of cracking process from natural gas, and you have to have compressors, and you have to have high temperatures, and finally you end up with ammonia in the gaseous form which isn't too useful. Then you have to liquify it in order to ship it someplace. So in my opinion, and I may be wrong, I don't think the Haber-Bosch process can be made on a mini-scale with any efficiency or any practicality.

Concerning the floating Haber-Bosch plant, I should emphasize that the Westinghouse proposal is only a proposal. To the best of my knowledge they're not even working on it at the present.

R. P. Sheldon. I wasn't thinking of something mini like the nitrogen generator, but something that would be still of fairly big size. How large would a shipboard plant be?

R. W. Treharne. I think I pass that on to Dr. Ando. But I think he mentioned something like 30 tons per day in order to be economically feasible. Do you want to answer that, Dr. Ando?

J. Ando. I mentioned about the phosphoric acid plant and 30 tons a day of phosphoric acid. Nitrogen? I think anyway that a small nitrogen plant is not economical. Anyway it cannot compete unless the nation has some policy not to import and it's for their own fertilizer use. And

then it's expensive, but it can be done. But in the free market I doubt there are any plants smaller than 100 tons per day. This is usual for nitrogen fertilizer.

T. Siddiqi. By way of comparison, Dick, Westinghouse along with Tenneco had developed offshore floating nuclear power plants, and that's a fairly sizeable operation. And the reason it was scrapped was not because of technological difficulties but because of the environmental concerns with what happens if there is an accident at some stage, and some of the radioactive material fell into the water.

And not too long ago a large-scale pulp mill was shipped all the way from Japan to the middle of the Amazon River where it's, I gather, in place now, and that was a fairly sizeable plant. I don't know enough about fertilizer manufacturing plants to be able to compare the scales with say a pulp mill or a nuclear power plant, but that might not be a limitation.

Going back to the statement that Dr. Treharne made about the 5 percent of natural gas being used was somewhat misleading, and that it's 50 percent of the interruptible supply. I'm not sure what the implication of that precisely is, because it means that if you don't want the production of the fertilizer mill to be interrupted even for a single day then it is important. But if you're talking about the annual yield of fertilizer from a given plant over a period of say several months or a year, I don't know if it would make a substantial difference in the annual output of the plant. In most cases it would not make too much of a difference if a fertilizer plant had to delay shipment of its materials for a few days while the exceedingly cold spell lasted.

PART 2

FERTILIZER NEEDS

CHEMICAL FERTILIZERS: THEIR APPLICATIONS, EFFECTIVENESS, AND LIMITATIONS

MASAO HAMAMOTO*

ABSTRACT

The main chemical fertilizers on the market are reviewed in terms of physical, chemical, and agronomic features; the problems with their use in tropical and subtropical regions are discussed. Commercial phosphorus and potassium fertilizers have no big problems in their applications, but water soluble nitrogen fertilizers have many problems caused by their great water solubilities and rapid nitrification characters. In the paddy field, these problems might be avoidable when the fertilizers are applied skillfully under deep reductive soil, even though troublesome. For use in upland agriculture, the nitrogen fertilizers must be improved so that they work more effectively and for a longer period, because the climate in this area is very hard on nitrogen applied in the soil. Looking toward the future, the possibility of improving nitrogen fertilizer is discussed by searching the seeds of new products now under development and research, such as nitrification inhibitors, coated fertilizers, and slightly water soluble nitrogen compounds. The most promising nitrogen will be the improved ureaforms series. Last, a way of promoting this research is proposed.

INTRODUCTION

It is obvious that genetics, fertilizers (and pesticides), and machines advanced agriculture in the northern developed nations to its present state. Recently, in order to increase the productivity of crops in the tropical and subtropical regions, the fertilizers which have been used conventionally in the developed nations were recommended strongly. But we must consider the differences in agricultural operations and climate between developed and developing nations. For example, in northern temperate climatic regions, even simple nitrogen such as an ammonia solution can be used effectively with the aid of a large application machine. On the other hand, in the tropical regions, high temperature and heavy rainfall are usual all year, and only manual labor and animal power are used. Thus, it is necessary to adjust or remake the fertilizer for use in the tropics. Urea is a typical example. We must not give up research simply because improvement of present fertilizer will make it more expensive.

REVIEW OF CHEMICAL FERTILIZERS

The main chemical fertilizers on the market are listed in Table 1, together with the description of the physical and chemical features of each product. The problems connected with their use in tropical and subtropical regions are discussed as follows.

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Table 1. Review of Chemical Fertilizers

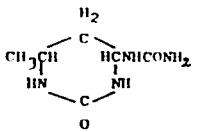
Fertilizers	Composition	Nutrient (%)	Solubility	sp. gr.	Appearence	Hygroscopicity	Packing	Reaction
Nitrogen								
Urea	NH_2CONH_2	46	110g/100g H_2O, 20°C	1.33	white prill	CRH 72.5% 30°C	plastic bag	neutral
Amm. Sulphate	$(NH_4)_2SO_4$	21	75g/ " , "	1.77	white crystal	" 81.0 "	"	acidic
Amm. Chloride	NH_4Cl	25	37g/ " , "	1.53	white granule	" 77.0 "	"	"
Ca Cyanamide	$CaCN_2$	21	decompose by water	1.38	grey-black powder	decompose	"	alkaline
Amm. Nitrate	NH_4NO_3	35	188g/100g H_2O, 20°C	1.66	white prill	CRH 59.4% 30°C	"	neutral
Ca Nitrate	$Ca(NO_3)_2 4H_2O$	12	660g/ " , 30°C	1.82	"	" 46.7 "	"	"
Kalk-Ammon Salpeter	NH_4NO_3 + $CaCO_3$	20.5			white granule		"	alkaline
Nitrogen Solution	NH_3, NH_4NO_3, UREA + H_2O	37-40			liquid			
Slow Nitrogen								
Ureaform	U-$(CH_2$-U'$)_n$-CH_2-U (UF)	38	slightly, 0.01-2/100g H_2O	bulk density 0.64 g/cm^3	white granule	no	paper, plastic	neutral
Iso-butylidene Diurea	$(CH_3)_2CHCH(NHCONH_2)_2$ (IBDU)	32	slightly, ca. 0.1/100g H_2O	0.64 sp.gr. 1.33	"	"	" , "	"
Crotonylidene Diurea	(Ø, 1) (CDU)	32	slightly, 0.12/100g H_2O	0.7-0.9 sp.gr. 1.33	"	"	" , "	"
Oxamide	$(CONH_2)_2$	31.8	slightly, 0.04/100g H_2O	1.2	white crystal	"	" , "	"
Coated Urea	SCU, Osmocote etc.		slow release		yellow granule	"	" , "	"
Nitrification Inhibitor	N-Serve, A . DD, etc.							
Phosphorus								
Super Phosphate	$CaH_4(PO_4)_2H_2O$ + $2CaSO_4$	15-20	water soluble		grey, powder	CRH 94.0% 30°C	paper	acidic
Triple Super Phosphate	$CaH_4(PO_4)_2H_2O$	40-45	water soluble		" , "	" 94.0 "	"	"

Table 1 (cont.)

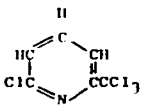
Fertilizer	Composition	Nutrient (%)	Solubility	sp. gr.	Appearence	Hygroscopicity	Packing	Reaction
Mono-Amm. Phosphate	$NH_4H_2PO_4$ (MAP)	60, (N 12)	water soluble	1.80	white powder, granule	CRH 91.6% 30°C	paper, plastic	acidic
Di-Amm. Phosphate	$(NH_4)_2HPO_4$ (DAP)	53, (N 21)	water soluble	1.62	white powder, granule	" 91.6 "	" , "	neutral
Fused Mg Phosphate	$(CaO)_x(MgO)_y(SiO_2)_zP_2O_5$	20	citric acid sol.	14.-1.5	green-black 0.2-1.5 mm	no	" , "	alkaline
Calcined Phosphate	$(CaO)_x(SiO_2)_yP_2O_5$	35-46	citric acid sol.		small granule, white	"	" , "	"
Rhenania Phosphate	$(CaO)_x(Na_2O)_yP_2O_5$	10-28	amm. citrate sol.		powder, grey	"	paper, in bulk	"
Thomas Slag	$(CaO)_x(SiO_2)_yP_2O_5$	18-20	citric acid sol.		" , "	"	" , "	"
<u>Potassium</u>								
Potassium Chloride	KCl	60	35g/100g H_2O, 20°C	1.99	white crystal	CRH 84.0% 30°C	paper, plastic	neutral
Potassium Sulphate	K_2SO_4	53	11g/ " , "	2.66	"	" 96.0 "	" , "	"
Potassium Silicate	$(K_2O)_xSiO_2$	20	slightly		grey, powder	no	" , "	alkaline

<u>Compound Fertilizer</u>

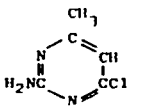
CDU (e. 1)



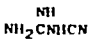
P-Serve



AM



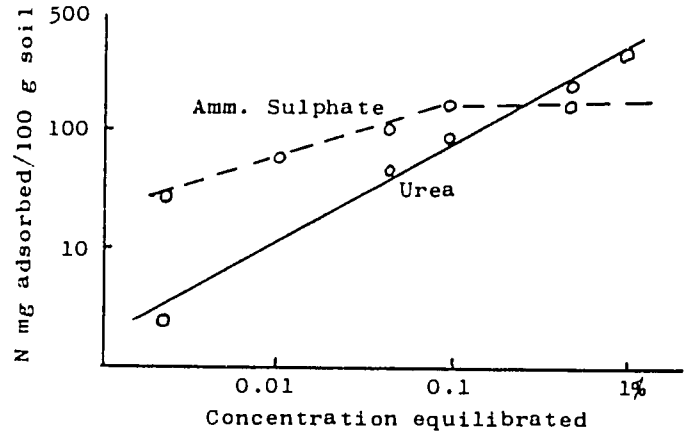
DD



Urea has become the main nitrogen fertilizer in the world because it provides the nitrogen most cheaply. Since its high water solubility causes serious hygroscopic trouble when stored and transported, plastic bag or air conditioned storage is necessary to protect the product from the humid air.

Its high water solubility also causes the large leaching loss agronomically by rain or irrigation water, when it remains in the soil in the form of urea. However, after about one week it decomposes to ammonium carbonate and this ammonium nitrogen is absorbed by the soil in the same manner as ammonium sulphate and chloride (Figure 1). Thus it is effective in paddy fields. Figure 2 shows the smaller loss of urea when it is absorbed by the soil as ammonium carbonate.

Fig. 1 Adsorption of nitrogen by soil

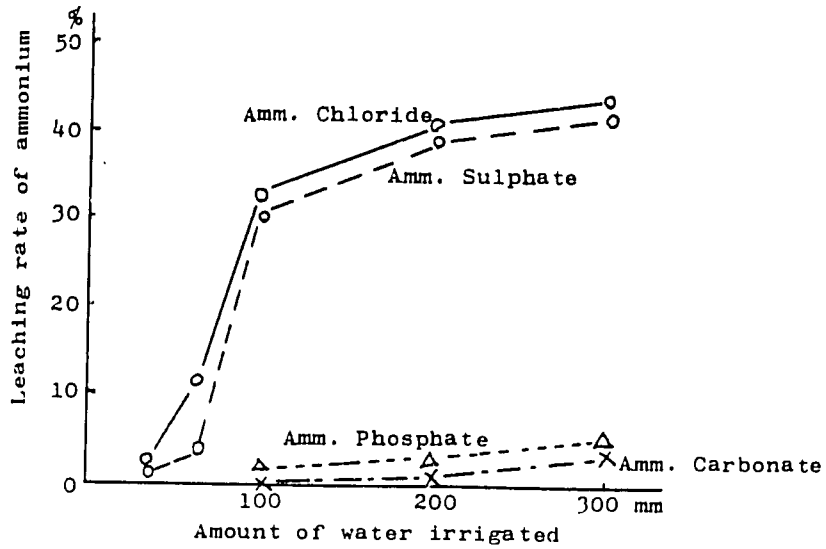


Mitsui, 1959
Volucanic ash soil of Tanashi

In upland soil conditions, the nitrification of urea is very fast when compared with other ammonium salts, as shown in Figure 3. This is the most defective feature of urea in a high temperature zone. Thus improvement of urea is necessary. The many attempts to improve urea are described later.

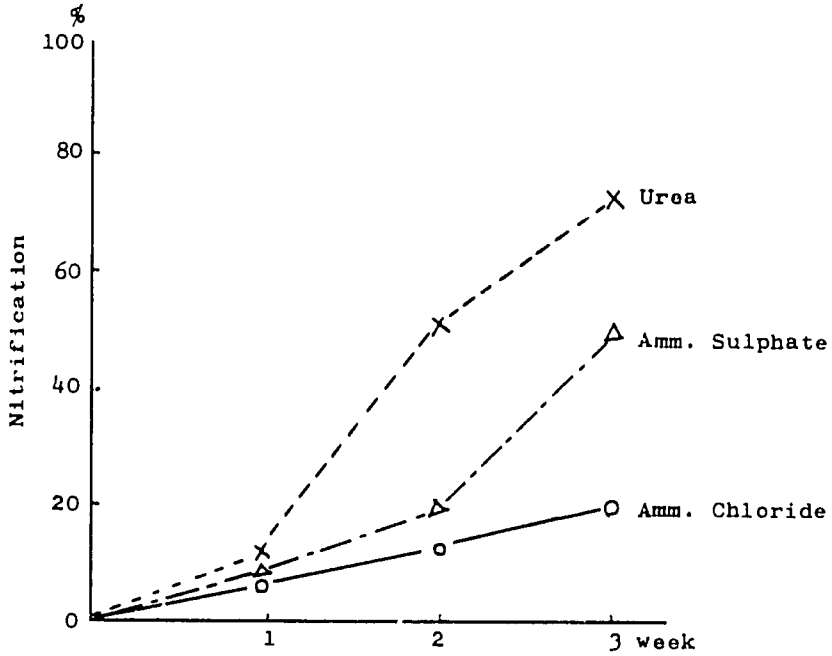
Ammonium Sulphate was most popular until production of urea increased. Now it is produced mainly as a by-product of other chemical industries. Abundant and long-term successive application of ammonium sulphate may cause acidification of the soil and the evolution of harmful hydrogen sulphide in the paddy field. However, a proper quantity of

Fig. 2 Leaching of ammonium as influenced by different accompanying anions



Okuda, 1959
Alluvial soil of Kyoto Univ.
Nitrogen was applied at the rate of 40 kg N/ha.

Fig. 3 Nitrification of Urea, Amm. Sulphate and Chloride



Yamada, 1975
Soil; Muara, Indonesia Latosol, pH 5.1 (H_2O), at 35°C

sulphur in the soil is very useful. Recently, the main phosphatic fertilizers have begun to change from superphosphates to ammonium phosphates from which effective calcium and sulphur are already removed. We must look again at the merits of sulphur of ammonium sulphate as well as its nitrogen.

Ammonium Chloride is manufactured by the "Ammonium Chloride and Soda Ash Dual Manufacturing Process" which is a modification of the Solvay Process and was developed uniquely in Japan. It is mainly used in paddy fields in Japan and Southeast Asia. Its nitrification is slower than that of urea or ammonium sulphate, as shown in Figure 3. It is said that chlorine helps the growth of healthy rice and also accelerates photosynthesis.

Calcium Cyanamide dates from 1905 and its production has decreased due to the production of cheap urea and ammonium sulphate. It is a good fertilizer and still has many users. It decomposes in the soil to ammonium nitrogen through free cyanamide and urea in about one week. Its nitrification is suppressed by co-existing dicyan-diamide which acts as a nitrification inhibitor. Calcium Cyanamide also acts as an insecticide, germicide, or herbicide. It is mainly used in paddy fields.

Ammonium Nitrate, Calcium Nitrate, and Kalk-Ammon Salpeter can not be used in tropical areas because of a large leaching loss of nitrate and serious hygroscopic trouble.

Nitrogen Solution (incorporated with ammonium nitrate, urea, and ammonia) cannot be used unless adequate storage facilities and suitable application equipment are present, as these are relatively more difficult to handle.

Coated Urea with waterproof materials is an old idea, and the first product was "Osmocote." The Tennessee Valley Authority (TVA) devoted themselves to develop the so-called "SCU" (Sulphur Coated Urea) and succeeded in the industrial manufacturing process. The products of this type have recently appeared on the market in the United States, Canada, Europe, and in Japan.

International Fertilizer Development Center (IFDC) has been conducting wide-range fertilizer tests of coated urea in paddy and upland fields in the tropical and subtropical regions. Their fruitful results will help agriculture in these areas in the near future.

Ureaforms Series (UF) will be explained in the section "Future Nitrogen Fertilizer."

Isobutylidene Diurea (IBDU) is a slow-acting nitrogen fertilizer specifically developed in Japan, and now widely used in the United States, Europe, and Japan for horticulture, lawns, and ornamental plants.

It is a condensation product between urea and isobutyraldehyde and its agronomic feature is that it is decomposed in the soil by chemical hydrolysis as well as by soil microbe action. It is effective in both paddy and upland soil conditions.

Crotonylidene Diurea (CDU) is also a slow-acting nitrogen fertilizer, invented and developed in Germany. Its use is for horticulture. It is a condensation product between crotonaldehyde or acetaldehyde and urea, and it is decomposed in the soil mainly by soil microbe action.

Oxamide has been known as a superior slow-acting nitrogen fertilizer since the 1950s, but its industrial production has been very difficult. In 1978, Ube Kosan Company in Japan succeeded in developing it and it soon will be on the market. It is produced in parallel with the production of oxalic acid. There are possibilities of manufacturing oxamide from carbon monoxide, ammonia and methanol (methanol can be recycled) directly; thus oxamide is one of the promising future nitrogen fertilizers. It is decomposed in the soil by both hydrolysis and soil microbe action.

Nitrification Inhibitors are very interesting products if they work as well as expected. N-Serve in the United States and AM and DD in Japan were fully effective in the incubation tests because they were mixed thoroughly with soil in the test flask. But in the fields the thorough mixing of them with soil is difficult. In order to do so we must have the help of machines, as is seen in the cotton fields of the United States where N-Serve is effectively applied with fertilizers. Further, it is better if the inhibitor has some vapor pressure, because the dispersion of inhibitor in the soil is easier in the vapor phase than in water solution in upland soil conditions, except for waterlogged paddy soil. The inhibitor with little vapor pressure or water solubility has no meaning. Additives to promote dispersion will be useful in the case of water-soluble inhibitors.

It would be useful if we could kill the nitrification bacteria in the aerobic and oxidized soil layer at 1-2 cm depth by applying a kind of inhibitor over the surface water manually or automatically. Some kind of bactericide or herbicide might have more or less this kind of action. Of course, environmental safety and preservation of the rice crop from harm must be confirmed.

Super Phosphate and Triple Super Phosphate are old but good fertilizers. They have water-soluble phosphorus. The former also has effective calcium and sulphur. These can be stored and handled in bulk states. They have acidic reaction and can absorb ammonia gas. The water-soluble phosphorus then turns to ammonium citrate or citric acid soluble phosphorus.

When developing countries consider building phosphatic fertilizer plants with imported phosphate rock, it will perhaps be better from an agronomic standpoint to choose super phosphate, instead of ammonium phosphate, so that calcium and sulphur remain in the products.

Mono- and Di-Ammonium Phosphate became the main exporting finished products from the phosphate rock deposit countries, because of the high nutrient contents and easiness of handling. (Phosphoric acid will also become the main exporting product.) They have water-soluble phosphorus. The tendency toward ineffective phosphate formation by reaction with active alumina in volcanic ash soil is larger in acidic super phosphate

than in neutral ammonium phosphate. The ammonium nitrogen of ammonium phosphate is known to be absorbed firmly by soil and less leachable than ammonium sulphate, as shown in Figure 2. In any case, ammonium phosphates will occupy first place in the phosphate fertilizer market for a long time to come. From an agronomic viewpoint, however, it is regrettable that they lose effective calcium and sulphur.

Fused Magnesium Phosphate is a product unique to Japan. It is produced by the fusion of phosphate rock with magnesium silicate and quenching of the melt. It contains not only calcium and phosphorus but also effective magnesium and silica. Its phosphorus is soluble in 2 percent citric acid solution. The release of phosphorus is very slow and depends on particle size. It can be stored and handled in bulk without change in physico-chemical properties due to humidity. It shows a slightly alkaline reaction (pH 8) and is effective in adjusting the acidic soil to neutral. Its most characteristic feature is that it has almost no reaction with active alumina in volcanic ash soil and maintains its effectiveness for a long time. Despite the rise in energy costs, the demand for fused magnesium phosphate is increasing.

Calcined Phosphate is a product of reaction between phosphate rock and steam at high temperatures and fluorine in rock is removed. Its phosphorus is soluble in 2 percent citric acid solution. It also contains calcium and silica, and is stored and handled in bulk.

Thomas Slag is a by-product of steel manufacture and is being used in Europe. The fertilizer properties are similar to the above-mentioned materials.

Potassium Chloride and Sulphate are widely used at every agricultural site. For tobacco and potatoes, potassium sulphate is preferable. Slow-release potassium silicate is planned to be produced by utilizing waste fly ash from coal in the steam power stations in Japan.

Compound Fertilizers are usually used in advanced countries. The unbalanced nutrient ratio in the soil often results in less yield, so compound fertilizers having average nutrients are used regularly.

FUTURE NITROGEN FERTILIZER IN TROPICAL AND SUBTROPICAL REGIONS

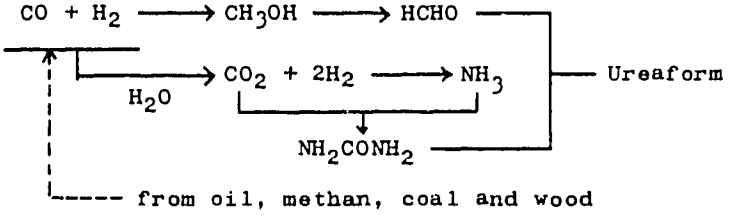
Tropical and subtropical regions are blessed with solar energy, high temperatures, and rainfall suitable for the growth of plants. However, the climate is very harsh on nitrogen applied to the soil. The nitrogen used in these areas must be resistant to leaching and nitrification, especially in upland soil conditions.

The application of nitrification inhibitors will not work effectively without skillful mechanical application. The use of coated fertilizers and some kinds of slow-release nitrogen fertilizers such as IBDU, CDU, and Oxamide will be restricted by limited production capacity and high prices caused by the limited supply of raw materials. The most promising one will be Improved Ureaforms series. The reasons are as follows:

1. Raw materials and possibility of large-scale production

Ureaforms series are known as the first product in the slow-acting nitrogen fertilizer group (since the 1940s). They are produced by the reaction between urea and formaldehyde, and formaldehyde is derived from methanol. The synthesis of methanol is carried out from the raw gas of $CO + H_2$ the same as in ammonia synthesis (Figure 4). Thus, as long as ammonia synthesis is carried out, raw gas of methanol can be derived from the same origin. The technology of producing methanol and formaldehyde resembles that of ammonia synthesis. Formaldehyde is the cheapest and most abundant aldehyde to react with urea.

Fig. 4 Manufacture of Ammonia, Urea, Methanol and Formaldehyde



2. Possibilities of improving Ureaforms series

Ureaforms series have been considered too slow-acting to be used for general crops, except for lawns. They contain several condensation products. Table 2 shows the composition of these products. Long and Winsor (1960) pointed out that trimethylene tetraurea is best in upland soil conditions and Hayase (1961) reported that dimethylene triurea is best in paddy fields. The higher condensates are ineffective. Generally, the effectiveness of Ureaforms series is expressed by indicating AI value, as explained in Table 3. The conventional commercial products have an AI value of 40-45 and the upgrading of AI value of them was difficult. Recently, Schneider and Veegens (1979) presented the possibility of upgrading AI value to 60, even 70. This report will spur other researchers and we can expect more research activities to open a large possible market for these improved products in tropical and subtropical regions.

3. Fundamental problems of slow release fertilizers

The agronomic merits in terms of high recovery rate, long-lasting effect and safety in large application have been emphasized every time a new product enters the market. But we must consider the important fundamental problems of general so-called slow-release fertilizers.

Table 2. Composition of Ureaforms Series

$$NH_2CONH_2 + HCHO \longrightarrow NH_2CO(NHCH_2NHCO)_nNH_2$$

n = 1	monomethylene diurea	(M2U)	a little soluble in water
n = 2	dimethylene triurea	(2M3U)	slightly soluble in water
n = 3	trimethylene tetraurea	(3M4U)	
n = 4	tetramethylene pentaurea	(4M5U)	

and the higher condensation products

Table 3. AI value (Activity Index)

$$AI = \frac{WIN - HWIN}{WIN} \times 100 = \frac{II}{II + III} \times 100$$

TN; Total Nitrogen

WIN; Cold water insoluble N (25°C)

HWIN; Hot water insoluble N (100°C)

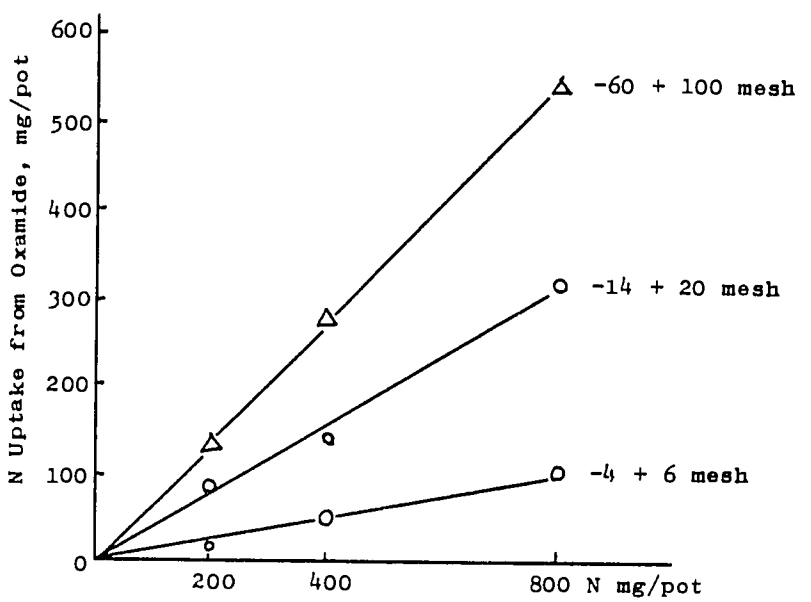
Fraction

I	Cold water soluble = TN-WIN	M2U, 2M3U,	Period of release a few weeks
II	Soluble hot, insoluble cold = WIN-HWIN	2M3U -- 5M6U,	several months
III	Hot water insoluble = HWIN	5M6U -- 8M9U,	1-2 years

(a) Analysis of yield based on the relationship between quantity applied and long-lasting effect.

De Ment (1961) discussed the relationship from the experiment conducted on Oxamide, as shown in Figure 5. This figure shows that the larger the particle size of Oxamide (meaning the slower the release rate), the more the fertilizer is needed to obtain regular yield by a single application, even though the effect of the fertilizer will remain in the soil. Thus we must select the fertilizer of the proper release rate to fit the period of plant growth. If we use too slow fertilizer we cannot gain the expected yield without applying a great amount. The plants need the proper nutrient concentration in the soil water.

Fig. 5 Effect of granule size and rate of application on uptake of nitrogen from O:



De Ment, 1961
Hartsells fine sandy loam
Average for unlimed, pH 5.2, limed, pH 7.3

(b) Mineralization mechanism (soil microbial action and hydrolysis)

The words slow-release and slow-acting have often been confused. The former means the slow release of available nutrients from the fertilizer granule which contains them, as in the case of coated fertilizers;

the latter implies the slow release of component from the fertilizer granule which decomposes to usable form. Slightly water-soluble nitrogen compounds are divided into two groups when the solute decomposes. One is decomposed by the microbial action of the soil; CDU and the condensation products higher than trimethylene tetraurea in the Ureaforms series are in this group. The other is decomposed by chemical hydrolysis; IBDU and Oxamide are in this latter group. Methylene diurea and dimethylene triurea are possibly divided into the hydrolysis group, which of course are all decomposed by soil microbial action.

Soil microbial action varies greatly depending on the changes in soil condition, such as temperature, moisture, pH, organic matter contents, mineral composition, and aerobic or anaerobic microbe flora. This discussion is important to proceed research.

(c) Control of the lasting period of effectiveness (size effect of the fertilizer granule)

Generally, dissolution velocity of slightly water-soluble compound is controlled by adjusting the size of the granule (and its hardness even in water). It is easier to match the period of fertilizer effect to the demand of plants than to select a chemical compound which will decompose at the proper rate in its powder form. We have experience in making long-lasting (three to five or more years) effective nitrogen fertilizer which is now under afforestation tests.

4. Possibilities of use

(a) Paddy fields

Urea may be useful if it could be applied skillfully under reductive deep soil. But many farmers want easy broadcasting on the surface of the field, even though they know that its efficiency is inferior. In Japan, deep placement was recommended for several decades, but few farmers did it. This means that better nitrogen fertilizer for broadcasting is needed. Dimethylene triurea is the most promising in the methylene urea series (Hayase, 1961). Further, it is better to formulate it to large and heavy granules in order to specifically get deep placement effect at broadcasting application.

(b) Upland crops (Foods)

Trimethylene tetraurea is most promising according to Long and Winsor (1960), but we must examine which is better between the old Ureaform of AI value 4045 and the newly-improved ureaforms series of AI value 50, 60, 70, or more.

(c) Industrial crops

The agriculture in the developing countries must not only be for food but also for industrial crops to strengthen the economy of each country.

(d) Forestry (tree planting)

Forestry is now in the limelight in the expectations of solar energy storage and future raw materials for chemical industries, as well as for paper and timber. So the forest must be maintained in good condition. We ought to plant nurseries for this purpose, but it is obvious that young trees are overcome by vigorous grass unless they grow rapidly. Fertilizer, especially long-lasting nitrogen, is the only solution to this problem. Ureaforms series is promising in use of container-grown nursery stock.

A WAY OF PROMOTING RESEARCH

The chemical fertilizers have advanced the agriculture in the world most effectively. The chemical fertilizers now on the market are the products of reaearch and development activities in the chemical industry and chemical engineering companies. New products such as slow-release fertilizers are also examples of their activities. No one except the above-mentioned companies has the ability to find a new chemical fertilizer. But these companies have aimed their activities only at profitable markets such as horticulture or ornamental plants and have not tried to find a fertilizer suitable for use in tropical areas, since they have not thought it profitable.

Agronomists have not had the opportunity to find a new chemical fertilizer for their use. They have only studied how to use a given fertilizer effectively. In tropical areas they have been selecting the cheapest fertilizer and suffering low efficiency. No one has ever tried to find a fertilizer for the tropics. A vicious circle exists which must be broken.

A way of promoting research in the companies who are capable of developing a new fertilizer and producing in a large scale is to let them know the potential large market for such a product in tropical and subtropical regions. In order to do this we must conduct wide fertilizer testing of promising trial products supplied through the cooperation of the chemical companies and the agricultural and forestry research organizations in tropical and subtropical regions.

This project must proceed against the thought that people will most probably not use more expensive fertilizer, even if it is improved. Thinking of the future, we need strong cooperation between agricultural research organizations and chemical industry.

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USE OF ORGANIC FERTILIZERS IN THE TROPICS AND SUBTROPICS

CHAR-FEN LIN*

ABSTRACT

The use of organic fertilizers in the developing countries has not received the attention it deserves from agronomists. Based upon a conservative estimation by FAO experts, there is a great potential for organic materials to be used as fertilizers in developing countries. In facing the low level of soil fertility, the rapid rise in fertilizer price, and the excess removal of soil nitrogen, special attention should be paid to the re-examination of the role of organic matter in crop production. In order to better understand the present situation of using organic fertilizers in developing countries, emphasis is laid in this paper on a review of responses of crops to various organic fertilizers including green manure, farmyard manure, compost, animal wastes, and crop residues. In addition, the city refuse compost, biogas plant, and the possibility of utilization of atmospheric nitrogen by biological N-fixation are also discussed. Their advantages and disadvantages are analyzed and future research suggested. Problems other than technical aspects in restricting the use of organic fertilizers such as land, labor, market, water, and transportation are also specified.

INTRODUCTION

Organic fertilizers are mainly derived from plant matter and human and animal wastes. They contain not only nutrients essential for plant growth but also organic matter which is known to improve soil fertility. However, they are heterogeneous in nature, bulky in volume, and difficult to handle. Thus, their importance has been neglected in the past.

The significance of organic fertilizers for food production may be illustrated as follows:

Low Level in Soil Fertility

Generally speaking, the higher the humus concent is, the higher the nutrient-supplying power of the soil. A survey of 410 paddy soils from the tropical Asian countries (Bangladesh, Burma, Khmer Republic, India, Indonesia, Malaysia, Philippines, Sri Lanka, and Thailand) by Kawaguchi and Kyuma (1977) revealed that the mean content of total organic carbon and total nitrogen were 1.4 percent and 0.13 percent, respectively, while those in temperate areas were 3.33 percent and 0.29 percent, respectively. This difference in organic carbon and total nitrogen may be ultimately reflected in the need for fertilizer (Parker, 1963).

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Rapid Rise in Fertilizer Price

Fertilizer prices in most countries were fairly stable up to 1972. In 1974, however, marked differences began to show up. A global comparison of fertilizer prices in 1972 and 1974 was studied by Von Uexküll (1975) who indicated that within the two-year period, fertilizer price increased by two and one half to four times. The price escalation played havoc with the foreign exchange of most developing countries in the tropics and subtropics.

Excess Removal of Soil Nitrogen

The nitrogen balance in plant production in the developed and developing countries was estimated by the scientists of the Rothamsted Experimental Station (1975). Although these estimates are often of uncertain accuracy, the trends are probably correct. They indicate that in developing regions such as India the climate stress exacerbates the effect of soil nitrogen and organic matter depletion. In Australia, legume-based pastures and leys play a major role in the N economy so that soil reserves are being built up by biological N_2-fixation. Our concern is more for those developing countries where a large number of people are still undernourished.

The present paper does not attempt to clarify the function of organic matter in soils, but aims to review the uses of organic fertilizer in the tropics and subtropics with respect to the Asian countries. Since the literature regarding the use of organic fertilizers in developing countries is sparse (at least that within the author's reach), some examples from the developed countries in the temperate regions or elsewhere are included. They may shed some light on the present situation of using organic fertilizers in the developing countries and the factors constraining the wider use of organic fertilizers in the area.

GREEN MANURES

The green manures refer to those crop-plants, which are plowed into the soil while still growing and usually blooming, for the purpose of improving soil fertility. Green manures are high in nitrogen, low in C/N ratio and contain considerable amounts of plant nutrients (Lin, 1950; Chang, 1965). The composition of green manure varies considerably with species, age, and growth condition (Yang, 1966).

On Upland Soils

Green manure crop is not a cash crop. The prerequisite for the successful introduction of green manure is in the fallow season or intercropping with the main crop without harmful effects such as competition with soil moisture, bringing in pests, and creeping on host plant. In Taiwan; problems in growing green manures for different main crops including rice, sugarcane, pineapple, citrus, banana, and tea have been reviewed by Chu (1954). Several promising green manures adaptable to different cultural practices were selected by Chang (1965) as follows:

1. Sugarcane: Mucuna capitata, Crotalaria juncea, Vigna sinensis, and Sesbania aculeata.

2. Pineapple: Mucuna capitata, Tephrosia candida.

3. Citrus: Desmodium ovalifolium, Centrosema pubescens, Pueraria phasioloides, Phaseolus calcaratus.

4. Banana: Centrosema pubescens, Pueraria phasioloides.

5. Tea: Lupinus luteus, Crotalaria striata.

To evaluate the economy of green manuring on sugarcane in Taiwan, Wang, et al. (1967) made a thorough review of the literature pertaining to green manure and conducted field trials on different soils. From the results, he indicated that when the rate of inorganic nitrogen application was small, the plots with green manure outyielded those without it; when the former was increased, the effect of green manure diminished accordingly. In other words, when there is lack of inorganic nitrogen fertilizer, green manuring is a good practice for increasing sugarcane yield.

Singh (1975) in India found that there were two effects in green manuring. One was the legume effect when the above-ground part was removed; the other was the green matter effect when the above-ground part was removed and ploughed into the adjacent plot. His results showed that the legume effect and the green matter effect were each responsible for about one-half the overall benefit from green manuring.

The East-West Center in Hawaii is conducting a project entitled I.N.P.U.T.S., which includes evaluation of intercropping of maize with different legumes in some Asian countries including Taiwan, India, Philippines, Sri Lanka, and Thailand, as well as Hawaii. The interim results compiled by Gunasena, et al. (1978) indicated that maize yield under intercropping was higher than that of its monocrop counterpart, but legume yield was decreased by intercropping in all cases. As far as the yield of the total system was concerned, the yield of the maize and soybean intercrop was higher than the yield of the corresponding monocrop. Similar results were also obtained in Nigeria by Agboola (1975). All these findings show the significance of the legume effect as designated by Singh (1975).

On Paddy Soils

Green manuring on paddy soils in Taiwan was reviewed by Chu (1954) who indicated that, based on the equivalent rate of N added, the effect of green manuring on the increase in rice yield as well as on the N-uptake of rice plants was about the same or even better than that of ammonium sulphate. It may be due to the fact that the nitrogen in green manure is released slowly as ammonium-N under submerged soils. However, on heavy and ill-drained paddy soils, the addition of green manure in excess of 5 t/ha fresh weight caused a decrease in rice yield, as found by Chang (1962, 1964). It may be due to the same reason which Rodrigo (1974) stated: the addition of easily decomposable green manure may aggravate the chemically reducing condition resulting in physiological disease in Sri Lanka. On the other hand, on sandy soils in the north-

eastern part of Thailand where chemical fertilizers are subject to leaching, the effect of green manure is more marked (Chang 1976). In other words, green manure is a good source of nitrogen in rice cultivation; its advantage or disadvantage depends upon the drainage condition of the soil.

Azolla

The water fern is widely distributed in rice fields from tropical to temperate regions. The nitrogen fixing bluegreen algae, Anbaena azollae is always found as symbiont in the cavities of leaves. There are six existing species (Moore, 1969). N-fixing power varies with species (Rains and Talley, 1978).

Results obtained from Azolla inoculum production trials in the Philippines (IRRI, 1976) indicated that the fresh weight of Azolla was 15 t/ha in about 25 days after inoculum; its nitrogen content was estimated at 30-40 kg N/ha. Due to its rapid multiplication by utilization of atmospheric nitrogen as N source, Azolla is considered to have a potential value as an N-supplying green manure crop in paddy rice cultivation as demonstrated in Vietnam (Moore, 1969), Philippines (IRRI, 1976), India (Singh, 1977), Sri Lanka (Peters, 1978), California (Rains and Talley, 1978) and mainland China (Lumpkin, 1978). Azolla can be grown as a green manure crop during the fallow season or as a dual culture with rice during the initial growing stage of the rice plant. One prerequisite for the successful introduction of Azolla cultivation is a relatively stable water supply. Temperatures at the time of cultivation should be within the range of 15° to 38°C. The aquatic environment is rather flexible within the pH range of 3.5 to 10, but is best in the range of 4 to 6.5, and salinity must be less than 1500 mg/L. Phosphorus is an important nutrient for Azolla. In Asia, insect pests of Azolla are members of the moth family Pyralidae and midge family Chironomidae (Lumpkin, 1978).

Current Problems and Future Research

The advantages of green manure over other methods of fertilizing include the following: first, either very little or no cash is generally involved; second, no transport costs are incurred; and third, livestock husbandry is not necessary. However, there are also a number of disadvantages:

1. There is no immediate return in terms of cash or food.

2. Incorporation of heavy green manure into the soil is difficult with hand tools, especially since it appears to a peasant farmer to be unnecessary labor.

3. Planting green manure as a sole crop does not fit well into the farmer's system of agriculture.

4. There is a lack of adequate water supply both for the sowing of a green manure crop and for its decomposition in soil. On the contrary, there is too frequent and too much rainfall, making sowing and growing a green manure crop difficult in some cases.

5. There is difficulty of acquiring seeds on a large scale and/or multiplying them.

6. Addition of mineral fertilizer and lime is necessary on some soils.

7. Azolla is water dependent a ' its use is limited.

For wider use of green manure, the following research is suggested:

1. Studies on the adaptabilities of various green manures to different agro-climate regions and cropping systems during the fallow season are necessary. The green manure selected must be easily propagated and harvested with minimum labor, preferably a self-seeded crop. The seed should be small and only a small piece of land is required for harvesting seeds by farmers themselves.

2. Studies are needed on the economic aspects of the growth of legume crops including the intercropping and monocropping systems under various soil and climatic conditions; particularly, how to reduce the depressing effect on legumes by counter crop should be stressed.

3. Comparative studies on the species of Azolla are necessary since the response of Azolla to environmental factors varies with the varieties. In addition, basic information regarding specific cultural practices involving the use of Azolla should be studied further in order to be applicable to a wide range of conditions.

FARMYARD MANURE (FYM)

Rural compost, farmyard manure, and animal wastes are included in this section. Precisely speaking, compost is prepared by heaping and moistening crop residues with either animal wastes or chemical N fertilizer. When the compost is well prepared, it contains an appreciable amount of plant nutrients and its C/N ratio is about 15 (Kumada, et al., 1972). Farmyard manure is a mixture of partially rotted straw and animal wastes. The value of farmyard manure or compost used as a plant nutrient source varies with the kind of raw materials, storage conditions, and duration (Tanaka, 1977).

On Upland Soils

The benefits of using FYM for growing crops have been described by Hall (1928). Results from a long-term (1954-1971) field trial in Holland in which potatoes/winter wheat/sugar beet/spring barley rotation was grown with optimum NPK with and without 20 t FYM/ha added in alternate years indicated that treatment with FYM increased all yields of rotation crops as compared with those without FYM (Haan and Lubbers, 1976). Widdowson, et al. (1974) in England indicated that FYM was less effective than chemical fertilizer when given alone. The combination of FYM and fertilizer gave a better yield than the single amount of fertilizer added. The residual effect of FYM lasted longer.

Recently, Gunasena (1978) reviewed the results of I.N.P.U.T.S. trials on the utilization of organic residues in India, Sri Lanka, the Philippines, and Thailand and indicated that the response of maize to

FYM was positive in all cases, but the magnitude of increase in maize yield was different from country to country due to the difference in soil N status.

The effect of compost and animal wastes including solid and liquid manure on sugarcane yield in a 10-crop field trial was studied by Yeh (1967) in Taiwan. He indicated that an addition of 30-40 t/ha of compost, or 20 t/ha of solid manure, or 100 t/ha of liquid manure to replace the equivalent amount of N in mineral fertilizer increased the sugarcane yield as compared to mineral fertilizer. The differences between them were, however, not statistically significant.

Although animal wastes as a plant nutrient source have the same value as chemical fertilizer, the excessive application of animal wastes may cause salt accumulation, nitrate pollution, metal toxicity, and pathogen hazards (McCalla, 1975; Suzuki, et al., 1977).

On Paddy Soils

Raheja, et al. (1975) indicated that in a 10-year experiment on rice at 23 locations in India, FYM increased the yield at 8 locations and inorganic N increased the yield at almost all locations. Mineral N was much more effective than the N in FYM.

In Taiwan, 54 field trials including first and second crops in 14 locations throughout the island were conducted during 1940-1942. In these experiments, compost was added at the rates of 0, 40, 80, and 120 kg N/ha. Ammonium sulphate added at the same rates were used as comparison. In addition, sufficient amounts of superphosphate and potassium sulphate were also added to all plots including the plot which received no nitrogen, in order to make sure that the growth of rice would not be hindered by the lack of these nutrients. The results indicated that rice yields treated with ammonium sulphate were all superior to those with compost on equal rate of N added. Taking the average yield of ammonium sulphate as 100 percent, those with compost had 90 percent for the first crop, and 95 percent for the second crop (Lin, 1955).

A long-term field trial was conducted on Taipei silt clay loam to justify the effect of compost on soil productivity. In the experiment, the organic manure plot received 93.5 kg N/ha as compost, or 20 t/ha fresh compost; and the inorganic NPK plot received the same rate of N as ammonium sulphate plus 41.5 kg P_2O_5/ha as superphosphate and 78.9 kg K_2O as potassium sulphate. During the initial 10 years, the rice yield treated with compost was inferior to that of NPK fertilizers, but the yield in the compost plot increased steadily and exceeded that of the NPK plot from the tenth year on (Lin, 1955; Lin, et al., 1973). Cooke (1977) indicated that continuous application of FYM would gradually increase the humus content of soil to an eventual equilibrium, but the loss of humus is equally fast when the application is stopped.

Addition of farmyard manure or compost alone usually gives a poorer result than inorganic N fertilizer on an equal rate of N added in a short-term field trial as shown above; it seems feasible to adopt a scheme of fertilization with a proper combination of organic and inorganic N as a means of increasing the yield of rice and maintaining

the soil productivity through the supply of organic matter. In the experiments all treatments were added at the same rate of 80 kg N/ha. Ammonium sulphate was used as inorganic N and compost as organic manure. The various proportions added of organic and inorganic N were as follows: 1:3, 2:2, and 3:1. Results from 54 field trials indicated that the best yield was obtained at a ratio of 1:3 with regard to the proportion of compost to inorganic N. This means that 20 kg N/ha as compost or 4-5 t/ha of fresh compost (based on N content at 0.4-0.5%) should be added for each crop of rice raised in conditions like those of Taiwan (Lin, 1955).

Current Problems and Future Research

Farmyard manure is the most abundant organic source of plant nutrient available to the developing countries as estimated by Singh (1975), but resources have not been fully utilized. Some of the obstacles are:

1. Farmers need to hire labor for transporting and processing a considerable volume of manure, particularly where vehicles are not available and traction power is limited. Therefore, labor costs will in many cases prove a deterrent to the intensive use of manure.

2. The use of manure as fertilizer competes with its use as fuel where firewood is insufficient. In India it has been roughly estimated that one-third of available dung is burnt for cooking purposes. The practice, which is also known in Africa, represents a constant drain on the fertility of the land (Duncan, 1975; Singh, 1975).

3. The supply of material necessary to maintain high levels of composting is generally not available on the farm. In dry areas, water may have to be provided for composition.

4. Since composting is labor- and time-consuming, the return of rice straw as compost has been progressively decreasing even in areas where a sufficient amount is available.

The following research is required for the future:

1. Studies on the adaptability of various species of quick growing trees or shrubs to a wide variation of soils and climatic conditions.

2. Studies on the safe handling, storage, and application of animal wastes including ways and means to avoid hazards from pathogenic organisms, which are toxic substances to man and animals and have a detrimental effect on farming.

3. Studies on the rapid method of composting by inoculating certain microorganisms in order to reduce the cost of labor. In Taiwan, the compost used for mushroom culture has been shortened to five days by inoculating *Micro-monopora* sp. and *Torula thermpile* (TARI 1974).

4. Studies on the proper combination of organic manure and inorganic N-fertilizer to increase food production and to maintain soil fertility.

CROP RESIDUES

Crop residues refer to the left-over portion of different crops after the usable portion has been removed. They are low in N content and high in C/N ratio. In attempting to use crop residues as a nutrient source, it must be borne in mind that net gain in mineralization leading to the release of nitrogen (and other nutrients) is governed by the amount of nitrogen in the organic material (about 1.5 to 2.5% being optimum for release) and its C/N ratio (Hirose, 1973).

On Upland Soils

By using N^{15} tracer techniques, Tokunaga (1975) provided evidence that utilization of N originating from the plow-in plant residues was approximately 5 percent for upland rice and 4 percent for barley at harvest. The value of crop residues plowed into the soil as a source of nitrogen for plant growth is usually small under practical field conditions.

In Hawaii, Asghar and Kanehiro (1977) indicated that dry matter yield of sugarcane decreased significantly with the addition of trash. It may be attributed to the immobilization of available forms of nitrogen in the soil as a result of a microbial population explosion during the decomposition process.

In Nigeria, Ayanaba and Okigbo (1975) indicated that surface mulch with corn stover gave a greater yield of maize than when buried into the soil.

In Taiwan, Su (1968) reported that 15 t/ha of crop residue mulching on a pineapple plantation would substantially improve the yield and quality of pineapple. Lin (1958) found that surface mulching with rice straw on a tea plantation on slope land would remarkably reduce the loss of soil from erosion.

Some evidence indicates that incorporation of crop residues into soil sometimes results in the accumulation of toxic substances. Linderman (1970) found that barley, cowpea, soybeans, and cotton produced acid phytotoxic to tobacco. Wu, et al. (1975) in Taiwan also found some phytotoxins of Centrosema inhibiting the growth of bananas.

On Paddy Soils

In Indonesia, Ismunadji (1973) conducted field trials treating with 3 t/ha of rice straw in combination with 90 kg N/ha as urea, 60 kg P_2O_5/ha as triple superphosphate. The result indicated that the addition of rice straw was beneficial to the increase of rice grain and uptake of nutrients, particularly potassium, as compared with the treatment without straw. Tokunaga (1975) mentioned that potassium released from crop residues is not negligible and will be a significant source of plant nutrients from the viewpoint of potassium needs of soils.

Recent studies at the IRRI (International Rice Research Institute, in the Philippines, 1974-1975) has demonstrated the benefit of supplying straw as a source of nutrients to rice. Leaving rice straw in the field after harvest accumulated substantial amounts of nutrients. During five seasons the following increases were observed: 0.74 percent in organic

matter, 0.03 percent in nitrogen, 3.3 ppm in phosphorus, and 0.32 meq K/100 gm soil. The nitrogen gained by the straw-treated soils amounts to 60 kg N/ha per season. When straw was added, grain yield was increased by 0.93 t/ha or 12 percent with IR 773-112-2 rice as compared with no straw treatment.

Rao and Mikkelson (1976) found that straw addition did not produce a significant amount of acetic, propionic, or butyric acids in the soil, and the plant showed no symptoms of organic acid toxicity. The main cause of retarded growth following rice straw incorporation is due to the immobilization of available nitrogen in the soil.

In Taiwan, Hong and Liu (1977) indicated that addition of rice straw into the soil would give a favorable effect on rice yield in the first crop. However, the interval between the harvest of the first crop and transplanting of rice seedlings of the second crop is about two weeks. Such a short interval may not allow sufficient time for the decomposition of rice straw into harmless form.

Chou and Lin (1976) demonstrated that rice residues submerged in soil released phytotoxic substances which would inhibit the radicle growth of rice seeds and the growth of rice seedlings. He further indicated that during the decomposition process, soil microorganisms played an important role; whether the phytotoxins derived from the metabolic by-products by microorganisms or directly from rice residues was uncertain.

Current Problems and Future Research

The application of crop residues is important, not only for recycling of plant nutrients and maintaining soil fertility but also for saving labor necessary for making and applying compost. However, there has been an increasing tendency in Taiwan, Thailand, Philippines, Malaysia, Indonesia, and Burma (Tanaka, 1977) to burn away crop residues, especially rice straw which is abundant in paddy fields. For a better understanding of the behavior of crop residues after incorporation into soils, the following research is needed:

1. Studies on the nitrogen transformation associated with the decomposition of rice straw in soils under various climatic conditions.

2. Studies on the nature of phytotoxic substances produced during crop residues' decomposition in soils and their effects on crop growth.

CITY REFUSE COMPOST

Most city refuse is usually collected and dumped on unused land to fill depressions or marshes. Mountains of waste are obviously a danger to the health of a city. To put waste in the wrong places merely increases pollution.

It was surveyed and estimated by Lee (1957) that the production of refuse in Taiwan was about 0.5 kg per capita per day. The refuse contains about 1% N, 0.5% P_2O_5, and 1% K_2O on a dry basis. If this refuse

is composted with the addition of night soil, a better quality of compost can be obtained.

The basic principle in city refuse composting is to decompose the collected refuse by incubation in a big rotary kiln for about one week under warm aerobic conditions. Under such conditions the spore-forming pathogenic germs present in refuse are forced to germinate and can thus be killed off during the process of composting (50° to 60°C) within a few days. Worm eggs and parasites are also destroyed (Stickelberger, 1975).

In Taiwan, the first pilot composting plant was built in 1956. The plant can handle 27 tons of raw refuse a day using a windrow process with periodic turning and addition of night soil. The quality of city refuse compost made by the plant within a 20-day period is comparable to that produced by farmers using sugarcane trash or rice straw in combination with animal wastes in a period of 5 to 6 months (Sun, et al., 1959).

Stephen and Lin (1972) indicated that addition of Bangkok refuse compost caused a significant increase in the vegetable yield of Brassia Chinensis. However, Purves and MacKenzie (1974) indicated that addition of unleached municipal compost produced B toxicity symptoms and significantly reduced the total yield of beans (Phaseolus vulgaris), whereas leached compost gave substantial yield responses and produced no toxicity symptoms. Tietjen (1975) illustrated that trace elements (Cu, Zn, Mn, Mo, and B) in municipal compost are 10 to 100 times higher than those in stable manure, thus the application of a very large quantity of municipal compost could be injurious to crop growth.

Current Problems and Future Research

The advantages of city refuse compost include: (1) Elimination of health hazards and offensive odor; (2) requiring less land; (3) salvage of reusable materials; and (4) disposing of a portion of human wastes for composting. However, many composting plants have been closed down in most industrialized countries such as the United States (Stickelberger, 1975) and Japan (Egawa, 1975). Even in the Netherlands where city refuse composting originated, preference for incineration has been noted. The reason for closing down most of the plants is primarily due to economic imbalance between increasing wages and the price of the products. On the other hand, 230 composting plants are still in operation in Western Europe. A few plants were also built in Latin America, Africa, and Asia (Bangkok, India, and the Philippines). Nevertheless, composting is still practiced in a number of places.

Since the compost-making using city refuse is originally planned to solve the disposal problem of town garbage from a sanitary viewpoint, the compost can be considered as a by-product and sold very cheaply. However, it would be too optimistic to expect profit from the refuse compost plant. The proceeds realized through the sale of the product might not be sufficient to cover the cost of processing. It seems that the government should subsidize the refuse compost plant instead of paying for the cost of disposing of the refuse by other methods. Further research should be done on:

1. Studies on the control and improvement of the quality of refuse compost. The most important requirements concerning compost quality involve:

(i) the absence of substances that are injurious to man, crop, or soil;

(ii) high content of organic matter and plant nutrients; and

(iii) low content of useless substances like stones, slags, fragments, plastic, etc.

2. Studies on the designing of compost plants with low cost but high efficiency in order to reduce the cost of production.

3. Studies on the utilization of by-products from city refuse other than compost.

BIOGAS PLANT

The basic principle in biogasification is known as anaerobic digestion in which dung or any other waste is fermented in the absence of air and the combustible gas methane is produced. The gas may be used for household cooking, lighting, or to generate electricity on the farm. After fermentation, the effluent may be used for the culture of chlorella or else applied to a crop as fertilizer (de Guzman and Huang, 1978). Thus, the recycling of animal, human, and other organic wastes through a biogas plant provides fuel and organic fertilizer and at the same time helps to improve the environment. Biogas technology has been regarded as a promising method for village-scale use in developing countries (Goldstein, 1979). Some data regarding some livestock wastes and the amount of gas generated and their utility are given in Tables 1 and 2 (Weitzenhoff, 1978).

TABLE 1-- LIVESTOCK MANURE AND ENERGY POTENTIAL*

Animal	Manure produced kg/day	Gas produced m^3/day	Heating value Gasoline equivalent (gal)
1 cow	24	1.5	0.2
100 cows	2,400	150	20
1 pig	4.1	0.45	0.06
1,000 pigs	4,100	450	60
1 chicken	0.14	0.04	0.007
5,000 chickens	700	200	35

* Weitzenhoff (1978)

TABLE 2-- BIOGAS UTILIZATION*

USE	m^3	RATE
Lighting (direct)	0.7	per mantle per hour
Cooking	0.34	per hour per 10 cm burner
	0.35	per person per day
Gasoline engine with 25% efficiency	0.45	per horse power per hour

* Weitzenhoff (1978)

Recently, Cheng and Wang (1977) made some field trials regarding the use of fermented effluents from the pig waste gas plant. The results indicated that the responses of maize and sorghum toward the fermented effluent and chemical fertilizer were the same at the equal rate of N added.

Some facts (Weitzenhoff, 1978) affecting methane generation are:

1. Anaerobic environment (without oxygen)

2. Proper carbon to nitrogen ratio of the organic feed stocks (approximately 20 to 1)

3. Optimum digestion temperature (27° to 37°C)

4. Proper pH level (7 to 8)

Most livestock manures already have the right carbon-to-nitrogen ratio and have a natural buffer to keep the pH in the proper range.

There are many types and sizes of biogas plants, but they consist mainly of two parts: digester and gas holder. The materials used for the construction of low-cost gas plants vary from country to country depending on whatever is locally available. The bag type plant recently developed in Taiwan consists of a PVC impregnated mud plate bag in which the manure is digested and the gas is stored in the one large air-tight bag (Figure 1) (Hong, et al., 1976). The bag type plant has proved to be very efficient, durable, relatively inexpensive, easy to construct, and easy to clean and repair (de Guzman and Huang, 1978). Goldstein (1979) recently made an estimate which included Burma, Indonesia, Khmer Republic, Korea, Laos, P.D.R., Malaysia, Philippines, Singapore, Thailand, and Oceania and which revealed the fact that there is a great potential for developing and implementing technology for biogas production in the Asian countries.

Current Problems and Future Research

The advantages of biogas technology have been mentioned before, but this program is also not free from obstacles. The following problems should be noted.

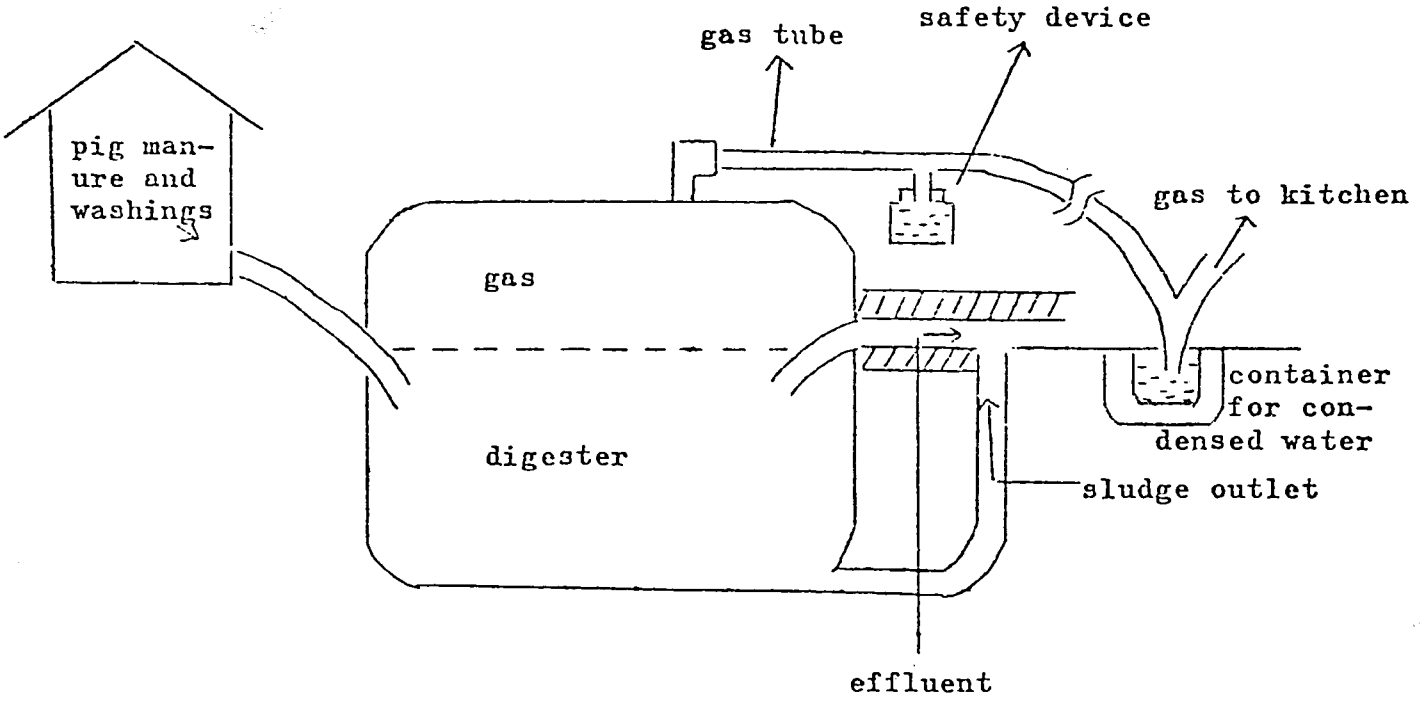

Fig. 1. Bag type of methane generator

1. Methane production is temperature dependent; therefore, in the cold winter of the tropics and subtropics its use is limited.

2. Farmers must own a certain amount of livestock in order to have sufficient animal wastes to feed the plant for daily use.

3. Almost all biogas plants now in use have a floating drum made of steel. Thus there is a problem with corrosion in the steel drum which considerably reduces the life span of the gas holder. The bag type plant as described may be one of the ways to solve this problem.

4. The owners often complained about the damage to appliances such as mantel and burners. It is necessary, therefore, to design simple appliances which could be made in the country and repaired by local craftsmen.

5. A biogas plant for weaker sections of society is costly at present with the prevailing technology. The major cost consuming item is the steel gas holder, followed by the appliances.

To ensure a continuous supply of animal wastes, mixed farming such as animal husbandry, forage crops, and mixed cropping should be established wherever feasible. Research work is also needed on the following problems:

1. The design of a very low-cost biogas plant and its appliances.

2. The design of such a plant in which CO_2 and H_2S can be separated very efficiently from CH_4.

3. Finding a suitable catalyst which would maintain the release of gas from the plant during the cold winter season.

BIOLOGICAL N-FIXATION

Nitrogen is the element that often becomes a limiting factor for food production in developing countries. The biological fixation of atmospheric nitrogen has great potential as a source of nitrogen for crop production.

Azotobacter

Many microorganisms have been reported to possess the ability to fix atmospheric nitrogen (Jurgensen, 1970). The distribution of nitrogen-fixing microorganisms in the paddy soils of southeast Asia has been studied by Kobayashi, et al. (1967). Although the importance of azotobacter in most soils is now thought to be small--usually less than 20 kg N/ha/year (Whitehead, 1963)--many Russian agronomists are convinced that non-symbiotic fixation is important and field inoculation with azotobacter culture is widespread (Cooper, 1959). The Russians considered a high level of organic matter to be necessary for successful inoculation with azotobacter and emphasized the fact that local strains of azotobacter are better than the foreign ones (Cooper, 1959). Wani, et al. (1976) also found that inoculation with azotobacter from the rhizosphere of the same rice cultivar gave the highest yield.

Rhizobium

The most important group, comprising the Rhizobium bacteria, is symbiotic and dependent on the growth of leguminous plants. The value and mode of action of Rhizobium are widely recognized and less controversial. Soils often contain several Rhizobium strains capable of nodulating a given plant, but they vary in their ability to form nodules and fix nitrogen. Effective strains fix much nitrogen, while ineffective ones fix little or none. Most studies of symbiotic nitrogen fixation in the tropics have been conducted in Australia with pasture problems. There are hardly any studies of Rhizobium-legume relationships in southeast Asian countries (Yoshida, 1975).

Recently in Nigeria, Kang (1975) reported that inoculation of rhizobium increased the yield of soybeans both in the pot and field trials. In the experiment three inoculants were used. He found that inoculation with Nitragin-S (USA) gave significantly less bean yield than that of IARI (Indian Agr. Res. Inst.) and CB 1809 (Tropical Inoculant, Australia) inoculants. The latter ones did not differ significantly from one another.

Blue-green Algae

Inoculating the paddy field with nitrogen-fixing algae has been reported as beneficial to the plant in Egypt (Ley, 1959), India (Relwani, 1964), and Japan (Watanabe, 1962).

The role of algae in fixing nitrogen in rice paddies under natural conditions is being investigated at IRRI (1974). The total estimated amount of nitrogen fixation during a crop season ranged from 2.3 to 5.7 kg N/ha in one field and from 18.5 to 33.3 kg N/ha in another. The feasibility of increasing rice yield through algal inoculation has not been established in the IRRI experimental farm.

The Rhizosphere

The rhizosphere or that portion of the soil near and under the influence of plant roots presents a special environment for nitrogen-fixing microorganisms. The amount of nitrogen fixed by the rhizospheric microflora of over 40 species of agronomically important tropical grain (including rice, maize, millet, and sorghum) has been reported (Rothamsted Exp. Sta., 1975).

Experiments conducted at IRRI showed that certain bacteria living in the root zone (rhizosphere) of the rice plant were capable of fixing atmospheric nitrogen. The total estimated amount of N fixed was about 35 kg N/ha in flooded rice paddies and 2 to 4 kg N/ha in upland rice soil per crop season (Yoshida, 1975).

Current Problems and Future Research

Although the importance of inoculation of Rhizobium for legumes is known worldwide, unfortunately the practical application to field conditions is still uncommon in the developing countries. The nitrogen obtained by biological fixation is at almost no cost. It produces high protein products and concurrently increases soil fertility and thus improves soil productivity. However, the activity of microorganisms is

influenced by environmental conditions and the adoption of the right strains. Consequently, the success obtained in one country may not be applicable to another. Research should be done on:

1. The rhizobium-legume relationship to make more effective nodules in various grain legumes in the tropics and subtropics, which has great potential. The nodulation problems of legume species for food grains including mung-bean, soybeans, peanuts, and cowpea should be investigated.

2. Algal nitrogen fixation has a great advantage over bacterial nitrogen fixation since algae are dependent on both atmospheric carbon and nitrogen, which are abundantly available in the atmosphere as carbon dioxide and nitrogen gas. However, it is difficult to establish new algal flora in the natural ecosystem in rice paddies and therefore the investigation of stimulating nitrogenase activity of nitrogen-fixing blue-green algae which naturally grow in rice paddies should receive greater emphasis.

SUGGESTIONS AND CONCLUSIONS

On the basis of various research findings, Singh (1975) reported that the total annual production of plant nutrients through organic wastes (human and animal wastes, rural and city composts, urban sewage, and others) was 103.41 million metric tons of NPK in 1971. He also made an estimate of 129.21 million metric tons of NPK in 1980. FAO Fertilizer Review as cited by Singh indicated that the fertilizer consumption in developing countries was 13.2 million metric tons of NPK during the year 1970-1971. Thus, the total production of major plant nutrients in organic manure that could be available for utilization is about 7.8 times larger than the consumption of chemical fertilizers during 1970-1971. However, to estimate the potential of organic manure production for farm utilization in developing countries is rather difficult, because the actual amount which could be utilized will depend on the ease and cost of collection, handling, methods of conserving, and application. Nevertheless, these findings may indicate the technical scope for use of organic fertilizers; even a modest percentage increase in utilization could contribute significantly to food production.

In view of the problems restricting the use of organic fertilizers, factors other than technical aspects such as land, labor, market, water, transportation, or a combination of these should be identified, and the technical research may then be directed to their solution. Since the decision of a farmer to accept a new practice largely depends upon economic and social pressures, such research should be oriented not only to technical feasibility but also to the socio-economic problems involved. Therefore, to ensure the best chance of acceptance by farmers, an integrated and multi-disciplinary approach to a wider use of organic fertilizers in crop production should be designed and planned by a combined effort of administrators, economists, engineers, and agronomists.

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THE EFFECT OF INTENSIVE USE OF CHEMICAL FERTILIZERS ON SOIL FERTILITY IN COMPARISON WITH THE USE OF ORGANIC MANURE

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ABSTRACT

Chemical fertilizers contribute to the increasing production of food, but it is feared that the decline of soil fertility may occur when fertilizers are supplied continuously on a long-term basis. In this paper the effects of intensive use of chemical fertilizers on soil fertility are discussed in comparison with the use of organic manure. Continuous application of organic manure improved chemical, physical, and biological properties of soil, as well as crop production.

Chemical fertilizers also improve soil fertility although not as well as organic manure. This may be due to the fact that the application of nitrogen fertilizer increases the remaining stumps and roots, provided the applied nitrogen is not over a definite strength. It can be said from long-term experiments that intensive use of chemical fertilizers never results in sterile and unproductive soil.

In order to conserve energy and resources and to improve soil fertility, it is important to find a technical and economic way to recycle all crop residues and animal wastes in the field.

INTRODUCTION

There are two types of food problems in the world. One is the long-term problem of food production to feed the constantly increasing population, especially in the developing countries; and the present prospect of food supplies in the future is far from reassuring. The second is the short-term problem which occurs sometimes as a food surplus and sometimes as a food shortage. For the time being, a discussion about food surplus may be omitted here. A food shortage occurred in the early part of this decade, and there is a possibility again this year that it might become a serious problem due to poor harvests in extensive areas of the world. It should be noted that each period of food shortage has been accompanied by an oil crisis and increased prices for fertilizer.

To solve both long-term and short-term food shortages, we should increase the yield per unit of land, since land that could be reclaimed for agriculture is limited. It is known that careless reclamation of land often causes greater damage. To increase the yield per unit of land, intensive modernization and improvement of agricultural methods

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must take place. It is undeniable, however, that intensive modernization may bring some adverse effects to the natural and social systems.

Prior to the latter half of the nineteenth century, chemical fertilizers were not used in agriculture and nutrients were supplied by only four sources:

1. Decomposition of soil minerals by weathering and hydrolysis;

2. Precipitation and irrigation water;

3. Biological fixation of nitrogen by leguminous plants and others; and

4. Agricultural and city wastes.

This natural supply system of nutrients was sufficient to maintain food production for centuries because of the low population. Decrease of soil fertility due to removal of nutrients by crops, leaching of nutrients by rain and snow, and soil erosion by wind and currents inevitably set up fallow periods and produced rotation systems. When chemical fertilizers were developed, they gradually replaced organic manure.

The chemical fertilizers supplemented the deficient nutrients in the soil efficiently and made possible food production to feed the rapidly increasing population. Fertilizer contributes to the increasing production of food, but it is feared that decline of soil fertility, pollution of rivers, lakes and inland seas, and accumulation of toxic materials in food and feed may occur when fertilizer is used excessively and incorrectly. This paper discusses the effect of intensive use of chemical fertilizer on soil fertility in comparison with the use of organic manure.

EFFECT ON THE CHEMICAL PROPERTIES OF SOIL

Fertilizer is applied to supply nutrients for the crop, but the uptake rate of nutrients from chemical fertilizer is not always high. It is said that the uptake rates for rice of nitrogen, phosphorus, and potassium are 30 percent, 3 percent, and 60 percent, respectively. The remainder which is not lost by leaching and denitrification is left in the soil. In a recent review of works utilizing ^{15}N labelled fertilizer, Kundler (1970) reported that first-year recovery of nitrogen in the crop was 30 to 40 percent, with 10 to 40 percent immobilized in the soil, 5 to 10 percent removed by leaching, and 10 to 20 percent unaccounted for. Thus the remaining immobilized nitrogen enriches the soil and contributes to increasing soil fertility every year.

While organic manures supply all nutrients, including trace elements, in forms that do not carry useless ions, the nutrients are spread through the mass of soil when manures are ploughed in. Nitrogen, phosphorus, and potassium enrich the subsoil. It is generally considered desirable to enrich the organic matter in soil which is the source of nutrients and indicates cation exchange capacity.

When organic manure is ploughed into the soil, much of the organic matter is quickly decomposed but some remains. When dressings are applied each year, an equilibrium is ultimately reached where the percent of carbon (C) in the soil becomes constant. For example, after 100 years of continuous treatment on Broadbalk Wheat Experiment at Rothamsted, the farmyard manure treated plot had 2.58% C, the fertilizer-treated plot had 1.19% C and the untreated plot had 1.09% C. The equilibrium value for % C in the soil depends upon the amount and the type of organic manure, soil type, and climate. Since the C/N ratio in cultivated soil is generally constant, nitrogen also reached an equilibrium (Cooke, 1977).

Hashimoto (1977) reviewed the experiment which was conducted on paddy soil in Japan. It was a long term experiment, the design of which is shown in Table 1. This experiment was composed of four treatments. Except for the untreated plot, N, P_2O_5, and K_2O were supplied equally each year in the other three plots. Chemical properties of the soil after 33 years are shown. The result of continuous application of organic manure was found to have the following effects: (1) it enriched organic matter and total nitrogen; (2) it increased ammonium nitrogen formed during four weeks' incubation, and (3) it increased soluble potassium. This indicates an overall improvement in soil fertility. The accumulated nitrogen associated with a large increase in nitrogenous soil fertility may contribute significantly to crop production. Incidentally, 70 percent of the nitrogen taken up by the rice plant comes from this soil nitrogen. The N-15 experiments conducted by IAEA (1978) indicate that the yields of rice grain are generally proportional to the uptake of nitrogen derived from the soil, as shown in Figure 1. While continuous application of chemical fertilizer

TABLE 1. CHEMICAL PROPERTIES OF SOILS AFTER 33 YEARS TREATMENT AT KONOSU, JAPAN

TREATMENT	DEPTH OF SOIL CM	pH (H_2O)	T-C %	T-N %	C/N	DRYING[2] EFFECT MG	CEC ME	BASE-SATURATION PERCENTAGE	1% CITRIC ACID SOLUBLE K_2O MG	AVAILABLE SiO_2 MG
NO TREATMENT	0-12	6.7	2.17	0.192	11.3	7.9	18.6	61.9	7.3	15.0
	12-25	7.0	1.24	0.127	9.8	1.7	20.4	61.2	7.9	17.1
	25-40	6.7	1.92	0.140	13.8	1.4	24.7	51.4	7.9	31.6
CHEMICAL[1] FERTILIZER	0-12	5.4	2.33	0.217	10.7	11.1	20.1	60.7	5.3	11.3
	12-22	5.9	2.14	0.146	14.6	3.6	25.2	49.3	4.8	27.0
	22-40	6.6	1.54	0.109	14.2	0.4	21.6	58.1	4.3	39.5
FYM + SOYBEAN[1] CAKE	0-14	5.9	3.14	0.315	10.0	23.1	22.0	58.4	13.1	8.9
	14-26	6.9	0.68	0.068	10.1	3.2	15.2	83.4	9.9	11.3
	26-40	7.0	1.16	0.103	11.2	4.9	25.5	50.7	5.8	21.0
COMBINATION[1] (Chem. Fert. + FYM + Soybean cake)	0-14	5.8	2.55	0.265	9.6	18.1	18.5	62.6	9.8	9.7
	14-21	6.8	0.60	0.076	7.9	3.1	14.7	83.7	4.2	13.4
	21-40	7.1	0.91	0.083	8.6	1.7	21.7	59.5	5.8	17.7

Note: 1. 100KgN/ha, 50KgP_2O_5, and 100KgK_2O were supplied in each plot except no treatment plot.

2. formed NH_4-N mg after 28 days incubation of 100 g of dry soil under flooded condition at 30°C.

increases organic matter content, it also increases the ammonium nitrogen formed in a four-week period. This is in agreement with the result of the Broadbalk Experiment.

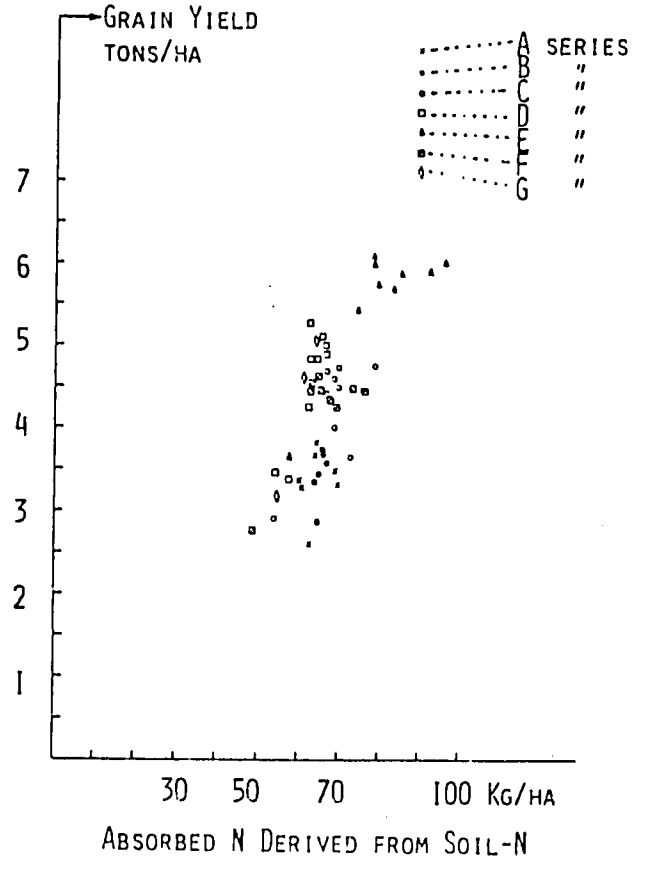

FIG. 1. RELATIONSHIP BETWEEN GRAIN YIELD AND ABSORBED N DERIVED FROM SOIL NITROGEN

A continuous application experiment in Japan in which different amounts of nitrogenous chemical fertilizer were supplied over a ten-year period showed results which are very suggestive. The more the level of nitrogen supplied, the more was accumulated in the soil, if the amount of nitrogen was not over 75Kg/ha, as shown in Figure 2. This may be due to the fact that the increased application of nitrogen increased the amount of stumps and roots, up to a certain level. Beyond this level, root growth tends to decrease and decomposition of soil organic matter is accelerated by the priming effect (Takai and Kitazawa, 1975). The actual rate of nitrogen might depend on soil and climate.

These experiments were conducted in the temperate zone, but Sanchez (1976) indicated the same tendency in tropical soil, as shown in Table 2 which reveals the effects of continuous manuring versus inorganic fertilization on paddy rice yields and soil properties over a ten-year period.

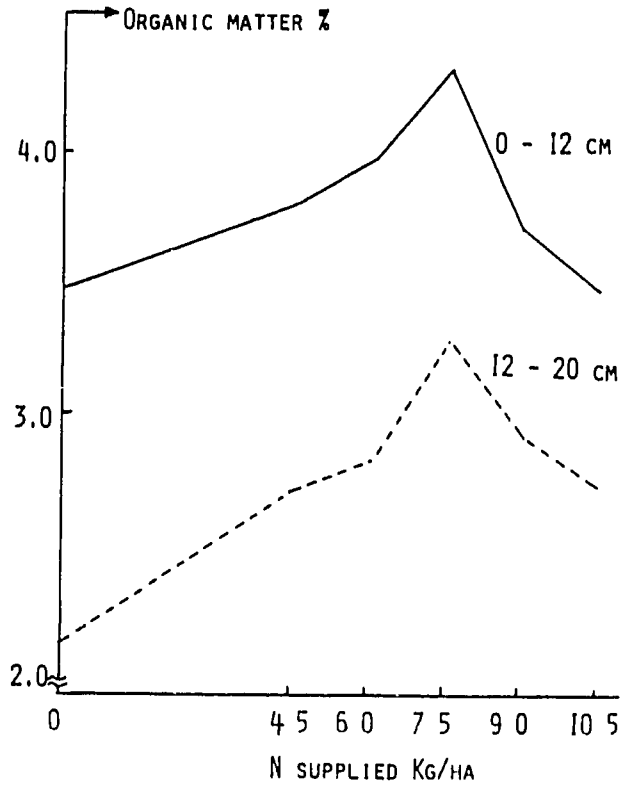

FIG. 2. THE EFFECT OF CONTINUOUS APPLICATION OF NITROGEN ON THE ORGANIC MATTER CONTENT OF SOIL AFTER 10 YEARS, AT KONOSU, JAPAN

TABLE 2--EFFECTS OF 10 YEARS OF MANURE AND FERTILIZATION APPLICATION ON LOWLAND RICE PRODUCTION AND THE PROPERTIES OF A VERTISOL IN BAGWAI, INDIA

ANNUAL APPLICATION	RICE YIELDS (TONS/HA)	ORGANIC C (%)	TOTAL N (%)	AVAILABLE P (OLSEN) (PPM)	CEC (MEQ/100 G)
NONE	0.88	0.70	0.063	10	31
MANURE (5.6 tons/Ha)	1.49	1.15	0.066	12	31
N (67 Kg/Ha)	1.55	1.12	0.066	11	31
P_2O_5 (67 Kg/Ha)	1.57	1.09	0.066	12	31

An annual rate of 5.6 ton/ha of animal manure increased yields as much as nitrogen or phosphorus fertilization. Both manure and fertilizer treatments slightly increased soil organic carbon and nitrogen.

In order to increase soil organic matter, straw application is sometimes recommended. However, it is worth indicating that straw should be incorporated far in advance of planting to avoid adverse effects due to the immobilization of nitrogen and the production of harmful substances. Tanaka (1974) mentioned that straw sometimes carried insect pests (stem borers, etc.) or diseases (Piricularia oryzae, Sclerotia oryzae, Xanthomonas oryzae, etc.) which may be carried over to the next crop of rice as a result of the straw incorporation. For this reason, the practice is not recommended in some areas.

There is an acidifying action from excessive fertilizer nitrogen on soil and it induces Al and Mn toxicities when compensating lime is not applied. However, it is not a serious problem if liming is carried on correctly.

EFFECTS ON THE PHYSICAL PROPERTIES OF SOIL

Soils continuously supplied with organic manure contain higher organic matter than soils supplied with chemical fertilizer. The former also include stable aggregates which are formed by polysaccharide and flagella of microorganisms. Accordingly, the bulk density becomes small, and pore space, water-holding capacity, and available water are all increased, as shown in Tables 3 and 4.

TABLE 3-- PROPERTIES OF SOIL AT HOOSFIELD BARLEY EXPERIMENT CONTINUOUSLY TREATED SINCE 1852

TREATMENTS	C %	N %	BULK DENSITY
Treated with NPK Fertilizers	1.10	0.105	1.50
Treated with FYM	3.38	0.29	1.29

Table 3 shows the data obtained in the Hoosfield Barley Experiment in which soil was continuously treated since 1852 (Cooke, 1977). Sanchez (1976) shows the data obtained in a long-term experiment conducted in India (Table 4). However, Salter and Williams (1969) stated that available water in the surface 30 cm soil is from 5 to 10 mm extra. This is only three days of transpiration in summer and may be useful in short droughts but not for prolonged drought as it was generally considered.

Certainly, improvement of soil physical properties by long-term application of organic manure makes soils more friable and tillable, germination becomes easier and there may be beneficial effects on seedlings and short season crops, but the effect on long season crops is not clear.

TABLE 4. EFFECTS OF LONG TERM MANURING APPLICATIONS ON THE PHYSICAL PROPERTIES OF SOME INDIAN SOILS

SOIL AND LOCATION	ANNUAL MANURE APPLIED (TONS/HA)	pH	ORGANIC C (%)	WATER-STABLE AGGREGATES (%)	BULK DENSITY (G/CC)	PORE SPACE (%)	AVAILABLE H_2O (0.1 - 15 BARS) (%)
ALLUVIAL	0	7.8	0.6	26	1.47	46	28
(SABORER)	74	7.5	2.9	56	1.29	50	37
VERTISOL	0	8.2	0.5	22	1.26	53	29
(POONA)	45	8.0	0.6	33	1.18	56	31
"RED"	0	5.8	0.6	29	1.37	49	21
(BIHAR)	9	5.7	0.7	33	1.30	51	23
"LATERITIC"	0	4.8	0.3	22	1.53	42	13
(ORISSA)	9	5.5	0.5	24	1.31	50	14

EFFECTS ON THE YIELD

The effect of long-term application of organic manure and chemical fertilizers on the chemical and physical properties of soil are mentioned above. It is most important to know the influence of these properties on the yield of crops. Several experiments with such objectives were conducted in Rothamsted Experimental Station and other sites from the middle of the nineteenth century. These experiments showed the superiority of farmyard manure to chemical fertilizers which were supplied continuously. Effects of continuous wheat experiments at Broadbalk are shown in Table 5. The results of carbon content were discussed earlier. Higher yields were obtained in the farmyard manure plot than in the chemical fertilizer plot in which nitrogen was supplied at a higher rate, except for the second wheat crop after the fallow period.

Cooke (1977) explained that the nutrients which are supplied with farmyard manure are spread to the whole layer of cultivated soil; and when organic nitrogen is mineralized it may be more readily taken up by crops, and rates of release may match crop uptake. Further, he explained that while inorganic nitrogen is ephemeral in soils which are readily lost by leaching, in dry periods surface dressing may be inactive. There is little possibility in the case of organic nitrogen treatment, and many nutrients can be provided without increasing the salt concentration in the soil solution.

Chemical properties of soils which were supplied by organic matter and chemical fertilizer in Konosu, Japan for a 30-year period were discussed earlier. The rice yields in these plots are shown in Figure 3. The conclusions from this experiment are as follows:

TABLE 5-- EFFECTS OF FERTILIZER AND FYM ON YIELDS OF WINTER WHEAT GROWN IN BROADBALK AT ROTHAMSTED
(Yields of Grain, tons/ha, at 85% Dry Matter)

PERIOD	1902-1911 WHEAT GROWN CONTINUOUSLY	1970-1975	1970-1975 WHEAT GROWN IN ROTATION 1st After Fallow	2nd After Fallow	In Rotation After Bean
VARIETY	SQUAREHEADS MASTER	CAPPELLE DESPREZ	CAPPELLE DESPREZ		
TREATMENTS					
None	0.80	1.70	3.13	1.40	2.67
FYM	2.62	5.80	6.48	5.88	6.76
PKNaMg	1.00	2.09	3.76	1.58	3.16
N_1PKNaMg	1.58	3.99	4.88	3.76	5.36
N_2PKNaMg	2.28	5.23	5.16	5.35	6.19
N_3PKNaMg	2.76	5.47	4.98	5.85	5.78
N_4PKNaMg	-	5.48	4.97	5.92	5.60

FYM is applied annually at 35 t/ha, N_1, N_2, N_3, N_4 are 48, 96, 144, and 192 KgN/ha. Annual rates of P, K, Na, Mg are 32, 90, 15, and 11 Kg/ha.

1. The yield in the untreated plot decreased gradually.

2. The yield in the other plots increased every year.

3. At the start of the experiment, the highest yield was obtained in the chemical fertilizer plot.

4. After about 15 years, the yield in the combination plot and then the organic matter plot outyielded that of the chemical fertilizer plot.

5. Finally, the yield in the combination plot was the best.

Gradual decrease of the yield in the untreated plot indicates the decrease in soil fertility. The yearly increase of the yield in the chemical fertilizer plot is caused by the increase in soil fertility, as discussed earlier. Yield increase in the organic matter plot also depended on the increase in soil fertility, but it is clear that it takes more than 20 years until the effect of organic matter appears. Finally, the highest yield found in the combination plot is caused by the acceleration of early growth due to mineral nitrogen and the maintenance of nutrient conditions at the middle and later stage of the rice plant by the organic nitrogen and nitrogen accumulated in the soil.

It should be pointed out, as Olson (1972) stated from the long-term results of the Broadbalk plots of Rothamsted and the Askov field in Denmark, that extended fertilizer use never results in sterile and unproductive soil.

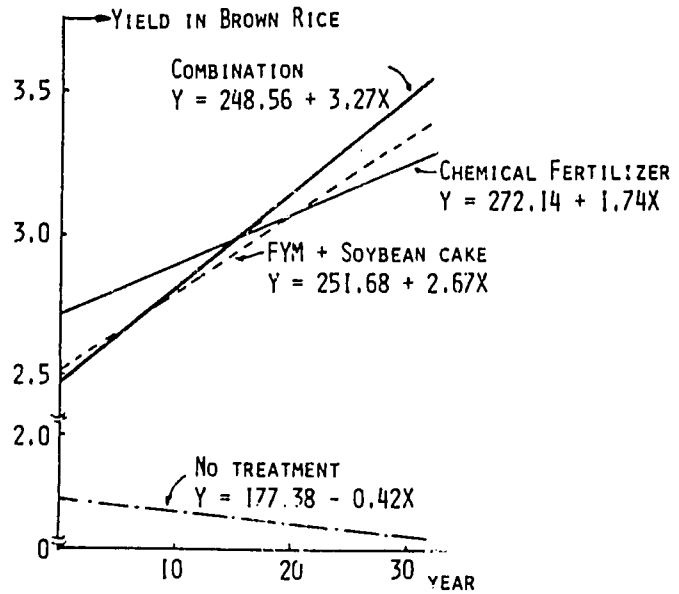

FIG. 3. THE EFFECT OF LONG TERM FERTILIZATION ON THE YIELD OF BROWN RICE AT KONOSU, JAPAN

OTHER UNKNOWN FACTORS

There are many reports that some kinds of chemical compounds in farmyard manure, plant residues, and humus accelerate plant growth, especially the elongation of roots, and gives the plants resistance against cold weather and drought. However, the explanation of these findings is not always complete. There should be further study to see whether these materials will have any effect on controlling crop yield. Continuous application of organic manure increases the activity of soil microorganisms, protozoa, and other organisms and accelerates their multiplication (Russel, 1973). Nitrogen fixation may be increased by the multiplication of heterotrophic nitrogen-fixing bacteria, while heavy use of nitrogen fertilizer is known to be inimical to the activity of symbiotic N-fixing organisms such as Rhizobium sp.

Multiplication of earthworms and other small organisms may bring an improvement in the physical condition of the soil. It is said that the size and number of earthworms invariably increase as soils are brought from a low to a high level of fertility through effective fertilization (Olson, 1972).

Enough fermented farmyard manure indicates a high ratio of bacteria to fungi, that is, B/F ratio. As the infectious diseases of soil are inhibited by soil bacteria, the application of farmyard manure may control

the plant diseases (Katoh and Suzuki, 1977). Evolved CO_2 due to the decomposition of organic matter increased the concentration of CO_2 in the crop canopy and may accelerate the photosynthesis. These are all possible; however, there are not enough data to conclude whether or not these phenomena actually affect the crop yield.

THE CHOICE BETWEEN ORGANIC MANURE AND CHEMICAL FERTILIZER

The decrease of organic manure application in developed countries and less application of organic manure in the tropical zone are supposed to be caused by socio-economic problems. Under these circumstances there are many opinions as to whether organic fertilizer should be used or replaced completely by chemical fertilizers. It seems to depend upon the expected yield, on the kind of crops and their varieties, and on environmental conditions. As already mentioned, organic manure out-yielded chemical fertilizer when supplied over the long term. However, even after 100 years of continuous application there was never any soil damage, even in upland soils where it might easily occur. This might be due to the effect of chemical fertilizer on the increase of stump and root residue which contributes to the maintenance of a sufficient level of soil fertility.

Cooke (1977) concluded from the results of Rothamsted's long-term experiment that soil organic matter will be maintained at a sufficiently high level by crop residues when adequate fertilizer is used. Farmers should not take special action to add extra organic matter if it will lessen their profit; and if making manure and growing leys is part of a successful system, these practices should continue. Further, he states that the large gains from organic treatment in the work described are sufficient to justify the return to the soil of all organic wastes produced on the farm. Straw and other crop wastes should be ploughed in, not burned, and animal manures should be used efficiently on the land and not be treated as sewage or be dried and burned as fuel.

It is a reasonable opinion that in order to save energy and resources it is important to find a technical and economical way to recycle all crop residues and animal wastes in the field. Further studies are necessary, since there is very little data about the maintenance of soil fertility in the tropical zone.

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ENVIRONMENTAL PROBLEMS OF INTENSIVE FERTILIZER USE

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ABSTRACT

Intensive use of fertilizers raises some concerns about water and air quality. Soluble P concentrations in runoff may increase enough to cause eutrophication of surface water. Nitrate N concentrations in drainage water may increase enough to present a hazard in drinking water. Nitrous oxide evolution from fertilized soils may increase enough to endanger the stratospheric ozone layer. These concerns should encourage management practices that maximize recovery of fertilizer nutrients in harvested plant material.

The environmental benefits of fertilizer use are not often recognized. Fertilizers may reduce runoff and erosion by increasing crop cover. By increasing production on some land, less suitable land can be removed from cultivation, which will reduce erosion and the need for fertilizers and pesticides on this land.

INTRODUCTION

Concern about the effects of nitrogen and phosphorus on water quality has focused attention on the contribution of fertilizers to this environmental problem. Water quality is not the only, and perhaps not the most important, environmental problem associated with intensive fertilizer use. Other real or potential problems include those associated with fertilizer manufacture, increased soil acidity, nutrient imbalances, accumulation of fertilizer contaminants in soils, and increased stratospheric nitrous oxide content.

There are also substantial environmental benefits from intensive fertilizer use. Production per unit area is increased with fertilizers. Land not suited for cultivation can be kept in grass or forest, which reduces erosion losses and the costs of cultivating extensive areas. In addition, the increased plant cover that is possible with proper use of fertilizers can reduce soil erosion from the cultivated area.

This review is a summary of knowledge of the environmental effects of intensive fertilizer use. The review of these effects will be limited to water and air quality, since soil quality is being reviewed separately at this workshop. The critical gaps in our knowledge will be pointed out, together with what research is needed to fill those gaps.

For a clearer understanding of the following discussion, intensive fertilizer use is defined to include cropping systems in which at least one plant nutrient is supplied at an amount that equals or exceeds that

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removed in crops. This definition emphasizes the importance of crop yields and all of the interacting factors that contribute to crop yields in proper fertilizer use.

WATER QUALITY

Fertilizer elements carried in agricultural runoff or drainage can impair water quality in two major ways. These are eutrophication of surface water and nitrate contamination of ground water. Often, it is not possible to tell how much impairment is due to fertilizers, and how much to other causes.

Eutrophication (excess fertility) of surface water increases the growth of undesirable algae and aquatic weeds, leading to problems with using the water for fisheries, recreation, industry, or drinking. The nutrients associated with these effects are nitrogen (N) and phosphorus (P). Other elements in fertilizers are usually present in water in non-limiting supply for plant growth.

After exhaustively surveying world literature, Vollenweider (1971) concluded that lake waters containing more than 0.02 mg/l of total P and 0.3 mg/l of bound inorganic N (principally nitrate and ammonium) are in danger of becoming eutrophic.

Phosphorus is usually the limiting element in fresh water. Only part of the P in surface water is available for algae or other plant growth (Golterman, 1975). Most of the dissolved P is readily available. Most of the particulate P is slowly available. The sorption characteristics of suspended sediments greatly influence the concentration of dissolved P (Kunishi and Taylor, 1977).

The bound inorganic N forms of importance in eutrophication are nitrate and ammonium compounds. Sufficient N for algal growth is often supplied in these forms through rainfall, biological N fixation, and other sources. Miller, et al. (1974) found in water samples from 49 widely distributed U.S. lakes, that algal growth was limited by P supply in 35 lakes, by N supply in 8 lakes, and by other factors in 6 lakes. The N limited lakes were mainly eutrophic and located in Western states. The amount of nitrate and ammonium also limits growth in marine waters (Ryther and Dunstan, 1971). Where marine waters or eutrophic fresh waters are affected by runoff or drainage from intensively fertilized areas, these N compounds may be especially important.

Nitrate levels in ground water may make it unacceptable for drinking. However, up to 10 mg of nitrate-N per liter of water are generally considered acceptable (National Academy of Sciences, 1978). This concentration is much higher than that considered critical for eutrophication, as stated above.

Effect of Fertilizers

More information is needed on the effects of intensive fertilizer use on quantities of fertilizer elements lost in runoff and drainage. This information should be obtained under best management of other factors in crop production, including crop varieties, tillage, irrigation and drainage, control of weeds, insects, and diseases. Nutrient

losses at varying fertilizer rates should be studied and response curves established, just as yield response curves have been. Little research has been conducted that satisfactorily answers Viets' (1975) important questions: "How much leakage of nitrate occurs from a system at a satisfactory production level? Can it be reduced without cutting the yield?" These same questions apply to P and other nutrients.

When fertilizers add more nutrients to the soil than are taken up by crops, the excess accumulates in the soil or is removed by other mechanisms. Excess P tends to accumulate (Johnston, 1976), but with time the availability of fertilizer P decreases and resembles that of the native soil P (Barrow, 1974). The organic N content of most intensively fertilized soils changes very little (Allison, 1966; Johnston, 1976) and excess N tends to be removed by leaching or denitrification. However, in dry or even moderately dry soils, leaching and denitrification often do not remove the excess N, which then accumulates in the soil or subsoil as nitrate (Jolley and Pierre, 1977 ; MacGregor, et al., 1974; Adriano, et al., 1972a).

Thus, intensive fertilizer use may affect the amounts of P or N lost in runoff or drainage in three principal ways: (1) by increasing total P content of eroded soil material, (2) by increasing solubility of P adsorbed on eroded soil material, and (3) by increasing nitrate concentrations in drainage water.

Increased Total P

The accumulation of total P in fertilized soils has been studied infrequently because a more important consideration for crop production is the effect of continued P fertilization on the amount of plant available P in the soil. However, Kao and Blanchar (1973) showed that 82 years of moderate P fertilization in Missouri increased plow-layer total P concentration to 700 mg/kg as compared with 418 mg/kg in a similar unfertilized soil. Unpublished data of Olness from our laboratory showed that a heavily fertilized potato soil from Maine contained 1330 mg/kg of total P in the plow layer as compared with 450 mg/kg in similar virgin soil. Thus, intensive fertilization can easily double or triple the total P content of surface soil, and hence of eroded soil material that is carried in runoff.

Increased Soluble P

Increased solubility of adsorbed P resulting from fertilization is important for water quality, just as it is for crop production. If two soils, one low in P fertility and one high in P fertility are suspended in a solution containing 0.1 mg/l of phosphate-P, the low P soil may remove P from solution and the high P soil may add P to solution. Kunishi and Taylor (1977) found that subsoil sediment from Pennsylvania removed P from solution at concentrations as low as 0.02 mg/l. Unfertilized topsoil removed P at 0.1 mg/l, whereas fertilized topsoil added P at 0.2 mg/l. They concluded that the soil materials suspended in runoff water would control the concentrations of soluble P.

Very few experiments have been reported in which soluble P levels in field runoff have been related to rates of P fertilization. Three

such experiments are summarized in Table 1. Rümkens and Nelson's (1974) experiment was conducted on small plots with five simulated rainstorms over a five-month period. Fertilizers were spread uniformly on the plot surface. The plots were then disked three times and protected from natural rainfall. Concentrations of phosphate-P in the runoff remained nearly constant during the experiment. The other two studies summarized in Table 1 were conducted on 5 to 33 ha watersheds and the soils were naturally somewhat variable. The results of Menzel, et al. (1978) could have been affected by pH and cropping practices, as well as by fertilization. Although Alberts, et al. (1978) did not specify pH values, those of the soils in their study typically range from 6.0 to 7.5. Unfortunately, the range of soil pH values in these experiments is very narrow. With more acid soils, we would expect lower concentrations of soluble P and less effect from fertilization.

TABLE 1-- DISSOLVED PHOSPHATE-P CONCENTRATION IN RUNOFF AS AFFECTED BY FERTILIZER P APPLICATIONS AND SOIL TYPE

Soil Type	pH	Fertilizer P Kg/ha-yr	Runoff P mg/l	Source
Typic Hapludalfs	7.0	0	0.07	Rümkens and Nelson (1974)
		56	0.24	
		113	0.44	
Pachic Argiustolls and	6.6-6.9	6.5 (wheat)	0.28	Menzel, et al. (1978)
Pachic Haplustolls	7.0-7.2	25 (cotton)	0.72	
Typic Hapludolls	--	39	0.14	Alberts, et al. (1978)
		97	0.23	

Tillage methods greatly affect the amounts of nutrients dissolved in runoff. Rümkens, et al. (1973) found that as compared with conventional tillage, reduced tillage methods for corn planting decreased soil losses in runoff 5 to 10 percent and increased the dissolved N and P concentrations about 100 and 1,000 times, respectively. From applying 170 kg/ha N as ammonium nitrate, maximum concentrations in the first runoff were 51 mg/l of ammonium-N and 72 mg/l of nitrate N. From applying 56 kg/ha P, the maximum phosphate P concentration was 17 mg/l. These maximum concentrations were measured at the edge of small (7.9 x 10.7 meters) plots at the time of the first runoff, and most of the

fertilizer was on the soil surface. These results illustrate the importance of incorporating fertilizers into the soil to reduce nutrient movement in runoff.

Concentrations of phosphate-P in subsurface soil drainage are usually below 0.05 mg/l, and are only slightly related to P fertilization in mineral soils (Viets, 1975). However, Miller (1979) found average phosphate-P concentrations as high as 18 mg/l for seasonal drainage from intensively fertilized organic soils in Ontario. Concentrations as high as 10 mg/l were found in drainage from similar soils in New York (Duxbury and Peverly, 1978).

Takamura, et al. (1977) measured the loss of P and N from paddy rice fields in Japan as affected by fertilization. Table 2 shows the fertilizers added and estimated fertilizer losses for poorly-drained, moderately-drained, and well-drained paddies. Differences between fertilized and nonfertilized paddies were used to estimate the losses shown in Table 2. As might be expected, surface flow accounted for most of the fertilizer loss from poorly-drained paddies, and percolation for most of the loss from well-drained paddies. Phosphorus losses in percolation were very low, and P loss in surface flow was less than 2 percent of that applied. The maximum N losses in surface flow and percolation were 17 and 15 percent, respectively, of that applied. Takamura, et al. (1977) presented water balance data that permitted the average annual nutrient concentrations to be calculated. For surface flow from the poorly-drained paddy, the total P concentrations were 0.52 and 0.03 mg/l with and without fertilizer, respectively. The corresponding total N concentrations were 4.6 and 1.5 mg/l. In percolation from the well-drained paddy, total N concentrations were 2.0 and 0.6 mg/l.

TABLE 2-- ADDITIONS AND ESTIMATED LOSSES OF FERTILIZER NUTRIENTS (kg/ha) FROM RICE PADDIES (FROM TAKAMURA, 1977)

	Poorly-drained paddy		Moderately-drained paddy		Well-drained paddy	
	N	P	N	P	N	P
Nutrients added	68.9	96.0	141.0	67.5	120.5	33.1
Loss in surface flow	11.6	1.8	6.6	0.2	2.9	0.0
Loss in percolation	2.2	0.0	1.8	0.1	17.8	0.0

Increased Nitrate

Concentrations of mineral N in runoff have been measured in two watershed experiments in which corn was grown at various rates of N fertilization. In Iowa, with a normal rate of 168 kg N/ha and an excessive rate of 448 kg N/ha, the average concentrations of mineral N (nitrate-N plus ammonium-N) were 2.5 and 3.4 mg/l, respectively (Alberts,

et al., 1978). In Missouri, with annual N applications ranging from 15 to 348 kg/ha, the mineral N concentrations in runoff increased in proportion to applied N (Smith, et al., 1974). However, the average N concentration observed with each fertilizer rate varied in different years. With 15 kg/ha N, the average annual concentration ranged from 1.4 to 7.2 mg/l, and with 348 kg/ha it ranged from 8.9 to 40.2 mg/l. The differences between years were apparently caused by different amounts of runoff and different timing of storm events in relation to the times of fertilizer application. In general, less than 10 percent of the fertilizer N was lost in runoff.

In several cases, accumulations of nitrate in soil profiles have resulted from excessive applications of N in fertilizer or manure (Adriano, et al., 1972a, 1972b; Jolley and Pierre, 1977; MacGregor, et al., 1974). Some of these investigations showed that more fertilizer N accumulated within the soil profile than was harvested in crops. For example, Figure 1 shows the results that Jolley and Pierre (1977) obtained after 17 years of fertilizer application on corn in northwestern Iowa. In this experiment, average yield (4,615 kg/ha) was highest with 56 kg N/ha. However, in the last two years of the experiment, with more favorable rainfall, yield (7,543 kg/ha) was highest with 112 kg N/ha. The nitrate recovered from the soil was found within the top 2.7 m, with the largest amount recovered between the 1.2- and 1.5-m profile depth. These data indicated that no nitrate had leached through the soil, so they considered the unrecovered N as denitrified.

The concentration of nitrate in drainage water depends on the amount of nitrate in the soil and the amount of water moving through it. Fried, et al. (1976) and Hebert (1977) proposed simplified mass balance calculations for predicting the long-term contribution of cropping systems to nitrate movement into groundwater. Their simplification assumes that a cropping system over time approaches a steady state, in which the total soil N remains constant and N inputs to the system (fertilizers, manure, irrigation water, rainfall, and biological fixation) equal N outputs (plant harvest, leaching, denitrification, erosion, runoff, and ammonia volatilization).

By combining the N balance and water balance calculations, Adriano, et al. (1972a, 1972b) predicted concentrations of nitrate-N in soil solutions percolating to groundwater. If present practices of fertilization and irrigation for vegetable production are continued in this area of southern California, the concentrations of nitrate-N are predicted to range from 20 to 40 mg/l. Similar calculations can be made for humid regions. For example, on Long Island, New York, about 100 kg/ha more N is applied annually in potato production than is removed in the crop (Bouldin and Selleck, 1977). If this amount of N were dissolved in the amount of water recharged annually to groundwater (55 cm), the predicted nitrate-N concentration would be 18 mg/l. This corresponds closely to concentrations found in shallow groundwater under potato fields.

Jansson (1975/76) demonstrated the interacting effects of fertilizer rates, crop yield, and runoff volume on N transport to Lake Mälaren in southern Sweden. The average application rate of fertilizer N on arable land, mainly small grains, increased from 45 mg/ha in 1964 to 81 kg/ha

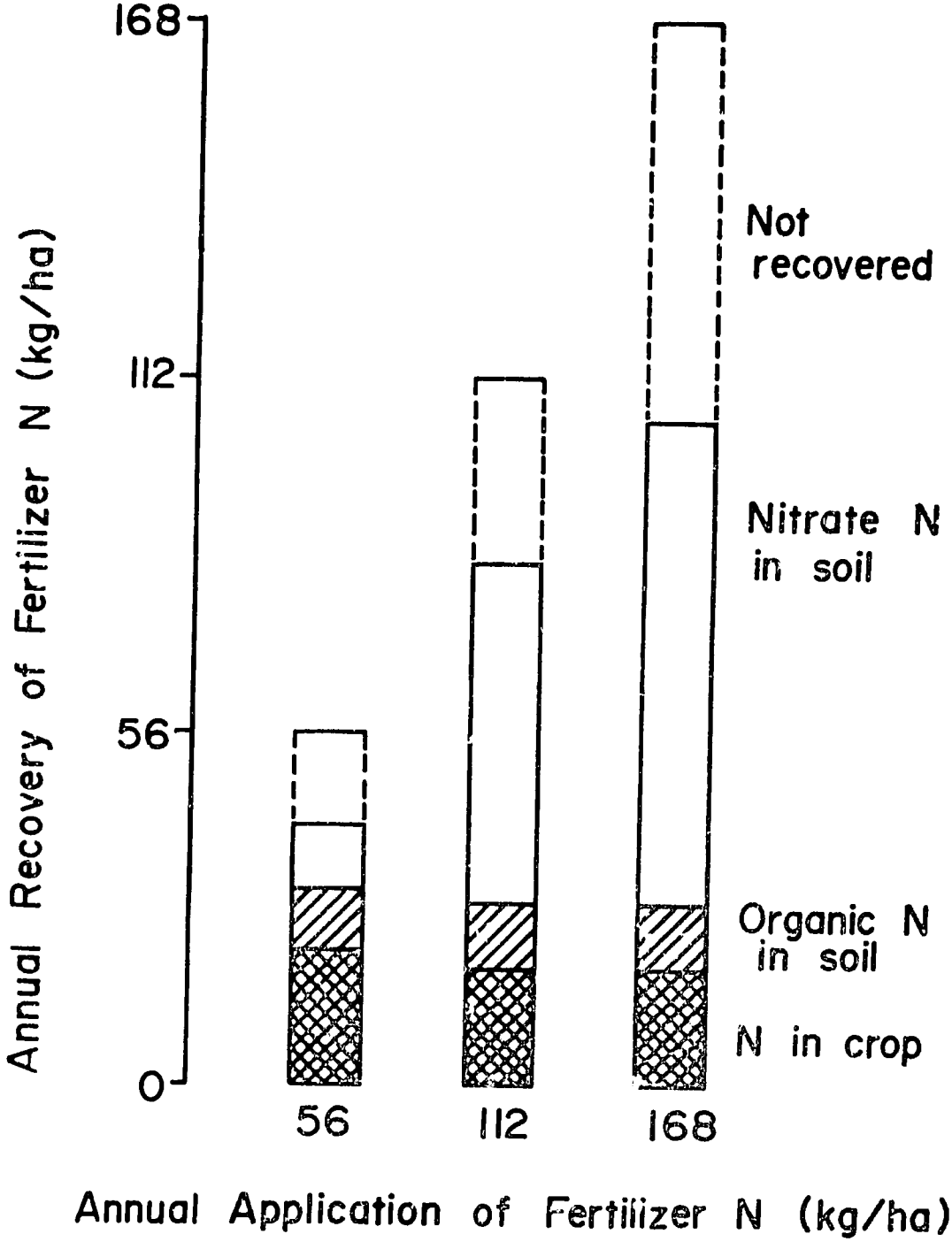

Figure 1. Annual recovery of nitrogen forms from 17 years of fertilizer applications on continuous corn in northwest Iowa (Jolley and Pierre, 1977).

in 1973. Average yields ranged from 1,860 to 3,180 kg/ha. By regression analysis, Jansson found that a 1 percent increase in fertilizer-yield ratio led to an increase of 1.7 percent in N discharge. A 1 percent increase in runoff volume increased N discharge by only 0.8 percent.

These calculations illustrate the need to maximize recovery of fertilizer nutrients in harvested plant material. By so doing, N and P losses to the environment can be minimized.

AIR QUALITY

Only within the last decade, concern has emerged about the effect of N fertilization on air quality. Possibly more nitrous oxide has evolved from fertilized soils than from unfertilized soils, and has diffused into the stratosphere where it can deplete the layer of ozone that protects the earth's surface from excessive solar ultraviolet radiations.

The amount of nitrous oxide evolved from soils is still uncertain. Nitrous oxide may be formed in both nitrification and denitrification (NAS, 1978). Blackmer and Bremner (1978) reported that increasing amounts of nitrate in the soil resulted in an increasing ratio of nitrous oxide to N_2 gas in the denitrification products. At very high concentrations, above 500 mg of nitrate-N per kg of soil, most of the evolved gas was nitrous oxide. Worldwide concentrations of nitrous oxide in the atmosphere were recently determined to be 300 to 330 ppb (v/v) (NAS, 1978), which are 20 to 30 percent higher than concentrations listed earlier. If this represents a real increase due to human activities, it could result from increased combustion of fossil fuels, as well as from increased fertilizer use.

Although nitrous oxide is quite stable in the troposphere, it reacts photochemically with ozone in the stratosphere. Calculations based on the most recent measurements of several competing reaction rates (NAS, 1978) predict a 10 percent decrease in ozone from a 100 percent increase of nitrous oxide in the stratosphere. This is less of an effect than was predicted earlier. The National Academy of Sciences concluded that fertilizers present much less of a hazard to the ozone layer than do fluorocarbons.

Water and air quality are affected by industrial N fixation and mining activities associated with fertilizer production. These activities include not only mining of phosphate rock and potassium minerals, but also the mining of the fossil fuels required for N fixation. Although the effects are substantial, they are restricted to relatively few localities and are beyond the scope of this review.

ENVIRONMENTAL BENEFITS

Some of the environmental benefits of fertilizer use are not widely understood. Fertilizers can increase crop production on land that is best suited for cropping. Viets (1975) pointed out that keeping crop acreage at the minimum essential for food, feed, and fiber production

benefits the environment in several ways. Less irrigation water is needed, which reduces the salt load in irrigation return flows. If production is confined to a smaller acreage, smaller amounts of herbicides and insecticides are needed. Finally, if the more erodible land can be kept in grass or forest, soil erosion is minimized.

Proper use of fertilizers can reduce erosion from cultivated land. Smith, et al. (1974) showed that fertilizer N for corn gave quicker and heavier plant cover that reduced erosion from summer rains in Missouri. Rates of fertilizer N ranging from 89 to 348 kg/ha were about equally effective in reducing soil erosion as compared with a rate of 15 kg/ha of N. Losses of eroded soil were reduced from 0.7 to 0.3 t/ha with no-till cultivation and from 2.4 to 1.6 t/ha with conventional cultivation. Although dissolved N concentrations in runoff were increased, as pointed out above, fertilization reduced losses of dissolved P in runoff and Kjeldahl N on sediment.

Thus, while it is necessary to be aware of environmental problems that may result from intensive fertilizer use and to exercise needed controls, the environmental benefits of intensive fertilizer use are also significant.

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HUMAN NUTRITION AND FERTILIZER NEEDS IN ASIA AND THE PACIFIC

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ABSTRACT

The major nutrition problems in Asia and the Pacific are reviewed. Three-quarters of people in the developing countries of this region failed to reach the recommended level of energy consumption. Protein, iron, and vitamin A deficiencies also constitute public health problems in these countries. In order to cope with the malnutrition problem, the increase in cereal crops production, and promotion of home garden and inland fish culture are especially recommended. A method, explained step-by-step, to estimate N and P_2O_5 requirements for different target years in order to produce enough food for nutritional improvement of people is introduced.

It is estimated that in order to meet the nutrition needs of people by the year 2000, five to six times of fertilizer consumption is needed. With some supplementary and complementary measures such as recycling of organic materials, better management of fertilizer, irrigation and crop variety improvement, inclusion of legume and green manure crops in the farming system, better pest control, and reducing postharvest losses, some 50 percent of the fertilizer needs for additional cereal production could be saved. The adjusted total fertilizer need will be three to four times the current consumption.

Some problems in preparing fertilizer requirement estimates are discussed and further research needs identified.

INTRODUCTION

Objective of this Paper

This paper attempts to estimate, country by country, the fertilizer needs in Asia and the Pacific based on food and nutritional requirements of the people. Agronomic, economic, institutional and environmental problems, though raised, are not considered in the calculation.

Human nutrition is an important dimension in determining the fertilizer needs of a country. It is hoped that the facts and problems might be presented to interested scientists and policymakers for their consideration in setting up priorities for future research and for development planning.

Coverage of this Paper

Countries covered in this study are: China, Japan, Republic of Korea, and Taiwan in East Asia; Burma, Cambodia, Indonesia, Laos,

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Malaysia, Philippines, Thailand, and Vietnam in Southeast Asia; Afghanistan, Bangladesh, India, Iran, Nepal, Pakistan, and Sri Lanka in South Asia; Australia, New Zealand, and other oceanic countries in Oceania; and the United States; occupying 46.2 percent of the world's arable land area and containing 60.0 percent of its total population.

The target years covered by the paper are 1980, 1990, and 2000, with 1975 as base year.

Magnitude of the Nutritional Problems in this Region

Many nutrition surveys were conducted in Asia and the Pacific in the past years. To sum up the results, energy, protein, iron, and vitamin A deficiencies are major public health problems in most countries. Deficiencies in iodine, thiamine, and ascorbic acid are either regional or seasonal. More than one-third of the people in rural areas and among the urban poor, particularly pregrant women, nursing mothers, and infants and young children, suffer from malnutrition in one form or another.

A food balance sheet, although having many limitations, is a most practical instrument to assess the adequacy of the food supply at a national level and to provide basic data for planning agricultural production and formulating food policy. The Food and Agriculture Organization of the United Nations (FAO) periodically publishes a Food Balance Sheet Series for different countries if their country statistics are adequate. The latest information was the 1972-1974 average. It revealed that about 75 percent of the people in the developing countries of Asia and the Pacific failed to reach the recommended level of energy consumption, while the problem of protein was generally less serious. When energy in cereal-based diet is sufficient, protein intake usually is also sufficient. Therefore, in this paper only the energy requirement is used to measure nutritional needs of people.

It may be mentioned here that the recommended level of food consumption is much higher than the physiological needs of an individual. People who consume less food than the recommended allowance do not necessarily suffer from malnutrition.

From an economic point of view, cereal crop is the preferred source of energy as well as protein, although starchy roots and tubers sometimes produce more energy than cereal crops in a unit area. Dark green leafy vegetables are very rich in iron, vitamin A, and ascorbic acid--the nutrients commonly deficient in diets--as well as some energy and protein. Fish supplies quality protein with high complementary value to cereal protein.

Fertilizer as a Major Determinant in Food Production

Among different inputs for food production such as irrigation, pest control, and varietal improvement, fertilizer is a far more important factor in determining the volume of cereal production. Of course, it is also essential to other crops, including vegetables.

Experience in Israel, Taiwan, and some other places indicated that fertilizer is also an essential component in the profitable management of fish ponds.

Hence, the calculation of overall fertilizer needs for nutritional requirements of people should include the needs for cereal crops, vegetables, and inland fish culture.

CALCULATION OF FOOD AND FERTILIZER NEEDS

Cereal Crops

Steps of calculation

Step 1: Establishment of food consumption level. The FAO and World Health Organization had a series of technical meetings and publications on the requirements of energy, protein, and other essential nutrients. The requirements are affected by age group composition, body weight, level of activity, and physiological condition of people. Mention must be made that based on recommended formulas, the calculated energy requirement is the actual physiological need of people, while for the protein requirement, it is the average safe level of intake, with no allowance for kitchen and plate waste, and for postharvest loss of food.

Kitchen and plate waste differ greatly among different cultural, social, and economic groups. A ten percent allowance (FAO, 1973) should be given. A conservative estimate on postharvest loss due to moisture, heat, rodents, insects, loss during transportation and distribution, and natural calamity is ten percent for grain crops and 20 percent for starchy roots and tubers (National Academy of Sciences, 1978). In other words, for food allocation at a retail level, a ten percent allowance should be added to energy and protein requirements at actual intake level. For planning national food supply, another ten percent should be added to give allowance for postharvest and other losses before food reaches the kitchen.

In compiling food balance sheets, some postharvest losses are being considered, usually at five percent, not sufficient to cover all losses which actually occurred. Thus the food availability as assessed through food balance sheets is about halfway between the food allocation at a retail level and the recommended level for planning national food supply.

With the above background, the nutrition requirements for people in Asia and the Pacific at different levels are estimated as shown in Table 1.

In the meantime, we must recognize the fact that it is difficult to pull down the level of food intake of people who are already above the recommended level. Hopefully, they could maintain the status quo without further increase in consumption.

TABLE 1-- ESTIMATED DAILY PER CAPITA CALORIE AND PROTEIN REQUIREMENT OF PEOPLE IN ASIA AND THE P...

Region	Physiological requirement			Food allocation at retail level		Recommended level at FBS		Recommended level for national food planning	
	Calorie	Protein, g Ideal	Protein, g Dietary (1)	Calorie	Protein, g	Calorie	Prot. g	Calorie	Prot. g
East Asia									
Adult male: 63 kg Adult female: 53 kg	2,250	30	50	2,475	55	2,600	58	2,700	61
Southeast Asia									
Adult male: 53 kg Adult female: 46 kg	1,990	28	47	2,189	52	2,300	54	2,400	57
South Asia									
Adult male: 62 kg Adult female: 49 kg	2,150	29	48	2,365	53	2,500	56	2,600	58
Oceania (2)									
Adult male: 63 kg Adult female: 54 kg	2,250	30	50	2,475	55	2,600	58	2,700	61
Australia, New Zealand, and U.S.									
Adult male: 65 kg Adult female: 55 kg	2,320	31	52	2,552	57	2,700	60	2,800	63

Footnotes: (1) Assuming the chemical score of dietary protein is 60. For developed countries it is, in fact, much higher.

(2) Not including Australia and New Zealand.

Step 2: Estimation of population in different target years. The population projection, medium variant, made in 1977 by the Department of Economic and Social Affairs, United Nations (1977), will be used to calculate food and nutrition requirements for different countries.

Step 3: Calculation of total calorie requirement. This is the product of the recommended level of energy requirement and projected population for different years, multiplied by 365 (days).

Step 4: Calculation of calories from vegetal origin. People's food comes from two sources, namely vegetal (cereal, starchy roots and tubers, sugar, nuts and beans, fruits and vegetables, and oil) and animal (meat, egg, milk, fish, and fats).

In the developing countries, people's calorie intake comes mostly from food of vegetal origin. As an average, 91.8 percent of calories in Asia (1972-1974) came from vegetal foods, ranging from 97.6 percent in Indonesia to 81.5 percent in Japan (FAO, 1978). Out of the calories from vegetal origin, some 70 percent came from cereals. In fact, the production of meat, egg, and to a lesser degree milk and pond fish also

depends on cereals and their byproducts. Hence, the increase in cereal production is a practical approach to improve energy and protein intake of people.

Calories from vegetal origin are the product of total calorie requirement and percentage of calories from vegetal origin in different countries, as revealed in their food balance sheets.

Step 5: Calculation of cereal equivalent. For each kg of milled cereal grain, there are some 3,500 Calories and 80 grams of protein. A common mistake people often make is to convert the weight of the cereal crop as harvested directly into energy and protein, using the above conversion ratio, giving no consideration to the inedible portions (husk and bran) and other uses (such as seed and feed), as well as losses which occur during the course of production to consumption.

The pattern of disposal of cereal crops varies greatly among different regions and countries. For instance, one-third of the barley produced in China is used to feed animals (FAO, 1971), while only ten percent of the barley produced in India is for animal feed. Also, the extraction rate of cereals is different. The wheat extraction rate in India is 90 percent, while that in China is only 75 percent.

To convert calories from vegetal origin into the cereal equivalent, three factors will be considered, namely:

1. The amount of individual cereal crop for human consumption in percentage of its production;

2. The relative importance of different cereals in local diet; and

3. The nutrition value of individual cereal crops.

Based on the information in the Food Balance Sheet, 1964-1966 average, and on a recent FAO food composition table (1972), the following figures are used for conversion:

Region	Food value for human consumption of local cereals at production			
	100 g		1 metric ton	
	Calorie	Protein, g	Calorie	Protein, g
East Asia (China)	231	4.8	231×10^4	4.8×10^4
Southeast Asia (Indonesia)	244	4.9	244×10^4	4.9×10^4
South Asia (India)	280	6.2	280×10^4	6.2×10^4

Step 6: Base-year cereal production. The 1977 FAO Production Yearbook gives the total cereal production of different countries in 1976. This is the latest available information and will be used as base-year cereal production for different countries.

The supply of cereal in a country depends on domestic production and possible cereal import and export. For most countries in Asia, domestic production supplies over 90 percent of the total requirement. For instance, India and Bangladesh imported only 5.3 percent (1965-1975) (Raychauduri, 1976) and 7.3 percent (1967-1977) (Institute of Nutrition and Food Science, 1977), respectively in the past ten-year period. The achievement of self-sufficiency in cereal production is the priority goal of most developing countries in Asia. It is assumed that cereal requirements will be fulfilled through domestic production throughout the target years in most Asian countries.

However, Japan and Thailand present two exceptions. Japan's domestic cereal production in 1976 represented only 43.46 percent of the total requirement (FAO, 1978). This percentage is assumed to be continued in the years to come. Thailand exported 5.3 million tons of rice (paddy equivalent) in 1976. It is assumed that this amount of rice will be continuously exported in future years.

Step 7: Calculation of additional cereal requirement. This is the difference between the base-year cereal production or, in the case of Japan and Thailand, cereal supply, and the estimated cereal requirement for different years. This additional cereal requirement is the basis for calculating fertilizer requirements for different years.

Step 8: Calculation of nitrogenous fertilizer requirement. Among different plant nutrients, N is most sensitive to cereal production. Possibly, among other factors, the soil in tropical and subtropical Asia is extremely low in nitrogen content.

In considering the N-responsive curves in different countries including the reports from India (Raychauduri, 1976) and Egypt (Hamissa, 1979) and the information obtained through personal communication with Dr. Yoshio Yamada of Japan and Dr. Young-Kun Shim of Korea, the following N-efficiency ratio for additional cereal production is arbitrarily made for present calculations:

Japan:	1 kg N = 5 kg cereal
Korea and Taiwan:	1 kg N = 7 kg cereal
Other Asian countries:	1 kg N = 10 kg cereal

The requirement of N for production of additional cereal is obtained by dividing the additional cereal requirement for different years with the above conversion ratio. The total N requirement is the sum of the base-year N consumption plus the amount of N required for production of additional cereal.

Step 9: Calculation of phosphorus fertilizer requirement. It is also arbitrarily assumed that the application ratios between N and P_2O_5 for different countries are as follows:

Japan:	1:1 or 100% N
Other East Asia countries:	5:3 or 60% N
Southeast Asia:	5:2 or 40% N
South Asia:	5:3 or 60% N

The calculation method is the same as described for Step 8.

Step 10: Calculation of fertilizer requirement for Oceania and the United States. Because of the fact that the food consumption level of their people has already far exceeded their nutritional needs, fertilizer requirements for Australia, New Zealand, and the United States will be calculated according to per capita fertilizer consumption rate of the base year multiplied by total populations in different years.

For other countries of Oceania, the fertilizer application rate of South Asian countries for different years will be used as the basis of calculation, as their data on base-year fertilizer consumption are not included in the FAO Production Yearbook. Statistical information on arable land area, fortunately, is available.

Total fertilizer requirement for cereal production

The total need for N and P_2O_5 for cereal production for different years is calculated in Table 2.

TABLE 2-- FERTILIZER REQUIREMENT FOR CEREAL PRODUCTION
(Unit: one million tons)

REGION	1975 (Base year) N	1975 P_2O_5	1980 N	1980 P_2O_5	1990 N	1990 P_2O_5	2000 N	2000 P_2O_5
Asia	8.717 (100.0)	3.486 (100.0)	26.186 (300.4)	13.605 (390.3)	50.807 (582.9)	27.378 (785.4)	74.260 (851.9)	40.709 (1,167.8)
Oceania	.196	.954	.225	1.050	.280	1.239	.335	1.420
U. S. A.	7.796	4.077	8.167	4.272	8.988	4.701	9.636	5.040
Total:	16.709 (100.0)	8.517 (100.0)	34.578 (206.9)	18.927 (222.2)	60.075 (359.5)	33.318 (391.2)	84.231 (504.1)	47.169 (553.8)

Step-by-step calculations for China, Indonesia, and India are illustrated in Appendix 1.

Rate of fertilizer application in different years

It is assumed that the area of arable land in the Asia-Pacific region (FAO, 1978) remains constant, as the possible expansion of areas through reclamation and opening of forestry and marginal land might be counterbalanced by the increased use of land area for building houses and other public facilities because of population growth, rapid urbanization, and construction of highways, airports, industrial zones, and recreation facilities.

The rates of fertilizer application for cereal crops in different years are estimated in Table 3.

TABLE 3-- ESTIMATED FERTILIZER APPLICATION RATES FOR CEREAL CROPS (Unit: kg/ha)

	1975		1980		1990		2000	
REGION	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5
Asia	21.1	8.4	63.4	32.9	122.9	66.2	179.7	98.5
	(100.0)	(100.0)	(300.5)	(391.7)	(582.5)	(788.1)	(851.7)	(1,172.6)
Oceania	4.1	20.6	4.9	22.7	6.1	26.8	7.3	26.0
U. S.	41.8	21.9	43.8	22.9	48.2	25.2	51.7	27.0
Weighted Average	25.9	13.2	53.5	29.3	93.0	51.6	130.4	73.0
	(100.0)	(100.0)	(206.9)	(222.2)	(359.5)	(391.2	(504.1)	(553.8)

It is apparent that the rate of fertilizer application, especially toward the end of this century, is extremely high in Asian countries, much beyond the optimal level of application for cereal crops. In order to produce the required amount of cereal, the actual application may be even higher in these countries, as the law of diminishing returns in fertilizer efficiency may set in even before the 1990 level of application.

Home Garden

Rationale

The value of small home gardens to the nutritional improvement of people has been reported (Yang, 1978). A well-kept small garden of 20 square meters (2/1000 hectare), with proper crop selection and rotation, sufficient water supply, and good care can produce enough vegetables with nutritional value in terms of the recommended dietary allowances of a five-member household, two percent of energy, ten percent of protein, one-third of calcium, one-fourth of iron, and 200 percent of vitamin A value and ascorbic acid. In the areas with less favorable soil and climatic conditions, the size of home gardens may need to be increased, say, to 40 square meters.

Because of the fact that their size is small and their produce usually does not enter the market channel, home garden areas are not often included in a country's crop acreage, nor their products in agricultural production reports. Hence, their fertilizer needs should be estimated separately.

Rate of fertilizer application

Based on the experience in Hawaii (University of Hawaii, undated), fertilizer needs for a 40-square meter garden are estimated at 4 kg of general garden fertilizer (10:20:10) for each crop, three crops a year. This is roughly equivalent to 1 kg N, 2 kg P_2O_5 and 1 kg K_2O, assuming part of the nutrients will be supplemented from local organic sources.

Calculation of total fertilizer needs

To calculate the total fertilizer need for home gardens, the following assumptions are made:

1. Because of the need for land space, home gardens will only be in rural areas. Each agricultural household will keep a home garden.

2. The current (1976) ratio of agricultural population against total population (FAO, 1978) will be applied throughout the target years.

3. Each household has five members. Hence, the total number of households in rural areas is obtained by dividing total agricultural population by 5.

4. Fertilizer needs for home gardens are separately estimated for Asia and Oceania countries other than Australia and New Zealand. The latter two countries and the United States have included home garden fertilizers in total fertilizer needs calculated based on per capita fertilizer consumption.

Fertilizer needs for home gardens are estimated as follows:

Unit: 1,000 metric ton

REGION	1980		1990		2000	
	N	P_2O_5	N	P_2O_5	N	P_2O_5
Asia	284.8	571.6	348.7	697.4	412.5	825.0
Oceania	1.0	2.0	1.3	2.6	1.5	3.0
Total	285.8	573.6	350.0	700.0	414.0	828.0

Aquaculture

Background

Facing the fact that ocean fish catch is declining, people are paying increasing interest and attention in recent years to inland fish culture as a measure to increase animal protein availability at an affordable price, to provide income and employment to rural people, and to generate organic fertilizer in farming systems.

Fish culture is highly concentrated in Asia. In a recent study (Bell, 1978), Pillay (1973) calculated finfish aquaculture in 42 countries, including China, at about 2.6 million hectares, with a total production of 3.7 million tons, of which 75 percent of the area and 90 percent of the production were from Asian countries.

FAO's Indicative World Plan for Agricultural Development (1969) considers a five-fold increase in aquaculture production by 1985. Bardach and Rytter (1968) estimated a ten-fold increase by the year 2000. Bardach indicated in a personal discussion that, of the increased production, a 50 percent increase could come from the expansion of fish pond acreage and the other half from the yield improvement through better technology, including intensive fertilizer application.

Rate of fertilizer application

For profitable operation of fish ponds, the application of fertilizers, particularly N and P_2O_5 to raise plankton in water, directly or indirectly for fish food, is being increasingly practiced in many countries. While the amount and frequency of chemical fertilizer application depend on many factors including the kinds, population density, and stage of growth, of fish and the amount of nutrients in water, based on the experience in Israel and elsewhere, the level of application is recommended at 400 kg N and 200 kg P_2O_5 per hectare.* The culture of crustacea, mollusks, and sea weeds requires either no or only negligible amounts of chemical fertilizers.

The FAO Fisheries (Aquaculture) Mission to China, which visited China in 1976, reported (FAO, 1977) "Organic manure is the main fertilizer used in ponds, lakes or reservoirs. No inorganic fertilizers are applied for fish rearing." It is assumed that, while organic manure will continue to be used in pond fish raising in China, chemical fertilizer will be gradually introduced and reach one-third of the recommended level by the year 2000. Other East Asian countries will reach the recommended level by then. Southeast and South Asian countries may reach half the recommended level, or 200 kg N and 100 kg P_2O_5 by 2000.

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* Personal discussion with Dr. John Bardach, Research Associate, Resource Systems Institute, East-West Center.

Calculation of total fertilizer need

Fish pond acreage in Asia is assumed to increase from 2,980,000 hectares in 1975 to 10,120,000 hectares in 2000, or a five-fold increase. The total need of N and P_2O_5 is calculated as follows:

Unit: 1,000 metric tons

	1980	1990	2000
N	75	528	1,887
P_2O_5	38	264	944

It is hoped that by 2000 about five grams of protein per person per day could come from pond fish for rural people in Asia.

Combined Total Fertilizer Need

To combine all the needs for cereal production, home garden, and fish culture, fertilizer requirements would increase tremendously over the base year of 1975, particularly in Asia, as shown in Table 4.

TABLE 4-- COMBINED TOTAL FERTILIZER REQUIREMENT
(Unit: one million ton)

REGION	1975		1980		1990		2000	
	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5
Asia	8.717 (100.0)	3.486 (100.0)	26.546 (304.5)	14.208 (407.6)	51.683 (592.9)	28.339 (812.9)	76.559 (378.3)	42.478 (1,218.5)
Oceania	.196 (100.0)	.954 (100.0)	.226 (115.3)	1.052 (110.3)	.281 (143.4)	1.242 (130.2)	.337 (171.9)	1.423 (149.2)
U. S.	7.795 (100.0)	4.077 (100.0)	8.167 (104.8)	4.272 (104.8)	8.988 (115.3)	4.701 (115.3)	9.636 (123.6)	5.040 (123.6)
Total:	16.708 (100.0)	8.517 (100.0)	34.939 (209.1)	19.532 (229.3)	60.952 (364.8)	34.282 (402.5)	86.532 (517.9)	48.911 (574.6)

As mentioned before, the requirements for Australia, New Zealand, and the United States are calculated according to per capita fertilizer consumption of the base year (1975). If they increase their food export in the future, which appears inevitable, their requirements for fertilizer must be proportionately increased.

Could we have enough raw materials to produce enough fertilizer to meet the calculated need in the next two decades? Could our crop and soil tolerate and be responsive to such a high rate of application? What is the possible environmental impact, not to mention the economic feasibility?

To find out measures to reduce chemical fertilizer need as calculated above yet not sacrificing the nutrition level of people is a real challenge confronting all of us.

POSSIBLE MEASURES TO REDUCE CHEMICAL FERTILIZER NEED

To search for ways and means to reduce the chemical fertilizer requirement, one would immediately think how to reduce food requirements. If we could keep population at zero growth, for instance, fertilizer requirements in the year 2000 would automatically be reduced by 60 percent. Of course, we could also keep people at the current level of food consumption, not raising their nutritional standard, and some 29 percent of the food may be saved toward the end of this century.

In view of the fact that the effort of different countries in population control has already been taken into consideration in the United Nations projection and that the upgrading of human nutrition is the primary objective of development planning of most Asian and Pacific countries, we must find other measures to reduce the chemical fertilizer requirement. Here are some possible alternatives.

Recycle Organic Materials

Organic materials include waste materials of plant, animal, and human origin. Singh (1974) estimated that a total of 48.17 million tons of N, 16.23 million tons of P_2O_5, and 39.05 million tons of K_2O were produced in 1971 through organic waste in the developing countries. This will increase to 60.12, 20.28, and 48.81 million tons, respectively, for the three nutrients in 1980. The developing countries in Asia represent roughly 70 percent of the human and animal population of the developing world and 42 million tons of N equals more than 160 percent of the calculated N requirement. If 20 percent of the organic materials could be recycled, 30 percent requirement of N could be fulfilled.

In fact, it is misleading to make direct comparison between organic manure and chemical fertilizer on the basis of the relative amounts of N, P, and K. Organic matters will be converted in soil into humus which plays an important role in improving the soil's chemical and physical properties and making nutrients more available to plants. Chinese farmers are traditionally experienced in recycling organic matters. Paddy yield in China was 3,546 kgs/hectare (1976) with 30.5 kgs of N application (FAO, 1978), while the average yield in the Philippines was 1,959 kgs of paddy with 34.1 kgs of N. The intensive application of organic manure is one of the contributing factors.

It is hoped that, with good management, 30 percent of both N and P requirements in Asia and the Pacific could be met with the recycling of organic materials.

Fertilizer Efficiency

Many studies indicated that nitrogen efficiency in tropical areas is less than 30 percent. With careful management in fertilizer application, with proper dose, method, and timing, N efficiency ratio could be

significantly increased, say, to 35 to 40 percent. The result of field study in the application of urea super granulate under the I.N.P.U.T.S. project is a good example. Yamada, et al. (1979) reported the amounts of urea with conventional application and urea super granulate with single deep placement required to bring about paddy yield increases as follows:

	Urea	USG	Efficiency: USG/Urea
For one-ton increase	60 kg N	41 kg N	1.46
For two-ton increase	120 kg N	87 kg N	1.38

With systematic research at country and regional levels coupled with intensive extension, a ten percent increase of fertilizer efficiency may be achieved.

Legumes in Cropping System

The leguminous crops, either grain legume or fodder, should be included as an integrated part of the cropping system. Aside from supplying a most valuable protein food for humans and feed for animals which, in turn, also improves human nutrition, the amount of nitrogen left in soil for the next crop could be substantial, ranging from 20 to 65 kg of N per hectare (Singh, 1974), depending on the kind of legume, growth condition, and other factors. In the case of green manure, legume or otherwise,* the supply of nutrients to the soil, in addition to other benefits, could be 89 kg of N per hectare.

With the frequent inclusion of legumes in the cropping system, the chemical fertilizer requirement may be saved at least two percent.

Other Measures to Increase Crop Yield

Irrigation plays a very important role in the increase of fertilizer efficiency. The experience in India (Raychauduri, 1976) found that wheat and millet could have an 80 percent increase in N efficiency and a 94 percent increase in P_2O_5 efficiency through irrigation, shown on next page.

While the increase of irrigated area in Asia as a whole in the past ten years, 1966-1976, is only 7.28 percent (FAO, 1978), some countries, notably India and Thailand, made substantial expansion, at 29.0 and 38.5 percent, respectively. The rate of annual expansion of irrigated area in India was 0.5 percent of the total arable land and that of Thailand was even higher. Assuming that the double cropping system could be

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* Azolla cultivation in the paddy field could produce 52 kg N/ha in 35 days (Rain and Talley, 1978).

	Fertilizer Efficiency in the Additional Production of Local Varieties of Food Grains in kg per kg of Nutrients (at the rate of 22.4 kg per hectare)		
	N	P_2O_5	K_2O
Wheat, unirrigated	7.6 (100.0)	4.2 (100.0)	3.8 (100.0)
Wheat, irrigated	14.1 (185.5)	8.7 (212.2)	5.3 (139.5)
Millet, unirrigated	6.8 (100.0)	5.4 (100.0)	3.7 (100.0)
Millet, irrigated	11.9 (175.0)	9.5 (175.9)	-- (--)

introduced in the irrigated area and that the yield could be increased by 50 percent as against unirrigated land, 1.5 percent of food grain could be increased annually, which, in turn, saves the corresponding percentage of fertilizer requirement.

Native cereal varieties mostly are not efficiently responsive to fertilizer application, and sometimes even have negative effects. In Malaysia, for instance, some native rice would cause heavy lodging and be more susceptible to insects and disease if chemical fertilizer is applied (Chee, 1969). Research and extension of proper varieties with genetic potential to respond to fertilizer with high yield is a prerequisite to promote increased fertilizer application. The expansion of high yielding varieties could make a phenomenal difference in food availability to a country. With a well-organized program, at least 1.5 percent of cereals could be increased through their varietal improvement which, in turn, reduces fertilizer requirement.

Pest (weed, insect, bird, rodent, and disease) control affects greatly crop yield. Crop loss due to pest could range from ten percent to total crop failure. While it is difficult to eradicate all such pests, with a good control program at least five percent more food grain could be produced. It means the saving of five percent fertilizer requirement.

Postharvest Technology

FAO placed an overall postharvest loss in the tropical area at 30 percent, including the perishable crops, (FAO, 1969). Of course, it is not economically feasible to reduce all the losses. Hopefully, part of the loss, say, five percent of cereal production could be prevented. This is reflected in the 1975 Resolution of the United Nations Assembly, committing member countries to reduce postharvest food loss by 50 percent by 1985.

Encouraging farmers to produce food requires motivation and incentive. Price guarantee, credit and input provision, institutional support, and profitable marketing are all essential components in the production system. Only through a well-planned "package deal" could the production targets for different years be achieved. However, this subject is not within the scope of this paper.

Adjustments to Fertilizer Requirement

To sum up, the possible adjustments to estimate fertilizer requirement in relation to the need of human nutrition are as follows:

		In percentage of fertilizer requirement for additional cereal production
		Decrease
1.	Recycling of organic materials	30.0
2.	Fertilizer efficiency improvement	10.0
3.	Nitrogen fixation through legumes and others	2.0
4.	Irrigation and drainage	1.5
5.	Genetic potential development and varietal improvement	1.5
6.	Pest control	5.0
7.	Postharvest technology	5.0
	TOTAL:	50.0

The above adjustments are applicable to the countries in Asia and the Pacific except Australia, New Zealand, and the United States where fertilizer requirement is calculated based on per capita consumption of base year.

Adjusted Rate of Fertilizer Application to Cereal Crops

With the above adjustments, the rate of application to cereal crops in Asia may be estimated in Table 5.

Apparently, Japan's rate of application will be still far above its optimal level of application. Unless there is a breakthrough in the development of the crop's genetic potential, the increasing of cereal imports to meet domestic requirements appears inevitable. The same may be true for Korea and Taiwan, although less serious than for Japan.

TABLE 5-- ADJUSTED FERTILIZER APPLICATION RATE FOR CEREAL CROPS
(Unit: kg/ha)

	1975		1980		1990		2000	
	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5
Asia								
East Asia								
Japan	156.5 (100.0)	156.7 (100.0)	287.4 (183.6)	287.7 (183.6)	349.7 (223.5)	349.9 (223.3)	398.2 (254.4)	398.4 (254.2)
Other East Asia	35.1 (100.0)	12.7 (100.0)	46.3 (131.9)	23.6 (185.8)	75.3 (214.5)	41.0 (322.8)	98.7 (281.2)	55.1 (433.9)
Southeast Asia	14.7 (100.0)	6.4 (100.0)	33.6 (228.6)	13.7 (214.1)	84.3 (573.5)	34.3 (535.9)	118.9 (808.3)	47.8 (746.9)
South Asia	11.7 (100.0)	3.4 (100.0)	20.2 (172.6)	10.4 (305.4)	45.1 (385.5)	25.2 (741.2)	74.9 (640.2)	43.1 (1267.6)
Asia as a Whole	21.3 (100.0)	8.4 (100.0)	33.2 (155.9)	18.0 (214.3)	63.3 (297.2)	34.9 (415.5)	92.0 (431.9)	51.4 (611.9)

Fortunately, the Southeast and South Asian countries are still within the limit of optimal fertilizer application of cereal crops. The Oceania countries other than Australia and New Zealand are assumed to have fertilizer application rates that are the same as those for South Asia.

Emphasis should be made here that this deduction of chemical fertilizer requirements shows only the direction and possibility. It requires a desperate combined effort in research, extension, efficient farm management, favorable marketing arrangements, improved rural institutions, and motivation and willingness of farmers themselves, supported by the government's determination and resource allocation. Otherwise, the scope of the food problem would be totally beyond control before the turn of this century, resulting in increased hunger and malnutrition in most countries of the Asia-Pacific region.

Adjusted Total Fertilizer Requirement

The adjusted total fertilizer requirement, including cereal production, home gardens, and aquaculture, for Asia and the Pacific in different target years is calculated in Table 6.

It must be emphasized here that the above fertilizer requirements for different years are the very minimum if the nutritional status of people is to be improved to an acceptable level. Of course, even at

TABLE 6-- ADJUSTED TOTAL CHEMICAL FERTILIZER REQUIREMENT
(Unit: one million tons)

	1975 (Base-year)		1980		1990		2000	
	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5
Asia								
East Asia	5.305	2.369	7.511	4.617	11.783	7.264	15.498	9.599
South East Asia	.837	.364	1.969	.877	5.004	2.147	7.431	3.165
South Asia	2.575	.753	4.608	2.543	10.265	5.972	17.380	10.240
Asia Total	8.717 (100.0)	3.486 (100.0)	14.088 (161.6)	8.037 (230.6)	27.052 (310.3)	15.383 (441.3)	40.309 (462.4)	23.004 (659.9)
Oceania Total	.196 (100.0)	.954 (100.0)	.219 (111.7)	1.048 (109.9)	.264 (134.2)	1.233 (129.2)	.309 (157.7)	1.407 (147.5)
U. S.	7.795 (100.0)	4.077 (100.0)	8.167 (104.8)	4.272 (104.8)	8.988 (115.3)	4.701 (115.3)	9.636 (123.6)	5.040 (123.6)
Total:	16.708 (100.0)	8.517 (100.0)	22.474 (134.5)	13.357 (156.8)	36.304 (217.3)	21.317 (250.3)	50.254 (300.8)	29.458 (345.9)

Details of calculations are shown in Appendix 2.

this level, there is no guarantee that people in Asia and the Pacific are all well nourished. Food produced is not necessarily distributed according to physiological need among different age, geographical, and socio-economic groups. This would require the support of effective nutrition education and equitable development planning of the country.

PROBLEMS, RESEARCH NEEDS, AND THE FUTURE

Problems

Data limitation

Background data used in the estimation of fertilizer needs come mostly from FAO publications, namely production and trade yearbooks and food balance series. However, there is no breakdown on fertilizer consumption by crops, and the latest data on fertilizer consumption that are included in the production yearbook are for 1975. There were considerable increases in fertilizer consumption in recent years. In other words, the percentage of increase in fertilizer consumption in target years against current consumption could be overestimated.

Food consumption pattern in different regions is based on 1972-1974 food balance sheets. Although dietary change may not be big, up-to-date information, if available, could give more accurate estimates.

Other information essential to the accuracy of calculations such as the responsive curves of major cereal crops to plant nutrients in different countries is also limited, and many assumptions are arbitrarily made to facilitate the calculation.

Consideration of other determinants

In order to fulfill the final goal of using fertilizer as a tool to generate food in meeting human nutritional requirements, all the related determining factors should be considered simultaneously. Any weak point in the complicated process would constitute a limiting factor in achieving the final goal.

Research Needs

Recycling of organic materials

In spite of the facts that there are many problems in recycling organic materials and that some countries, notably Japan and Taiwan, are gradually giving up this practice due to the convenience of chemical fertilizer application, this approach has the greatest potential to replace, at least partly, and complement chemical fertilizer. It is especially true that the conventional raw material for manufacturing nitrogenous fertilizer becomes increasingly scarce and other alternative sources are yet to be developed.

Research should be conducted in organic materials collection, processing, and application, as well as their social, economic, and environmental impacts.

Efficiency in fertilizer application

This is the second major potential to reduce fertilizer requirements. Although the joint research conducted under I.N.P.U.T.S. has yielded promising results in nitrogenous fertilizer application to paddy fields, the research should be continued to cover other nutrients and other crops in different soil and climatic conditions.

Improvement in farming system

The efficient use of resources, including water, organic manure and chemical fertilizer, improved crop varieties, pest control, and other inputs to increase food production must be started from individual farm level. Currently, we often make fragmentary research on certain sectors of the farming system and neglect to view the farming system as an integral unit; thus many resources are wasted in achieving the desired objectives.

Research should be conducted at the farm and village levels to mobilize all available inputs to optimize farm output in terms of income and nutrition. Public policy and programs affecting farm production should be assessed simultaneously.

Postharvest technology

Most of the loss and spoilage of harvested crops happens on farms and improving the drying and storage facilities at the farm and village levels would not commit many resources, since simple grain storage bins or "silos" can be made with locally available materials.

In view of the fact that the reduction of postharvest loss means the increase in food supply which, in turn, reduces fertilizer needs, research in this area is urgently needed by food technologists and other related scientists.

Future Prospects

Producing enough food to feed the ever-increasing population is the single greatest challenge confronting humanity. Fertilizer application is a major determinant to increase food production. With the dedication and close cooperation of geologists, crop and soil scientists, engineers, economists and nutritionists, backed with the determination and political will of the governments concerned, I am confident we could win the challenge in the next two decades. Hopefully, some breakthrough in scientific research, such as genetical potential development, could answer food problems after the turn of the century.

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APPENDIX 1-- CALCULATION ON FERTILIZER NEEDS FOR CEREAL PRODUCTION BASED ON NUTRITIONAL NEED OF PEOPLE IN THREE SELECTED ASIAN COUNTRIES

	1980	1985	1990	1995	2000
East Asia					
China (Mainland)					
1. Calorie/person/day (1972-74: 2,278)	2,400	2,500	2,600	2,650	2,700
2. Population, 10^6	889.852	953.908	1,010.427	1,067.478	1,119.612
3. Total Calorie req./yr, 10^{12}	779.510	870.441	958.895	1,032.518	1,103.378
4. Calorie from vegetal origin, (90.8%), 10^{12}	707.795	790.360	870.677	937.526	1,001.867
5. Cereal equivalent, 10^6 mt	306.404	342.147	376.917	405.855	433.709
6. Base-year (1976) cereal production, 10^6 mt	242.984	242.984	242.984	242.984	242.984
7. Additional cereal req., 10^6 mt	63.421	99.163	133.933	162.871	190.725
8. N requirement, 10^6 mt					
a. Add. cereal production (1 kg N = 10 kg cereal)	6.342	9.916	13.393	16.287	19.073
b. Base-year (1975) consumpt.	3.922	3.922	3.922	3.922	3.922
Total:	10.264	13.838	17.317	20.209	22.995
9. P_2O_5 requirement, 10^6 mt					
a. Add. cereal production (60% N)	3.805	5.950	8.036	9.772	11.444
b. Base-year consumption	1.319	1.319	1.319	1.319	1.319
Total:	5.124	7.269	9.355	11.091	12.763
Southeast Asia					
Indonesia					
1. Calorie/person/day (1972-74: 2,029)	2,100	2,200	2,300	2,350	2,400
2. Population, 10^6	154.869	175.471	196.576	217.623	237.507
3. Total Calorie req./yr, 10^{12}	118.707	140.903	165.026	186.666	208.056
4. Calorie from vegetal origin, (97.6%), 10^{12}	115.858	137.521	161.065	182.186	203.063
5. Cereal equivalent, 10^6 mt	47.483	56.362	66.011	74.667	83.223
6. Base-year cereal supply, 10^6	25.675*	25.675	25.675	25.675	25.675
7. Additional cereal req., 10^6 mt	11.808	30.687	40.336	48.992	57.548
8. N requirement, 10^6 mt					
a. Add. cereal production (1 kg N = 10 kg cereal)	1.181	3.069	4.034	4.900	5.577
b. Base-year consumption	.402	.402	.402	.402	.402
Total:	1.583	3.471	4.436	5.302	6.157
9. P_2O_5 requirement, 10^6 mt					
a. Add. cereal production (40% N)	.472	1.228	1.614	1.960	2.302
b. Base-year consumption	.111	.111	.111	.111	.111
Total:	.583	1.329	1.725	2.071	2.413

* Including 2.002 million tons of cereal imported in 1976

APPENDIX 1-- (Continued) CALCULATION ON FERTILIZER NEEDS FOR CEREAL PRODUCTION BASED ON NUTRITIONAL NEED OF PEOPLE IN THREE SELECTED ASIAN COUNTRIES

	1980	1985	1990	1995	2000
South Asia					
India					
1. Calorie/person/day (1972-74: 1,968)	2,000	2,150	2,300	2,450	2,600
2. Population, 10^6	694.309	782.890	876.051	969.748	1,059.429
3. Total Calorie req./yr, 10^{12}	506.846	614.373	735.445	867.197	1,005.398
4. Calorie from vegetal origin, (94.6%), 10^{12}	479.476	581.197	695.731	820.368	951.107
5. Cereal equivalent, 10^6 mt	171.249	207.569	248.473	292.986	339.679
6. Base-year production, 10^6 mt	122.597	122.597	122.597	122.597	122.597
7. Additional cereal req., 10^6 mt	48.643	84.972	125.876	170.389	217.082
8. N requirement, 10^6 mt					
a. Add. cereal production (1 kg N = 10 kg cereal)	4.864	8.497	12.588	17.039	21.708
b. Base-year consumption	1.774	1.774	1.774	1.774	1.774
Total:	6.638	10.271	14.362	18.813	23.482
9. P_2O_5 requirement, 10^6 mt					
a. Add. cereal production (60% N)	2.918	5.098	7.553	10.223	13.025
b. Base-year consumption	.478	.478	.478	.478	.478
Total:	3.396	5.576	8.031	10.701	13.503

APPENDIX 2-- ADJUSTED ESTIMATE OF FERTILIZER REQUIREMENT IN ASIA AND THE PACIFIC
(Unit: In Million Metric Ton)

	1975		1980		1985		1990		1995		2000	
	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5
Asia												
A. East Asia (China, Japan, Republic of Korea)												
1. Cereal production												
Japan	.691	.692	1.269	1.270	1.425	1.426	1.544	1.545	1.651	1.652	1.758	1.759
Other countries	4.614	1.677	6.088	3.108	8.024	4.270	9.911	5.401	11.499	6.354	12.986	7.247
	5.305	2.369	7.357	4.378	9.449	5.696	11.455	6.946	13.150	8.006	14.744	9.006
2. Home garden	--	--	.114	.228	.122	.245	.129	.259	.137	.273	.143	.287
3. Fish culture	--	--	.040	.021	.099	.049	.199	.099	.358	.179	.611	.306
Subtotal	5.305	2.369	7.511	4.627	9.670	5.990	11.783	7.304	13.645	8.458	15.498	9.599
	(100.0)	(100.0)	(141.6)	(195.7)	(182.3)	(253.4)	(222.1)	(307.3)	(257.2)	(357.8)	(292.1)	(406.1)
B. Southeast Asia (Burma, Cambodia, Indonesia, Laos, Malaysia, Philippines, Thailand, Vietnam)												
1. Cereal production	.837	.364	1.906	.777	3.413	1.426	4.786	1.949	5.626	2.265	6.750	2.715
2. Home garden	--	--	.046	.092	.052	.105	.059	.118	.066	.133	.073	.146
3. Fish culture	--	--	.017	.088	.058	.029	.159	.080	.329	.165	.608	.304
Subtotal	.837	.364	1.969	.877	3.523	1.560	5.004	2.147	6.021	2.563	7.431	3.165
	(100.0)	(100.0)	(235.2)	(240.9)	(420.9)	(428.6)	(597.9)	(589.8)	(719.4)	(704.1)	(887.8)	(869.5)
C. South Asia (Afghanistan, Bangladesh, India, Iran, Nepal, Pakistan, Sri Lanka)												
1. Cereal production	2.575	.753	4.465	2.284	7.035	3.824	9.935	5.567	13.109	7.471	16.516	9.514
2. Home garden	--	--	.125	.250	.142	.284	.160	.320	.179	.357	.196	.392
3. Fish culture	--	--	.018	.009	.062	.031	.170	.085	.351	.176	.668	.334
Subtotal	2.575	.753	4.608	2.543	7.239	4.139	10.265	5.972	13.639	8.004	17.380	10.240
	(100.0)	(100.0)	(179.0)	(337.7)	(281.1)	(549.7)	(398.6)	(793.1)	(529.7)	(1063.0)	(675.0)	(1359.9)
Total												
1. Cereal Production	8.717	3.486	13.728	7.439	19.897	10.946	26.176	14.462	31.885	17.742	38.010	21.235
2. Home garden	--	--	.285	.570	.316	.634	.348	.697	.382	.763	.412	.825
3. Fish culture	--	--	.075	.038	.219	.109	.528	.264	1.038	.520	1.887	.944
	8.717	3.486	14.088	8.047	20.432	11.689	27.052	15.423	33.225	19.025	40.309	23.004
	(100.0)	(100.0)	(161.6)	(230.8)	(234.4)	(335.3)	(310.3)	(441.3)	(382.1)	(545.8)	(463.4)	(659.9)

APPENDIX 2-- (Continued) ADJUSTED ESTIMATE OF FERTILIZER REQUIREMENT IN ASIA AND THE PACIFIC
(Unit: In Million Metric Ton)

	1975		1980		1985		1990		1995		2000	
	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5
Oceania												
A. Australia and New Zealand												
1. Cereal production	.192	.953	.210	1.042	.228	1.132	.246	1.220	.263	1.304	.279	1.387
2. Home garden	—	—	—	—	—	—	—	—	—	—	—	—
3. Fish culture	—	—	—	—	—	—	—	—	—	—	—	—
Subtotal	.192	.953	.210	1.042	.228	1.132	.246	1.220	.263	1.304	.279	1.387
B. Other Oceania Countries												
1. Cereal production	.004	.001	.008	.004	.012	.007	.017	.010	.023	.013	.028	.017
2. Home garden	—	—	.001	.002	.001	.002	.001	.003	.001	.003	002	.003
3. Fish culture	—	—	—	—	—	—	—	—	—	—	—	—
Subtotal	.004	.001	.009	.006	.013	.009	.018	.013	.024	.016	.030	.020
Total												
1. Cereal production	.196	.954	.218	1.046	.240	1.139	.263	1.230	.286	1.317	.307	1.404
2. Home garden	—	—	.001	.002	.001	.002	.001	.003	.001	.003	.002	.003
3. Fish culture	—	—	—	—	—	—	—	—	—	—	—	—
	.196	.954	.219	1.048	.241	1.141	.264	1.233	.287	1.320	.309	1.407
	(100.0)	(100.0)	(111.7)	(109.9)	(123.0)	(119.6)	(134.7)	(129.3)	(146.4)	(138.4)	(157.7)	(147.5)
U. S. A.												
1. Cereal Production	7.796	4.077	8.167	4.272	8.589	4.492	8.988	4.701	9.329	4.880	9.636	5.040
2. Home garden	—	—	—	—	—	—	—	—	—	—	—	—
3. Fish culture	—	—	—	—	—	—	—	—	—	—	—	—
Total	7.796	4.077	8.167	4.272	8.589	4.492	8.988	4.701	9.329	4.880	9.636	5.040
	(100.0)	(100.0)	(04.8)	(104.8)	(110.2)	(110.2)	115.3)	(115.3)	(119.7)	(119.7)	(123.6)	(123.6)
Grand Total	16.709	8.517	22.474	13.367	29.262	17.322	36.304	21.317	42.921	25.225	50.254	29.451
	(100.0)	(100.0)	(134.5)	(156.9)	(175.1)	(203.4)	(217.3)	(250.3)	(256.9)	(296.2)	(300.8)	(345.8)

Source: 1975 Fertilizer consumption is based on FAO Production Yearbook.

FERTILIZER REQUIREMENTS FOR SOME MAJOR FIELD CROPS UNDER IRRIGATED AGRICULTURE OF ARID AND SEMI-ARID REGIONS

M.R. HAMISSA*

INTRODUCTION

The rapid increase in the population in Egypt with a limited cultivated area arouses an acute need for additional production of various crops. Therefore, efforts have been focused on tackling problems that lead to significant increase in crop production. Among the many factors which may achieve such a target is the proper fertilization of different crops.

Egyptian soils, in common with most of the arid and semi-arid regions, are relatively rich in some mineral elements required for plant growth, but deficient in organic matter and some nutrient elements, particularly nitrogen. They are also cultivated twice or thrice a year. This intensive cultivation depletes the soil of some plant nutrients which should be compensated by fertilizer application.

In this paper results of four series of field trials on cotton, wheat, maize, and rice are presented.

The main target of this investigation is to study the response of these crops to N, P, and K and to determine the optimum rate of fertilizer application in order to gain information on which to base fertilizer recommendation.

EXPERIMENTAL:

For the purpose, four series of field trials were conducted on cotton, wheat, maize, and rice over a long period. Experimental sites were distributed throughout the country representing the major regions where each crop is cultivated. By the end of 1978, results of 138, 132, 68, and 64 field experiments on cotton, wheat, maize, and rice, respectively, were accumulated and ready for the study.

Experimental treatments for each crop are indicated in Tables 1, 2, 3, and 4. The experimental setup of each trial was designed in randomized complete blocks in four replications.

Composite soil samples were taken from the experimental sites to the depth of 20 cm. The soil samples were air dried, ground to pass through 1 mm.

Available nitrogen which includes the total ammonium and nitrate nitrogen soluble in 1% K_2SO_4 solution was determined according to Koenig method (1930). Available phosphorus was determined by Olsen, et al. method (1954). Other chemical constituents were determined according to the official chemical methods (Jackson, 1958).

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TABLE 1-- FERTILITY TREATMENTS OF WHEAT EXPERIMENTS

Treat. No.	Rate of application in kg/ha N	P_2O_5	K_2O
1	-	36	57
2	36	36	57
3	72	36	57
4	108	36	57
5	144	36	57
6	180	36	57
7	108	-	57
8	108	18	57
9	108	36	-

TABLE 2-- FERTILITY TREATMENTS OF MAIZE EXPERIMENTS

Treat. No.	Rate of application in kg/ha N	P_2O_5	K_2O
1	-	-	-
2	72	-	-
3	108	-	-
4	144	-	-
5	180	-	-
6	216	-	-
7	144	36	-
8	144	36	57

TABLE 3-- FERTILITY TREATMENTS OF COTTON EXPERIMENTS

Treat. No.	Rate of application in kg/ha N	P_2O_5	K_2O
1	-	-	-
2	36	-	-
3	72	-	-
4	108	-	-
5	144	-	-
6	180	-	-
7	36	36	-
8	72	36	-
9	108	36	-
10	144	36	-
11	180	36	-
12	180	36	57

TABLE 4-- FERTILITY TREATMENTS OF RICE EXPERIMENTS

Treat. No.	Rate of application in kg/ha N	P_2O_5
1	-	-
2	24	-
3	48	-
4	72	-
5	96	-
6	120	-
7	144	-
8	24	36
9	48	36
10	72	36
11	96	36
12	120	36
13	144	36
14	-	36

RESULTS AND DISCUSSION

Description of Soil Samples Used in the Study

As previously mentioned, soil samples were collected from different experimental sites for chemical analysis and soil definition. In general, most of the soils on which these studies were conducted are classified according to the world soil map as fluvisol soils. Their texture varies from sandy loam to heavy clayey.

Average results of chemical analysis of these samples are presented in Table 5. It is clear from the data reported in the Table that there is a wide range in the different chemical constituents of various soils. However, results show that the pH values fall in the range of the slight alkaline reaction. They are rich in calcium carbonate, but poor in organic matter. Average determinations of the total soluble salts are low and under the level of toxicity. Cation exchange capacity is rather high. The concentration of total and soluble nitrogen is fairly low. In regard to the available P determined by Olsen's method, the values are moderate. The results may also indicate that the soluble and exchangeable potassium extracted by the ammonium acetate method is fairly high, reflecting the general characteristics of most Egyptian alluvial soils.

TABLE 5-- CHEMICAL ANALYSIS OF SOIL SAMPLES TAKEN FROM EXPERIMENTAL SITES OF VARIOUS CROPS

Determination	Range of results	Mean value
pH (2.5:1)	7.3 - 8.3	7.9
$CaCO_3$%	2.1 - 8.3	3.9
Total soluble salts %	0.09 - 0.33	0.17
Organic matter %	1.22 - 2.24	1.7
Total nitrogen %	0.07 - 0.113	0.087
Total soluble nitrogen ppm.	13.00 - 58.00	37.00
Nitrate N ppm.	12.00 - 15.00	6.4
Available P (Olsen) ppm.	1.00 - 29.00	12.00
Available K (am. acct.) ppm.	288.00 - 663.00	464.00
C.E.C. m.e./100 gr. soil	31.00 - 61.00	46.00
Exchangeable Ca.m.e./100 gr. soil	10.00 - 34.00	22.00

RESPONSE OF CROPS TO N, P, AND K

Wheat

Response of wheat to N, P, and K

Average results of 69 field trials on local long strawed wheat varieties and 63 experiments on medium strawed varieties are reported in Table 6. It is clear from the data that the medium strawed varieties outyielded the long strawed varieties. They are also more responsive to higher doses of nitrogen. This might be due to their higher yield potential which requires more nutrients and their tolerance to lodging under high rates of nitrogen.

Taking the overall average of 132 experiments into consideration, it is clear that wheat did respond markedly to nitrogen application. The yield increased as the rate of N increased up to 180 Kg N/ha. At this particular rate, the increase in yield amounted to 61 percent over that obtained from the check treatment. However there was no appreciable increase in yield after 144 Kg N/ha where the yield was increased by 58

TABLE 6-- RESPONSE OF WHEAT TO N, P, AND K
(AVERAGE YIELD OF WHEAT GRAIN IN TON./HA.)

Treat. ment No.	Rate of appl. (kg/ha) N	P_2O_5	K_2O	Yield of long st. var.*	Yield of medium st.var.**	Overall average yield	increase over control	% Increase
1	-	36	57	2.681	3.020	2.843	-	-
2	36	36	57	3.334	3.695	3.506	.663	23.3
3	72	36	57	3.724	4.255	3.977	1.134	39.9
4	108	36	57	3.966	4.662	4.298	1.455	51.2
5	144	36	57	4.106	4.902	4.485	1.642	57.8
6	180	36	57	4.145	5.069	4.586	1.743	61.3
7	108	-	57	3.838	4.448	4.129	1.286	45.2
8	108	18	57	3.895	4.605	4.234	1.391	48.9
9	108	36	-	3.870	4.580	4.209	1.366	48.0
Number of expts.				69	63	132		
Period				1973/74 - 1977/78				

* Long strawed varieties = Giza 155 and 156
** Medium strawed varieties = Super X-Maxi PaK-Chenab-Giza 158 and Sackha 8.

percent over the check. Such a result was in full agreement with those found by several workers in Egypt as well as in other countries (Crowther, Temforde and Mahmoud, 1937; Hamdi, Agiza and El Shabassy, 1963; Chandnani and Kavitkar, 1955; and Hamissa, et al., 1978).

In regard to the response of wheat to P, comparison between treatments Nos. 4, 7, and 8 may indicate that the response of wheat to P was fairly low compared with that obtained from N.

The same trend was also obtained regarding the effect of potash. Comparison between treatments 4 and 9 shows no appreciable effect due to K application, indicating that most Egyptian soils are rich in this particular element, as shown in Table 5.

Optimum rate of N application for wheat

As was pointed out before, nitrogen had the most important effect upon the production of this particular crop. Therefore, the calculation of the nitrogen response curve for wheat is of great interest in order to find out what amount of yield is associated with a given rate of nitrogen.

The average data of 132 experiments presented in Table 6 showed that a curve linear relationship exists between yield produced and rates of N added. Thus a polynomial equation was tried and the following quadratic equation was calculated.

$$Y = 2.876 + .01869x - .00005131x^2$$

whereas,

Y = wheat yield in ton./ha.

x = amount of applied fertilizer N in kg/ha.

The above mentioned equation was found to be highly significant as shown from the analysis of variance presented in Table 7 and illustrated by curve in Figure 1. From this curve it is shown that the maximum yield was obtained at 180 kg N/ha. However, to determine the optimum economical rate, the net profit through the fertilizer use to wheat was worked out using the data obtained from the calculated equation of the nitrogen response curve as presented in Table 8. A graph was then constructed as shown in Figure 2, whereas the cost of fertilizer and the value of the response were plotted on a hectare basis against the amount of nitrogen applied. The point at which the difference between the cost of fertilizer and the value of the response was the greatest represents the point of the maximum profit and in turn the optimum rate. This point can be determined by drawing a line tangent to the value of the increased yield and parallel to the cost of the nitrogen applied.

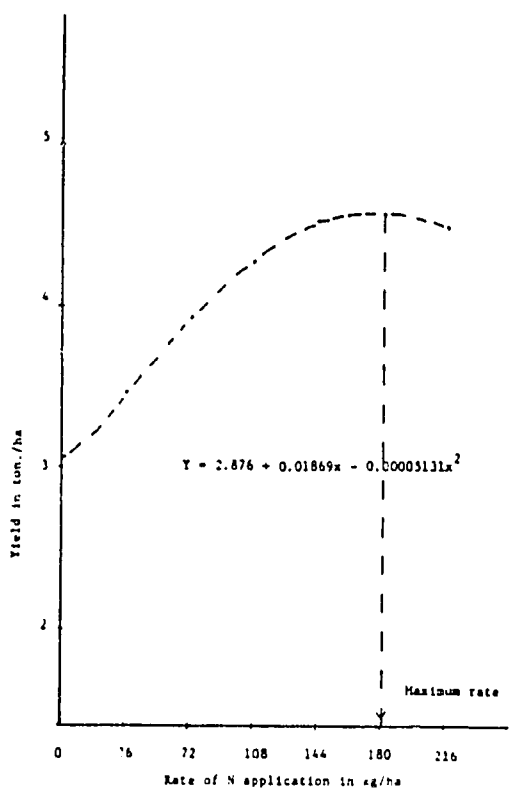


Fig. 1. Wheat N Response Curve (Ave. of 132 Experiments)

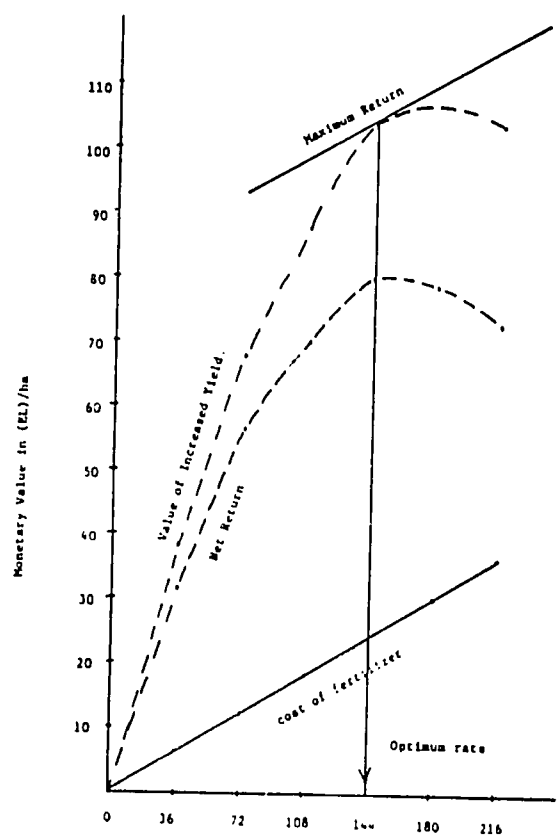


Fig. 2. The Optimum Economical Rate of N Application for Wheat

Therefore, according to the data presented in Table 8 and illustrated in Figure 2, 144 kg N/ha could be considered as the recommended rate for wheat fertilization in Egypt. Further addition beyond this rate would add more to expenses rather than to crop value.

TABLE 7-- ANALYSIS OF VARIANCE FOR THE QUADRATIC EQUATION OF WHEAT. y

Source of variance	d.f	S.S.	M.S.S.	F.
Regression	2	2.1925	1.09625	77.4^{xx}
Deviation from regr.	3	.0425	.01416	
Total	5	2.235		

TABLE 8-- ESTIMATION OF PROFIT THROUGH THE USE OF FERTILIZER NITROGEN FOR WHEAT.

Rate of N (kg/ha)	Cost of(1) fert./ha (E.L)	Crop yield (3) (ton/ha)	Yield increase (kg/ha)	Value of increased yield (2) (E.L)	Net Profit per ha. (E.L)
0	0.0	2.876	-	-	-
36	6.00	3.482	606	38.378	32.378
72	12.00	3.956	1080	68.396	56.396
108	18.00	4.296	1393	88.219	70.219
144	24.00	4.525	1649	104.431	80.431
180	30.00	4.578	1702	107.788	77.788
216	36.00	4.519	1643	104.051	68.051

(1) Cost of fertilizer at subsidized rate = .166 EL/kg N.
(2) Local price of wheat = 63.33 EL/ton.
(3) Calculated yield from the quadratic equation of the response curve EL = 1.43 US $.

Maize

Response of maize to N, P, and K

Average results of 68 experiments conducted through the period 1974/1978 are presented in Table 9. The data show that maize is a heavy nitrogen feeder plant. Its response to nitrogen is quite marked. The yield increased as the rate of N increased up to 216 kg N/ha. At this rate, the yield was increased by 49 percent over that obtained from the check treatment.

TABLE 9-- RESPONSE OF MAIZE TO N, P, AND K
(AVERAGE YIELD IN TON./HA.)

Treat. No.	Rate of Application kg/ha N	P_2O_5	K_2O	Ave. yield ton/ha	Increase in yield kg/ha	% Increase
1	-	-	-	3.562	-	-
2	72	-	-	4.398	836	23.5
3	108	-	-	4.681	1119	31.4
4	144	-	-	4.938	1376	38.6
5	180	-	-	5.111	1549	43.5
6	216	-	-	5.308	1746	49.0
7	144	36	-	5.011	1449	40.7
8	144	36	57	5.025	1463	41.1
Number of experiments				68		
Period			1974 - 1978			

On the other hand, comparison between treatments Nos. 4 and 7 did not show any appreciable effect due to P application. The same trend was also obtained with regard to the potassium effect. The yields of treatments Nos. 7 and 8 are very close to one another with no marked difference. Such results coincide with data reported by Amer, 1961 and Hamissa, et al., 1971.

Optimum rate of N application for maize

As was pointed out before, under local conditions nitrogen is considered to be the limiting factor for maize production as far as nutrient elements are concerned. Therefore, calculating the N response curve for this particular crop is considered important. According to the same procedure followed before, the quadratic equation of average results of 68 experiments was worked out as follows:

$$Y = 3.572 + .01266x - .00002188x^2$$

whereas

Y = maize yield in ton./ha

x = amount of applied fertilizer nitrogen in kg/ha.

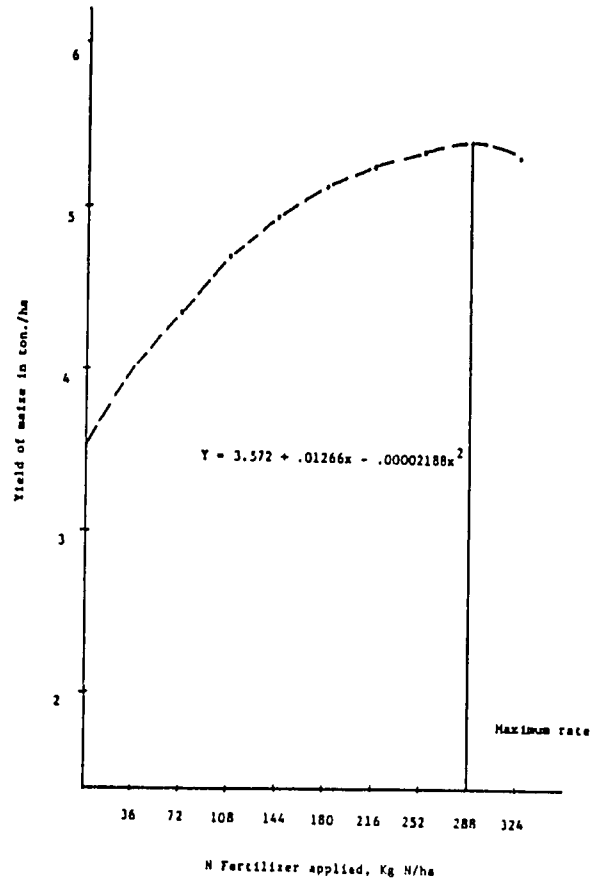
The above mentioned equation is highly significant, as indicated in Table 10 and illustrated by the curve in Figure 3.

According to the nitrogen response curve, it is shown that the maximum yield of maize was obtained at the rate of 288 kg N/ha.

In regard to the most economical yield, the data presented in Table 11 and illustrated in Figure 4 might suggest that 252 kg N/ha could be the recommended rate of nitrogen for maize to obtain the highest return.

Fig. (3) Maize N Response Curve

(Ave. of 68 Experiments)



N Fertilizer Applied, Kg N/ha

Fig. (4) The Optimum Economical Rate of N Application for Maize

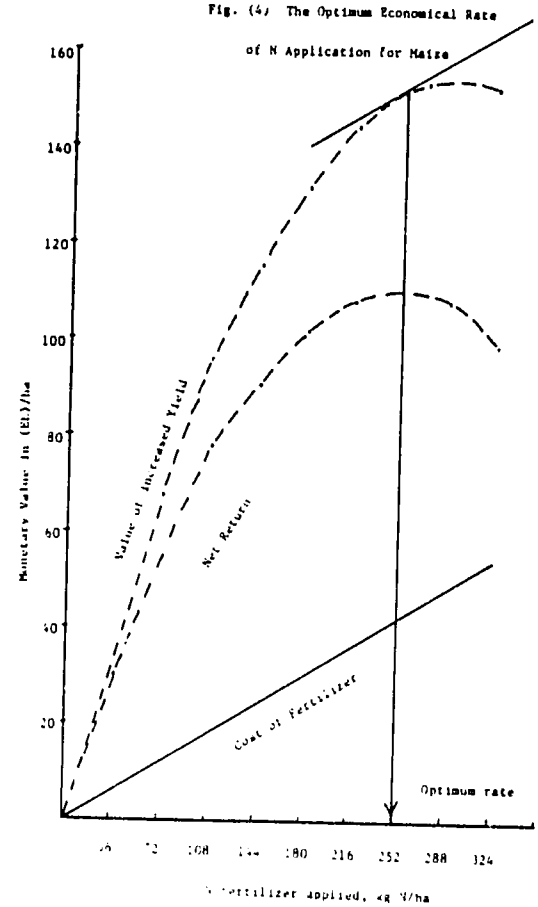


TABLE 10-- ANALYSIS OF VARIANCE FOR THE QUADRATIC EQUATION OF MAIZE

Source of variance	d.f	S.S.	M.S.S.	F
Regression	2	1982814.9	991407.4	34.8^{xx}
Deviation from regr.	3	85532.5	28510.8	
Total	5	2068347.3		

Rice

Response of rice to N and P

Previous work (Hamissa, et al., 1971) indicated that rice under local conditions did not respond to potassium application. Therefore, the current study is concerned with the response of this particular crop to N and P when each nutrient was added alone and in different combinations. Average results of 64 experiments conducted through the period 1966-1978 are presented in Table 12.

As indicated in Table 12, the paddy was materially affected by nitrogen application. Increase in yield due to N application at different rates ranged between 422 and 811 kg/ha. Such increases amounted to 23 percent to 45 percent over that obtained from the check treatment.

TABLE 11-- ESTIMATION OF PROFIT THROUGH THE USE OF FERTILIZER NITROGEN FOR MAIZE

Rate of N (kg/ha)	Cost of(1) fert./ha (E.L)	Crop yield (3) (ton/ha)	Yield increase (kg/ha)	Value of increased yield (2) (E.L)	Net profit per ha. (E.L)
0	0.0	3.572	-	-	-
36	6.00	4.000	428	36.166	30.166
72	12.00	4.370	798	67.431	55.431
108	18.00	4.714	1142	96.499	78.499
144	24.00	4.941	1369	115.681	91.681
180	30.00	5.142	1570	132.665	102.665
216	36.00	5.286	1714	144.833	108.833
252	42.00	5.373	1801	152.185	110.185
288	48.00	5.403	1831	154.720	108.720
324	54.00	5.377	1805	152.523	98.523

(1) Cost of fertilizer at subsidized rate = 166 EL/kg N
(2) Local price of maize = 84.5 EL/ton.
(3) Calculated yield from the quadratic equation of the response curve
EL = 1.43 US $.

TABLE 12-- RESPONSE OF RICE TO N AND P (AVERAGE YIELD OF PADDY IN TON./HA)

Treat. No.	Rate of application (kg/ha) N	P_2O_5	Yield of paddy (ton/ha)	Increase in yield kg/ha	% Increase
1	-	-	4.317	-	-
2	24	-	5.322	1005	23.3
3	48	-	5.622	1305	30.2
4	72	-	5.983	1666	38.6
5	96	-	6.150	1833	42.4
6	120	-	6.240	1923	44.5
7	144	-	6.248	1931	44.7
8	24	36	5.469	1152	26.7
9	48	36	5.769	1452	33.6
10	72	36	6.152	1835	42.5
11	96	36	6.357	2040	47.2
12	120	36	6.362	2045	47.4
13	144	36	6.469	2152	49.8
14	-	36	5.134	817	18.9

Number of experiments 64
Period 1966 - 1978

It is also noted that the yield increased gradually as the rate of N increased up to 144 kg N/ha. However, there was no appreciable difference between the yields obtained from 72 up to 144 kg N/ha.

In regard to the effect of P, the response was still observable but less than with nitrogen. Average increase in yield when P was added alone at the rate of 36 kg P_2O_5/ha amounted to 19 percent over that obtained from the check treatment. When P and N were applied together, the increase in yield due to the two nutrients was less than the same increase attributed to each nutrient applied alone. Such a result coincided with previous findings in that respect (Crowther, Temforde and Mahmoud, 1937; Gracie and Khalil, 1948; and Hamissa, et al., 1974).

Optimum rate nitrogen application to rice

The same procedure followed in wheat and maize for calculating the nitrogen response curves was also adopted. The quadratic equation of the average results of 64 experiments was found to be:

$$Y = 4.441 + .0312616x - .0001318x^2$$

whereas

Y = paddy yield in ton./ha.

x = amount of applied fertilizer N in kg/ha.

Such an equation was found to be highly significant as shown in Table 13 and illustrated by the curve in Figure 5. From the N response curve it is shown that the maximum yield was obtained at the rate of 120 kg N/ha.

TABLE 13-- ANALYSIS OF VARIANCE FOR THE QUADRATIC EQUATION OF RICE

Source of variance	d.f	S.S.	M.S.S.	F.
Regression	2	2867624	1833812	83.8^{xx}
Deviation of regr.	4	68480	17120	
Total	6	2936104		

On the other hand, according to data presented in Table 14 and illustrated in Figure 6, the most economical yield was obtained at the rate of 96 kg N/ha where the maximum profit was achieved. This rate in general is the locally recommended rate of N application for rice in addition to 36 kg P_2O_5/ha. However, it has been found in a previous study (Hamissa, et al., 1974) that the previous crop to rice in the crop rotation had a significant role in estimating the optimum rate.

Fig. (5) Rice N Response Curve

(Ave. of 64 Experiments)

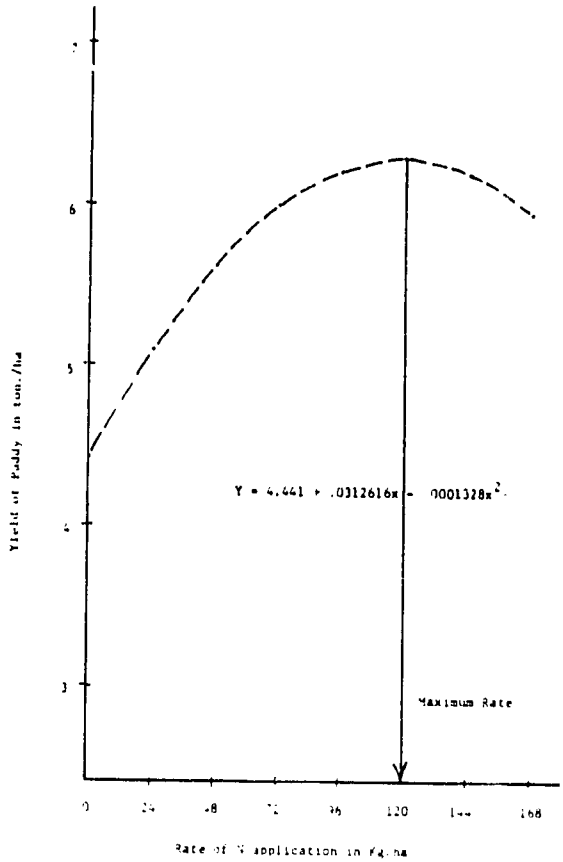


Fig. (6) The Optimum Economical Rate of N application for rice

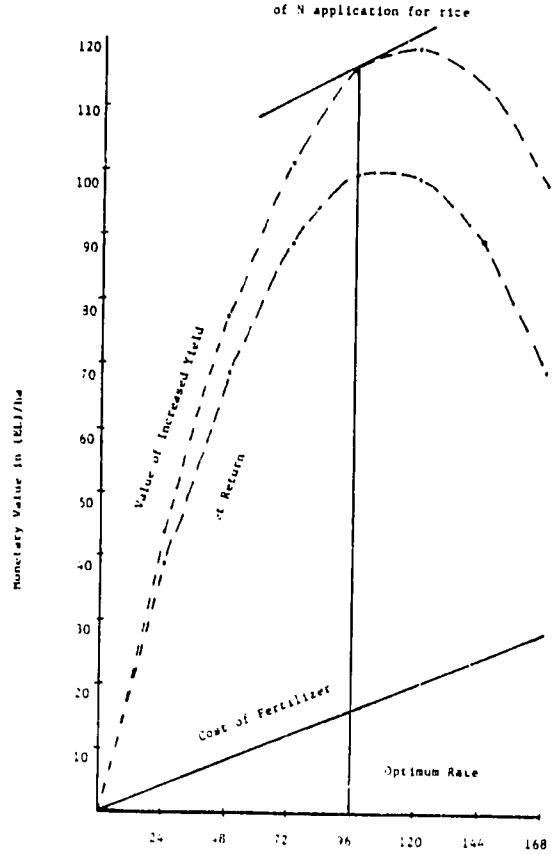


TABLE 14-- ESTIMATION OF PROFIT THROUGH THE USE OF FERTILIZER NITROGEN FOR PADDY

Rate of N kg/ha	Cost of(1) fert./ha (E.L)	Crop yield (3) (ton/ha)	Yield increase (kg/ha)	Value of increased yield (2) (E.L)	Net profit per/ha (E.L)
0	-	4.441	--	-	-
24	4.00	5.115	674	43.816	39.810
48	8.00	5.635	1194	77.610	69.610
72	12.00	6.004	1563	101.595	89.595
96	16.00	6.218	1777	115.505	99.505
120	20.00	6.280	1839	119.535	99.535
144	24.00	6.189	1748	113.620	89.620
168	28.00	5.945	1504	97.760	69.760

(1) Cost of fertilizer at subsidized rate = 166 EL/kg N
(2) Local price of paddy = 65 EL/ton.
(3) Calculated yield from the quadratic equation of the response curve
EL = 1.43 US $.

Cotton

Response of cotton to N, P, and K

Cotton is the most important cash crop in the country. Among the factors which increase its production is the proper fertilization. One hundred thirty-eight field experiments were conducted through the period 1974-1978 including different cotton varieties raised under different soil conditions at various locations. Average results of these trials are presented in Table 15.

TABLE 15-- RESPONSE OF COTTON TO N, P, AND K
(AVERAGE YIELD OF SEED COTTON IN KG/HA.)

Treat. No.	Rate of application (kg/ha) N	P_2O_5	K_2O	Yield (kg/ha)	Increase in yield (kg/ha)	% Increase
1	-	-	-	2298	-	-
2	36	-	-	2609	311	13.5
3	72	-	-	2774	476	20.7
4	108	-	-	2849	551	24.0
5	144	-	-	2928	630	27.4
6	180	-	-	2913	615	26.8
7	36	36	-	2684	386	16.8
8	72	36	-	2800	502	21.8
9	108	36	-	2935	637	27.7
10	144	36	-	3006	708	30.8
11	180	36	-	2991	693	30.2
12	180	36	57	3003	705	30.7

Number of Experiments 138
Period 1974 - 1978

From the data reported it is shown that cotton did respond to N at different rates. The yield increased gradually and consistently as the rate of N increased up to 144 kg N/ha. At this particular rate, the yield was increased by 27 percent over that obtained from the control. Thereafter, when the rate of nitrogen was increased up to 180 kg N/ha, the yield started to decline. Such behavior was in direct contrast to that of maize which proved to be more responsive to nitrogen than cotton.

In regard to P application, comparison between treatments Nos. 2 to 6 and 7 to 11 might indicate an observable response to P; however, this response was much less than that to nitrogen.

Taking the economic aspect into consideration, P application to cotton is still profitable.

As for the effect of potash on the crop yield, comparison between treatments 11 and 12 indicated no appreciable response--a result which is in accord with results obtained from other crops indicating that there are surplus amounts of available potassium in Egyptian soils to cover the requirements of these crops from this particular element.

Optimum rate N application to cotton

Again, the data of 138 field trials were processed and the quadratic equation was worked out according to the following:

$$Y = 2.293 + .0081555X - .00002720X^2$$

whereas

Y = seed cotton yield in kg/ha

x = amount of applied fertilizer N in kg/ha.

Analysis of variance has shown the equation to be highly significant as indicated in Table 16 and Figure 7 which illustrates the nitrogen response curve. From this curve it can be seen that the maximum yield was obtained at the rate of 144 kg N/ha.

Taking the economical production into consideration, it has been found from the data presented in Table 17 and illustrated in Figure 8 that the optimum rate is also 144 kg N/ha where the maximum return was achieved.

Fig. (7) Cotton N Response Curve

(Ave. of 138 Experiments)

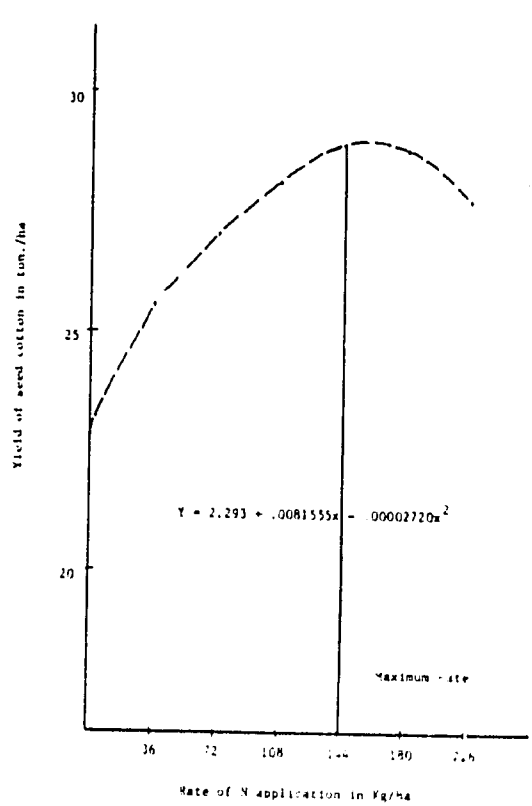


Fig. (8) The Optimum Economical Rate

of N Application for Cotton

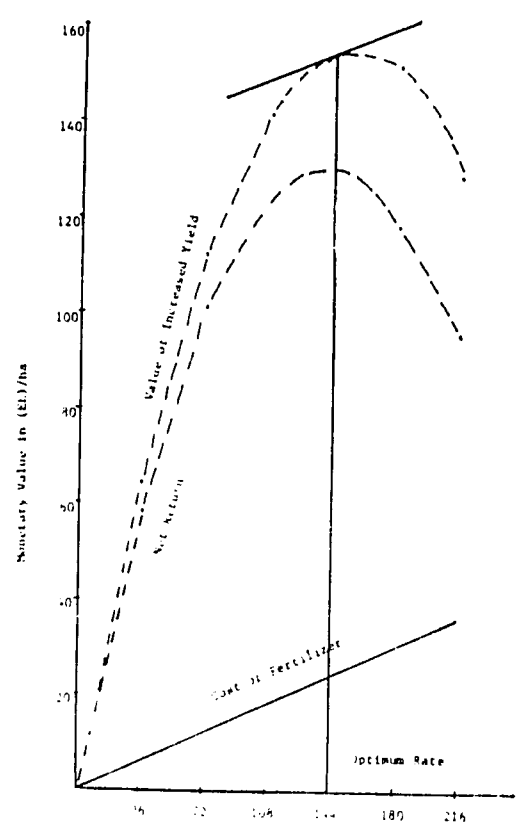


TABLE 16-- ANALYSIS OF VARIANCE FOR THE QUADRATIC EQUATION OF COTTON

Source of variance	d.f	S.S.	M.S.S.	F.
Regression	2	287352	143676	160xx
Deviation from regr.	3	2689	896	
Total	5			

TABLE 17-- ESTIMATION OF PROFIT THROUGH THE USE OF FERTILIZER NITROGEN FOR COTTON

Rate of N (kg/ha)	Cost of(1) fert./ha (E.L)	Crop yield (3) (kg/ha)	Yield increase (kg/ha)	Value of increased Yield(2) (E.L)	Net profit per/ha (E.L)
-	-	2293	-	-	-
36	6.00	2552	259	65.776	59.776
72	12.00	2739	446	113.266	101.266
108	18.00	2857	564	143.233	125.233
144	24.00	2903	610	154.916	130.916
180	30.00	2880	587	149.075	119.075
216	36.00	2786	493	125.202	89.786

(1) Cost of fertilizer at subsidized rate = 166 EL/kg N.
(2) Local price of seed cotton = 253.96 EL/ton.
(3) Calculated yield from the quadratic equation.
EL = 1.43 US $.

THE GENERAL TREND OF THE WHOLE RESULTS

To summarize the general trend of the whole results, it has been revealed from the data reported in Table 18 that nitrogen is the most effective nutrient and proven to be the element most lacking in Egyptian soils for increasing the production of the tested crops.

It was also shown from the previous discussion that the maximum and optimum rates of nitrogen application differ from one crop to another, being the least for rice and the most for maize. However, with the exception of cotton, the rates of N for producing the highest yields are much more than optimum economical rates at which the maximum returns are achieved.

Again, it was shown that when the crop was over dressed with N, the crop did not increase and sometimes was reduced.

As far as the response to P is concerned, the data reported in Table 18 may suggest that response of various crops to P was still observable; however, it was fairly low compared with that to nitrogen.

With respect to K, the general trend of the results did not show any appreciable response to this particular element, indicating that most Egyptian soils are still rich in available potassium. However, in some individual cases, response to this element could be detected.

TABLE 18-- GENERAL TREND OF THE RESPONSE OF VARIOUS CROPS TO N, P, AND K

Fertilizer treat.	Relative values of crop produced				
	Wheat	Maize	Rice	Cotton	Mean
Without N	100	100	100	100	100
N at opt. rate	157	150	142	127	144
Without P	100	100	100	100	100
36 kg P_2O_5/ha	104	101	105	102	103
Without K	100	100	-	100	100
57 kg K_2O/ha	98	100	-	100	99

OTHER FACTORS AFFECTING THE DETERMINATION OF OPTIMAL RATES OF FERTILIZERS

To determine the optimum rate of fertilizer application for any crop, beside the general knowledge based on: (1) the results of a sufficient number of field experiments that test different quantities of plant food and measure the extra yields given by the dressings, (2) the cost of fertilizer applied, and (3) the value of the crop produced; other factors should be taken into consideration. These factors significantly affect the response of the crop to fertilizers and, in turn, the optimum rate of fertilizer application. Among these factors are the following:

1. Soil test values which assess the available nutrients in the soil.

2. Plant tissue tests which often show when crops contain too few nutrients for satisfactory yield.

These two factors are materially influenced by the following:

a- Nutrient cycle on the farm

b- Past manuring with organic manure and fertilizers that leave residues of N, P, and K.

c- Farming system and crop rotation.

3. Local weather and the characteristics of the whole season.

4. Irrigation practices and interactions with fertilizer.

5. Additional application, harvesting, and marketing costs.

In addition there are other factors which affect the relative efficiency of a given rate of fertilizers such as the source of fertilizer, timing, and fertilizer placement.

SUMMARY AND CONCLUSION

1. The main purpose of the study was to gain information on which to base fertilizer recommendations to farmers to increase their crop production through the efficient use of fertilizers.

2. About four hundred rate experiments were conducted on wheat, maize, rice, and cotton in different locations in the country over a long period.

3. In these experiments levels of nitrogen were combined with P and K to study the response of these crops to N, P, and K and to determine the optimum rate of fertilizer application for each crop.

4. Composite soil samples were taken from the experimental sites for chemical analysis and soil definition.

5. With no exception all crops significantly responded to N. Response to P was observable but much less than N. Potassium had no appreciable effect.

6. N response curve for each crop was established using the quadratic equation which was highly significant.

7. The optimal rates (kg N/ha) for various crops and the percent increase in yield due to N application were as follows:

Crop	Optimum rate	% Increase in yield
Wheat	144	57
Maize	252	50
Rice	96	40
Cotton	144	27

8. Besides a general knowledge based on fertilizer experiment results, an adviser's decision on optimum rate of fertilizer may depend on other factors which could affect the response and adjust the correct amount of fertilizer to be applied.

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EFFECT OF FORM AND RATE OF NITROGEN FERTILIZER ON YIELD AND NITROGEN CONTENT OF PADDY RICE UNDER SUBTROPICAL CONDITIONS

T.C. JUANG*

SUMMARY

Two experiments located in Taichung and Pingtung were carried out to investigate the effect of form and rate of nitrogen fertilizer on yield, nitrogen content and absorption rate of paddy rice. Two forms, USG (urea supergranules) and urea, were used at the Taichung site, and three forms, USG, urea, and ammonium sulfate, were used at the Pingtung site. At the Taichung experiment, grain yield was 18.6 percent, 20.1 percent, 21.9 percent, and 18.1 percent higher in USG treatments than urea treatments at N rates of 44, 66, 88, and 132 Kg N/ha, respectively. At the Pingtung experiment, grain yield of USG treatment was also higher than that obtained from urea and ammonium sulfate treatments at the same rate of 66 Kg N/ha. At 132 Kg N/ha, while the plant nitrogen content was higher with USG, the grain yield was not the highest. This indicates that application of 132 Kg N/ha of USG was excessive for rice growth in the Pingtung area. The phenomena of over-nutrition was observed. The results obtained from this experiment suggest that the use of USG fertilizer may be very effective for increasing the grain yield of paddy rice in the subtropics. However, the optimum rate of this nitrogen fertilizer may vary with the native nitrogen fertility of the paddy soils. The present nitrogen application rate for paddy rice may need to be readjusted when the use of USG fertilizer is recommended.

INTRODUCTION

Soil nitrogen and fertilizer nitrogen are two sources of nitrogen nutrition for rice growth. In the subtropics, since organic matter is decomposed rapidly due to high temperatures, soils are very often low in organic nitrogen content. Therefore, it might be suspected that fertilizer nitrogen would play an important role in increasing rice yield. However, many field experiments have indicated that nitrogen fertilizer did not increase rice yield very much. For instance, in Taiwan the increase in grain yield of rice has been about one ton per hectare with nitrogen fertilizer (Lian, 1976; Wu, Chung and Liu, 1976). This suggests a lower efficiency of fertilizer use, as indeed the absorption rate of nitrogen fertilizer has been observed to be less than 30 percent on an average (Chiu, 1976). The remainder is mostly lost by volatilization as ammonia and N_2, by leaching of ammonium and nitrate, and by denitrification due to oxidation-reduction processes. The ammonia-volatilization is considerable in alkaline paddy soils. The N loss by leaching through the soil profile would not be so serious, since the

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permeability of water is low in most paddy fields. Oxidation-reduction processes would be the most important cause of N-loss under paddy condition (Broadbent, 1977); De Datta, 1977; Yamada, et al., 1978).

The uppermost layer, usually of several millimeters, of submerged paddy soils is oxidized, while the underlying layer is reduced. Ammonium ions locally placed in paddy soils can move to the oxidized domain and can be oxidized to nitrite or nitrate. Thus formed, these oxidized nitrogen compounds can be readily denitrified by the reduction process, because these anions diffuse quickly into proximate reduced domains (Aomine, 1962). Therefore, controlling the velocity of movement of ammonium ions and the placement of nitrogen fertilizer would be important strategies for increasing the efficiency of nitrogen fertilizer.

Aomine and Juan (1978) studied the movement of ammonium and found that the adsorptive property seemed to be the most influential factor on the movement of ammonium in paddy soils, where the adsorptive property had a close relation with the cation exchange capacity (CEC) of soild. Unfortunately, paddy soils in Taiwan are often low in CEC, probably because of the low specific surface area of soils and the high temperature in the subtropics. Therefore, we may suspect that an application of slow-released nitrogen or deep placement of nitrogen fertilizer would be an effective practice for increasing rice yield, especially in subtropical areas (Marumoto and Higashi, 1976). USG fertilizer was used in this experiment to investigate the effect of different form and rate of nitrogen fertilizer on the yield and nitrogen content of paddy rice.

MATERIALS AND METHODS

Two field experiments located in Taichung and Pingtung were carried out. The soil properties of these two sites are shown in Table 1.

Table 1. Soil properties

	Taichung	Pingtung
Classification	Sandstone-Shale alluvial soil	Slate alluvial soil
Texture	Silt loam	Silty clay loam
pH	6.80	6.30
Organic matter, %	1.45	2.28
Total nitrogen, %	0.088	0.19
CEC, me/100g	11.0	10.6

For the Taichung experiment, two forms of nitrogen fertilizer (USG and urea) were used at rates of 44, 66, 88, and 132 Kg N/ha. For the Pingtung experiment, three forms (USG, urea and ammonium sulfate) were used at rates of 66 and 132 Kg N/ha. The USG, supplied by the International Fertilizer Development Center (IFDC), Alabama, USA, were placed centrally between every four hills of rice, at a depth of around 5 to 8 cm, and used as a single application one week after transplanting. For the USG used in these experiments, mean weight was 0.985 gm and mean N content was 0.441 gm per granule. Urea and ammonium sulfate were applied in three split applications, one-third at transplanting, one-third at maximum tillering, and one-third at panicle initiation. The P and K were applied as superphosphate and potassium chloride at the rates of 60 Kg P_2O_5/ha and 60 Kg K_2O/ha, respectively.

Tainan No. 5 was selected as the test plant. The treatments were arranged in a randomized complete block design with three replications. In both experiments, rice plants were spaced at 20 cm x 25 cm. The area of each plot was 10 m^2 (2 m x 5 m). Rice plants were transplanted on August 12, 1978 and January 1, 1979 in the Taichung and Pingtung experiment sites, respectively.

Plant samples were taken twice, at 80 days after transplanting (DAT) and at harvest at Taichung, and three times, 30, 60, and 90 DAT at Pingtung. All plant samples were dried at 70°C for 24 hours, then ground. Nitrogen determinations were made by Kjeldahl method. Soil analyses were made on samples collected before experiments were set. The results of soil analysis are listed in Table 1.

RESULTS AND DISCUSSION

Effect on Yield and Yield Components

Grain yield and yield components of rice plant at Taichung are shown in Table 2. It is clear that USG treatments increased the grain yield more than urea treatment. The grain yield at 132 Kg N/ha as urea was 33 percent higher than that of no nitrogen fertilizer treatment, while the grain yield of 44 Kg N/ha USG treatment was 40 percent higher than no nitrogen fertilizer treatment. In comparing the grain yield at the same rate of nitrogen fertilizer, USG treatments yielded 18.6 percent, 20.1 percent, 21.9 percent, and 18.1 percent higher than the corresponding urea treatments at 44, 66, 88, and 132 Kg N/ha, respectively.

Tiller number, number of grains per panicle, percent filled grain, and weight of 1,000 grains are shown in Table 2. For these four components, only tiller number per hill was significantly different among treatments. This suggests that USG increased tiller number at the maximum tillering stage as well as at the harvesting stage.

Grain yield, tiller number and height of rice plant at Pingtung is shown in Table 3. The grain yield of each treatment in this experiment was much higher than that of the Taichung experiment. At the rate of 66 Kg N/ha, USG was most efficient in increasing grain yield. However, ammonium sulfate was most effective at the rate of 132 Kg N/ha. The grain yield of USG 132 treatment was not significantly different from that of USG 66 treatment. This suggests that the applications of 66 Kg

Table 2. Yield components of paddy rice at Taichung

Treatment	Grain yield		Tillers per hill		No. of grains	Percent filled grain	wt. of 1000 grains
	Kg/ha	indes	maximum tillering	harvesting	per panicle	%	gm
N-0	2616	100	13.8	9.5	63.9	74.5	24.6
Urea-44	3081	118	17.3	13.2	74.6	81.7	27.2
Urea-66	3081	118	17.8	13.0	71.5	81.9	27.6
Urea-88	3353	128	17.3	13.2	72.7	80.5	26.5
Urea-132	3486	133	19.4	13.5	80.9	79.4	26.4
USG-44	3655	140	17.3	13.8	80.6	79.4	27.8
USG-66	3715	142	19.4	17.3	82.8	81.4	27.5
USG-88	4096	156	22.2	16.2	86.6	82.9	28.0
USG-132	4108	157	23.3	19.2	86.9	77.4	28.1
L.S.D. 5%	409		2.6	3.1	NS	NS	NS
L.S.D. 1%	604		3.5	4.1			

Table 3. Grain yield, tillers number and height of rice plant at Pingtung

Treatment	Grain yield		Tillers per hill		Plant height, cm	
	kg/ha	index	panicle initiation	harvesting	panicle initiation	harvesting
N-0	5693	100	20.0	18.3	63.8	87.7
Urea-66	6735	118	22.8	20.8	67.0	95.6
Urea-132	7292	128	23.1	21.7	72.7	102.2
USG-66	7152	126	23.2	22.0	71.5	99.4
USG-132	7360	129	25.1	22.8	76.1	107.6
AS*-66	6937	122	23.5	21.1	68.2	96.3
AS -132	7506	132	24.6	22.7	74.1	101.3
L.S.D. 5%	379		2.6	2.6	4.0	5.0
L.S.D. 1%	526		--	--	5.7	6.9

AS*: Ammonium Sulfate.

N/ha as USG might be sufficient for rice growth while using 132 Kg N/ha as USG might be in excess. Although the grain yield was not significantly different, plant height of USG 132 treatment was found significantly greater than that of USG 66 treatment. This indicates that too much nitrogen was supplied for rice plant with USG 132 treatment at the early stage, which resulted in vigorous vegetative growth and delayed reproductive growth.

Effect on Plant N Content

Nitrogen content of rice plants at Taichung is shown in Table 4.

Table 4. Plant nitrogen content of paddy rice at Taichung

Treatment	N content, %		
	Straw		grain
	80 DAT*	harvesting	
N-0	0.907	0.820	1.187
Urea-44	0.957	0.877	1.280
Urea-66	1.017	0.977	1.353
Urea-88	1.097	0.977	1.373
Urea-132	1.353	1.113	1.453
USG-44	1.030	1.097	1.360
USG-66	1.110	0.990	1.357
USG-88	1.127	1.227	1.400
USG-132	1.543	1.110	1.383
L.S.D. 5%	0.256	NS	0.162
L.S.D. 1%	--		--

DAT*: Days after transplanting.

At 80 days after transplanting (DAT), the plant N content of USG treatments was higher than that of urea treatments. However, there were no differences in N content in grain between USG and urea treatments. The following formula was used to estimate the absorption rate of nitrogen fertilizer:

Absorption rate of N-fertilizer (%)=

$$\frac{\text{N in N-fertilized plant} - \text{N in no N-fertilized plant}}{\text{amount of N applied}} \times 100$$

Absorption rates shown in Figure 1 indicate that 76 percent, 51 percent, 59 percent, and 42 percent of N in USG form were absorbed, while only 27 percent, 32 percent, 32 percent, and 30 percent of N in urea form could be absorbed at the rates of 44, 66, 88, and 132 Kg N/ha, respectively.

The nitrogen content of rice plants at Pingtung is shown in Figure 2. The plant nitrogen content of USG 132 treatment was much higher than that of USG 66 and the other treatments. This shows more evidence in addition to plant height for the result of over-nutrition of USG 132 plants. Ishizuka (1976) suggested that there are three harmful effects from excess supply of nitrogen: delay of the onset of the next stage of growth, greater susceptibility to lodging, and favoring the growth of pathogenic fungi such as rice blast pathogens. In the Pingtung experiment, no pathogenic disease or lodging were observed. Therefore, delay of plant growth might be the main cause, resulting in insignificant differences in grain yield between USG 66 and USG 132 treatments.

Optimum Rate Under Subtropical Climatic Condition

Reconsidering the yield response to application of nitrogen fertilizer and the soil properties of two experimental sites, a relation between yield response and soil properties might be observed. As mentioned before, the organic nitrogen content of soil in the subtropics is quite low, so the yield response might be very critical to the increase of soil nitrogen content. Pingtung soil had a higher soil nitrogen content than Taichung soil (0.19 percent and 0.088 percent, respectively), and we may suspect that Pingtung soil could supply more nitrogen for plant growth than Taichung soil. For this reason, the grain yield continued to increase at Taichung even when USG was applied at 132 Kg N/ha. In the case of Pingtung, the grain yield was not significantly increased by USG when the N rate was raised from 66 to 132 Kg N/ha.

Yield response to nitrogen fertilizer, particularly USG treatments, might also have been influenced by climate. The experiment at Taichung was carried out from August to December; in other words, during the crop season when the temperatures went from high to low. In contrast, the Pingtung experiment was carried out from January to April, or when the temperatures went from low to high. The different temperature patterns might influence the mineralization rate of organic nitrogen in soil and the N absorption rate of the plants and then influence the yield response to nitrogen fertilizer.

In conclusion, USG has proved to be effective in paddy soils in terms of N absorption rate and yield response, especially in the subtropics. The optimum rate of N fertilizer may vary in different soils due to the variation of the nitrogen supplying capacity of the soils. The present application rate of N fertilizer in most rice countries may need to be reduced by 20 to 30 percent if USG fertilizer is recommended.

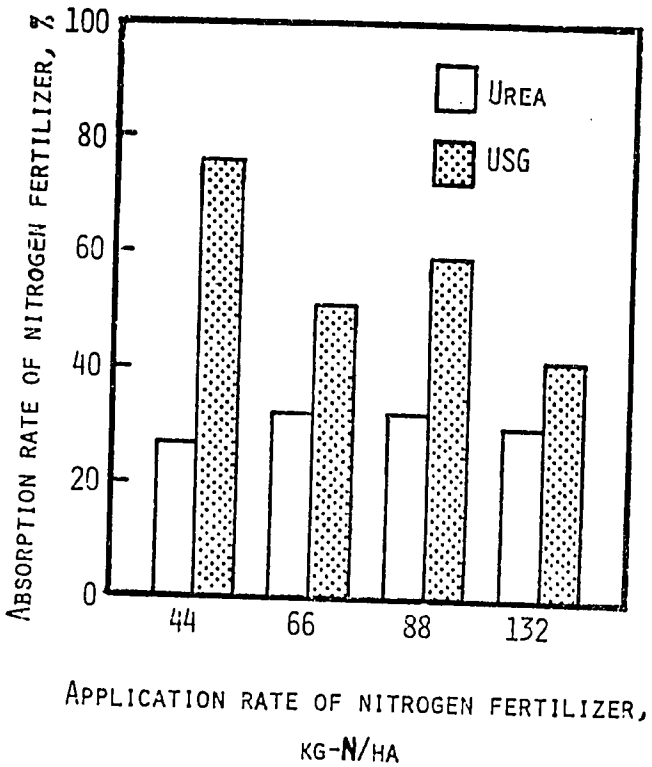

Fig. 1. Absorption rate of nitrogen fertilizer of paddy rice at Taichung.

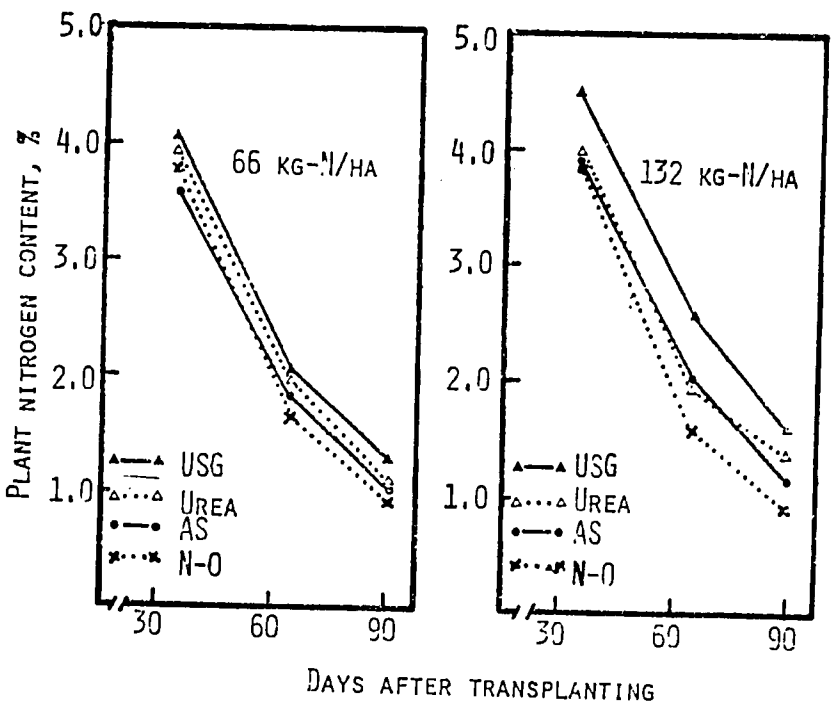

Fig. 2. Plant nitrogen content of paddy rice at Pingtung.

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EFFECTIVENESS OF FERTILIZER USE: AN ASSESSMENT OF THE GRAIN:FERTILIZER RATIO

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SUMMARY

A survey of N yield response data from some 8500 rice experiments and 6100 wheat experiments conducted in Bangladesh, Egypt, India, Philippines and Canada/U.S.A. indicates that grain:fertilizer-use ratios of between 14 and 20 may be expected for rice and between 17 and 21 for wheat, at fertilizer applications of between 50 and 100 kg N/ha, under average farming conditions. This would indicate that the currently held value of 10 as the average grain:fertilizer-use ratio, is fairly conservative. We feel that this can be safely revised to 15, particularly for the high-yielding varieties of rice and wheat. Values of up to 20 may be more in order, particularly at N applications of between 50 and 100 kg/ha.

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Fertilizer use continues to grow in the world. This is particularly true in developing countries where current usage is low and the need to increase food production, high. However, most of these countries do not currently produce adequate fertilizer to meet domestic need. Those endowed with suitable raw materials are increasing or planning to increase fertilizer production; others continue in their quest for assured, reasonably priced, supplies over long periods of time.

Estimation of long-range fertilizer needs is essential for designing internal fertilizer manufacturing capacities as well as projecting import needs. In either case, we need a sound basis on which these estimates may be prepared, as fertilizer surpluses may bring about financial losses, and fertilizer deficits, food production shortages.

Planners use various bases for projecting long range fertilizer needs. These include:

- trend analysis
- estimation of price incentives, credit and other support likely to be available to farmers
- analysis of agricultural development programs likely to be implemented
- consideration of food production targets being planned

For planning purposes, a rule of thumb generally followed is to assume that 10 kg of food grain are produced by using one kg of fertilizer nutrient. This is based on cumulative experience with fertilizer use over a number of

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years. More recently, however, crop varieties grown and crop management practices used have changed significantly. In such a situation, this grain:fertilizer ratio (GFR) of 10:1 may need revision. We, therefore, endeavored to re-examine this figure on the basis of more recent results reported in the literature.

METHOD OF ASSESSMENT

We conducted a literature search to obtain a general pattern of the response of crops to fertilizer use in various countries. Rice and wheat were the two crops surveyed in view of their particular importance in developing countries. In most cases, the data obtained pertained to dwarf, fertilizer-responsive varieties of these two crops. Bangladesh, Egypt, India and Philippines were surveyed for rice; and Egypt, India, and U.S.A./Canada, for wheat. This was because these two crops are important in these countries, and also because data pertaining to them was more readily available. The Philippines data was also segregated on wetland and dryland basis. The various sources from which data was obtained are listed under References.

Results of some 8500 rice experiments and 6100 wheat experiments from these countries were pooled together and an analysis of the average response of the two crops to nitrogen application was undertaken. We considered yield response to nitrogen only as simultaneous consideration of P and K would have confounded the analysis.

The original works and reviews that were included in this analysis are cited in the bibliography. Results of a coordinated N efficiency study on rice conducted in 7 countries under the East-West Center's INPUTS project (Yamada et al., 1979), have also been considered in our analysis.

RESULTS AND DISCUSSIONS

Regression equations for crop response to N in various countries are indicated in Table 1. Considerable locational variation was found in the response of rice and wheat to N application. This would be expected from the variation in agroclimatic conditions, inherent soil fertility, and crop varieties used among the various experimental locations. In some countries, the average response was linear, reflecting perhaps that higher levels of N need to be considered there. In other countries, the response was quadratic. Under these conditions the grain:fertilizer-use ratio (GFR) was found to decrease with increasing levels of N application. Combined analysis of data from all countries resulted in an average GFR on rice of about 29 at 10 kg N/ha application, dropping to 18 at 100 kg N/ha and to 12 at 150 kg N/ha (Fig. 1). Corresponding GFR figures for wheat were about 31, 22 and 17 (Fig. 2).

Table 1. Crop Response to Nitrogen Use--Regression Equations for Rice & Wheat

Country	Regression of Yield Response to Nitrogen	
	Rice	Wheat
Bangladesh	$Y = 1828 + 17x$	
Egypt	$Y = 5301 + 30x - 0.21x^2$	$Y = 3021 + 11x$
India	$Y = 3428 + 10x$	$Y = 1799 + 31x - 0.06x^2$
Phil. pines		
Dryland	$Y = 4079 + 53x - 0.23x^2$	
Wetland	$Y = 4442 + 9x$	
U.S.A./Canada		$Y = 2617 + 33x - 0.12x^2$
Average (all countries)	$Y = 3642 + 30x - 0.12x^2$	$Y = 1975 + 32x - 9.102x^2$

FIG. 1
RESPONSE OF RICE TO N APPLICATION
(ALL COUNTRIES COMBINED)

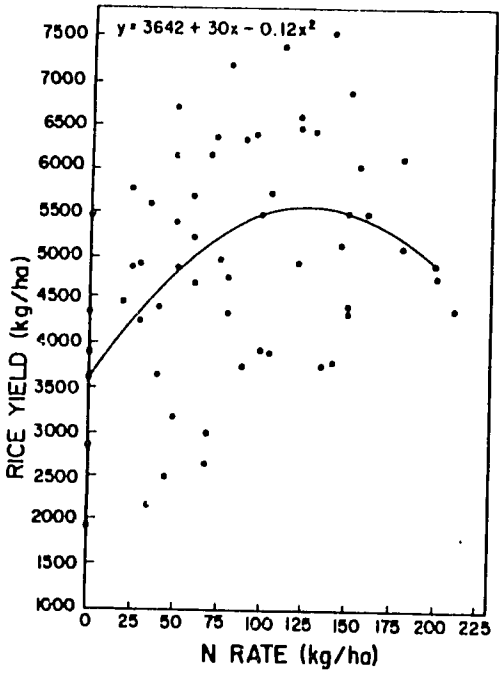
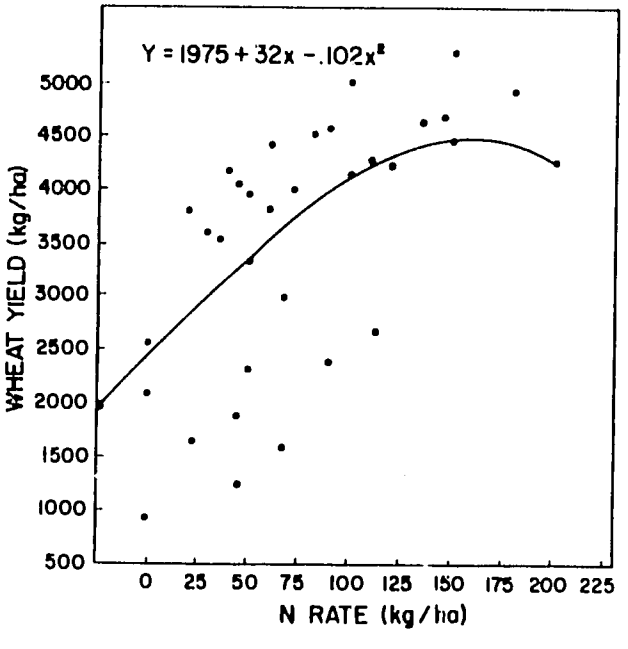


FIG. 2
RESPONSE OF WHEAT TO N APPLICATION
(ALL COUNTRIES COMBINED)



Rice

In the case of rice, linear response to N was obtained in Bangladesh, India, and Philippines (wetland), with GFR values of about 16 in the first named country, and about 10 in the other two (Table 2). In Egypt and the Philippines (dryland), the response was quadratic, with GFR values ranging

TABLE 2. ESTIMATED YIELDS OF RICE AND GRAIN:FERTILIZER RATIOS AT DIFFERENT N RATES IN SELECTED COUNTRIES

N Rate	11 countries combined		Bangladesh		Egypt		India		Philippines (Dryland)		Philippines (Wetland)	
Kg/ha	Yield Kg/ha	G:F Ratio	Yield Kg/ha	G:F Ratio	Yield Kg/ha	G:F Ratio	Yield Kg/ha	G:F Ratio	Yield Kg/ha	G:F Ratio	Yield Kg/ha	G:F Ratio
0	3642	-	1828	-	5301	-	3428	-	4079	-	4442	-
10	3934	29.2	1994	16.6	5986	28.4	3529	10	4589	50.9	4538	9.6
20	4202	28.0	2160	16.6	5828	26.3	3630	10	5053	48.7	4633	9.6
30	4446	26.8	2326	16.6	6036	24.5	3731	10	5470	46.4	4729	9.6
40	4665	25.6	2492	16.6	6187	22.1	3832	10	5842	44.1	4824	9.6
50	4861	24.4	2658	16.6	6303	20.0	3933	10	6168	41.8	4920	9.6
70	5180	22.0	2990	16.6	6410	15.8	4135	10	6681	37.2	5111	9.6
100	5479	18.4	3488	16.6	6254	9.5	4438	10	7106	30.3	5398	9.6
150	5498	12.4	43.8	16.6	5155	-	4943	10	6895	18.8	5876	9.6
200	4916	6.4	5148	16.6	-	-	5448	10	5533	7.3	6354	-

from 29 (at 10 kg N/ha) to -11 (at 200 kg N/ha) in the former, and from 51 to 7 at the same N levels, in the latter. Data from the INPUTS study indicates a linear response to N in practically all countries, with GFR ranging between 7 and 35 in individual countries and averaging around 19 (Table 3). This pattern was obtained when N was applied as urea in the conventional broadcast-and-incorporate manner. When N was deep-placed as urea supergranule (USG), however, the response to N increased considerably and a quadratic pattern emerged in most countries with GFR values averaging 31 and 23 at 10 and 100 kg N/ha, respectively. Decreased N losses due to deep placement of USG in the reduced soil zone is considered to be the factor contributing to the increased N efficiency in this case (Yamada et al., 1979).

TABLE 3. GRAIN:FERTILIZER RATIOS FOR RICE
SUMMARY OF INPUTS STUDIES IN VARIOUS COUNTRIES

	Grain:Fertilizer Ratios at Various N (Kg/ha) Levels														
	1975-76 Results					1978-79 Results									
						With Urea					With USG				
Country	10	30	50	70	100	10	30	50	70	100	10	30	50	70	100
India (1)	30	23	21	19	15	19	19	19	19	19	53	44	40	36	30
Korea	28	18	17	17	16										
Japan (1)	23	19	9	8	7	19	19	19	19	19	18	18	18	18	18
Iran	32	28	7												
Egypt	31	27	24	20	13										
Korea (1)	27	15	15	14	14										
Taiwan (1)	22	22	22	22	22	6.6	6.6	6.6	6.6	6.6	11	11	11	11	11
Taiwan (2)	6	6	6	6	6										
Pakistan (1)	55	55	55	55	55	15	15	15	15	15	18	18	18	18	18
Korea (2)	34	19	18	18	17										
Pakistan (2)						12	12	12	12	12	18	18	18	18	18
India (2)						35	35	35	35	35	71	67	63	58	18
Bangladesh						22	22	22	22	22	16	16	16	16	16
Sri Lanka						18	18	18	18	18	44	41	37	33	28
Philippines						32	29	26	24	20	50	45	40	35	28
Japan (1)						12	12	12	12	12	33	31	28	25	21
Average	28.8	22.3	19.4	17.9	16.5	19.1	18.8	18.8	18.7	18.7	31.4	29.3	27.5	25.5	23.0

Wheat

In the case of wheat, linear response to N was observed in India, with GFR around 23 (Table 4). In Egypt and Canada/U.S.A., on the other hand, a quadratic response to N was obtained. In this case, GFR ranged between 17 and 12 in Egypt, and between 32 and 9 in Canada/U.S.A., at 10 and 200 kg/ha application, respectively.

TABLE 4. ESTIMATED YIELDS OF WHEAT AND GRAIN:FERTILIZER RATIOS AT DIFFERENT N RATES IN SELECTED COUNTRIES

N Rate	All countries		India		Egypt		U.S.A & Canada	
Kg/ha	Yield Kg/ha	G:F Ratio	Yield Kg/ha	G:F Ratio	Yield Kg/ha	G:F Ratio	Yield Kg/ha	G:F Ratio
1	1976	-	1799	-	3021	-	2617	-
10	2283	30.8	2237	23	3047	16.7	2932	31.5
20	2571	29.8	2466	23	3209	16.4	3223	30.3
30	2838	28.8	2696	23	3364	16.1	3490	29.1
40	3086	27.8	2926	23	3513	15.8	3733	27.9
50	3313	26.8	3156	23	3656	15.5	3953	26.7
70	3708	24.8	3615	23	3925	14.9	4319	24.3
100	4151	21.8	4305	23	4282	14.0	4688	20.7
150	4488	16.8	5454	23	4758	12.5	4824	14.7
200	4328	11.8	6603	23	5084	11.9	4359	8.7

Notwithstanding locational and varietal variations that may result in big differences between GFR values for rice and wheat in individual cases, the similarity in trend and magnitude between the average GFR values for the two crops is noteworthy. This is quite understandable considering the similarities in the growth and rooting habits between the two crops, when dwarf varieties of one are compare with dwarf varieties of the other, and traditional varieties of one, wi se of the other.

Since the yield response to N is quadratic in most cases, GFR values accordingly vary with N. Thus, in developing any rule of thumb regarding how many kg of food grain will result from a kg of N application, it is also important to specify the N level under consideration. In most developing countries, the current use of fertilizer is low, and ranges between 5 and 35 kg N/ha in the Asia/Pacific region (FAO, 1979). Thus, greater benefit from N application can be expected here than in those developed areas where average N application is over 100 kg/ha. In the case of rice, a GFR of between 18 and 25 can be possible with N applications of between 50 and 100 kg/ha; in the case of wheat, corresponding GFR figures will be between 27 and 22.

A factor to consider, however, is that the above-mentioned results were obtained in controlled experiments, most of which were conducted at experimental stations, and under close supervision and improved management practices. Under farmers' conditions, a decreased efficiency can be expected. We would like to give a 25 percent margin for this.

Thus, under farmers conditions, grain:fertilizer ratios of between 14 and 20 may be expected for rice with N applications of between 50 and 100 kg/ha; and between 17 and 21 for wheat at same levels of N use. More recent

data from Pakistan (Saleem and Bertilsson, 1980) received too late for inclusion in the above analysis, indicates a GFR range of 8.7 to 13.8 for wheat, and 8.3 to 13.0 for rice. Their experiments were conducted in farmers' fields.

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ASSESSMENT OF ARABLE LANDS

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ABSTRACT

One of the dilemmas facing the Asia-Pacific nations is the finding of a solution to the food/population equation. With two-thirds of the world's population inhabiting this region, the critical need for food production efficiency is obvious. However, the agriculturally-related resource information available to food production decision-makers and policy-makers is woefully inadequate. This paper seeks to define the resource information problem, to describe new resource data acquisition and analysis systems, and to propose a research agenda for the Asia-Pacific in the 1980s. The long range objective of the suggested research is to provide a resource information system which can deliver accurate, useful, timely and financially affordable resource information to decision-makers.

THE FOOD/POPULATION EQUATION

Most of the papers presented thus far in this conference have dealt with facts and descriptions of past and current situations as these relate to fertilizer flows and needs in the Asia-Pacific region. This paper will explore the difficult problems related to future fertilizer needs by assessing the arable lands of the Asia-Pacific region.

During the past decade, increasing attention, with frequent expressions of alarm, has been given to the global population/food dilemma. However, even prior to the 1970s over a period of two centuries, thoughtful and concerned persons wrestled with problems related to the carrying capacity of the world. Since 1798, when Thomas Malthus published "An Essay on the Principle of Population," there have been repeated warnings that the human population, subject to exponential increase, could--or at some time surely would--overtake food supplies, which Malthus assumed could increase only arithmetically.

Across the centuries there have been localized famines and some food shortages of wide extent. During this century there were major shortages in the years following World War I, in the late 1940s and early 1950s following World War II, in the mid-1960s after two years of drought on the Indian subcontinent, and in the early 1970s when world grain production dropped 35 million tons. Yet it has been only since 1960 that large numbers of people and national and world leaders began to appreciate the serious and chronic nature of the world food problem.

Even the most optimistic projections give cause for concern in providing food for the global population during the decades ahead.

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There is an urgent need for more accurate and effective food and population information which can carefully monitor significant changes in population and food supply.

Recently, Dudal (1978) summarized the results of numerous studies related to the world's capacity to feed a rapidly expanding population. These studies reveal great differences among the estimates of arable land within a finite total land area. The food production from the world's arable lands is highly variable and is greatly affected by the technology which is used and by the various social and economic conditions which prevail. Moreover, land which is considered arable for cassava or sugarcane may not be suitable for wheat and soybeans. The lands of the world which have been classified as arable represent an exceptionally broad range in potential productivity of food.

According to Dudal (1978) the area of arable land increased by 135 million hectares during the 1957-1977 period, an increase of approximately nine percent of the current 1.5 billion hectares of cultivated land in the world. During the same period the world's population increased from 2.8 to 4 billion, an increase of 40 percent. In terms of increased production, the additional arable land at a low level of agricultural inputs would provide food for only an additional 400 million people. The food supplies for the 800 million additional people have been obtained from an intensification of agriculture on land already under cultivation. This intensification is reflected, in part, by a dramatic increase of annual fertilizer use, from 24 million tons of plant nutrients (N, P_2O_5, K_2O) in 1957 to 88 million tons in 1976/77, and a considerable expansion of irrigation. It is significant, however, that 110 million hectares or 70 percent of the additional arable land was added in developing countries while intensification of production occurred in industrialized nations which consumed 85 percent of the world's fertilizer production.

The food production task in Asia-Pacific then has two vital components or requirements:

- o identification, assessment and development of current and potentially arable land, and
- o intensification of production on currently cultivated lands.

The remainder of this paper will address the problem of identifying and assessing arable lands.

NEW INFORMATION TECHNOLOGY FOR RESOURCE ASSESSMENT

The past two decades which produced dramatic changes in the global food/population equation have brought equally dramatic changes in our capabilities to survey and monitor the earth surface environment.

In 1948 the British astrophysicist Fred Hoyle wrote: "Once a photograph of the Earth, taken from the outside, is available--once the

sheer isolation of the Earth becomes plain--a new idea as powerful as any in history will be let loose."

Soon after being named by President Carter as administrator of NASA, Dr. Robert Frosch (1977) made this observation:

> We are the first generation to see the Earth as a whole. For centuries man has observed and tried to represent by drawings tiny areas of the Earth surface. He would piece these drawings together in an attempt to show what the Earth would look like if he could see it as a whole. A few decades ago he made a great leap forward by inventing the camera, then later placing the camera on aircraft. By these developments man extended his powers of observing the surface of the Earth. He could see much larger areas and less piecing together was necessary. But this is the first generation that has seen data that went the other way. Data which provide a broad synoptic view of the Earth can also be used to extract great details. So in a sense, we have turned the whole enterprise around. Instead of starting with the details and trying to construct the big picture, we now have the capability to go the other way--to look at the big picture and then figure out how to extract the details that explain it.

One of our major concerns in this conference is to see the big picture related to arable lands in Asia and the Pacific and then to analyze the changes necessary to make those lands more productive and to determine how much fertilizer is needed on these arable lands during the next two or three decades. One of the dilemmas we face is that of obtaining information essential to making an accurate, credible assessment of arable lands and fertilizer needs.

For decades scientists have been steadily adding to our understanding of soils, climate, and agricultural production. In fact, ninety percent of all the scientists who have ever lived are working now. And mankind's store of knowledge is doubling at least three times per century. The new technology related to observation and monitoring earth surface features promises to accelerate our knowledge of land, vegetation, and water resources. This may be especially significant in those land areas of the world where there is limited information about the soils and their potential productivity, and about crop response on these soils to different kinds of management.

However, there are many areas in Asia-Pacific where decision makers and policymakers cannot wait for 30 years to double our knowledge of land resources and management systems capable of providing adequate, nutritious food for the expanding populations. Three areas of recent technological developments related to agricultural and food information systems promise to reduce the time to provide essential resource information.

1. Data Acquisition

Major advancements have been made since 1960 in instruments, remote sensing devices, equipment, and sampling strategies for observing, characterizing, and monitoring a target or scene. New data acquisition

methods in the laboratory, in the field, from air and space platforms provide new vistas of the earth, never available before, from the sub-atomic structure to thousands of square kilometers in a single synoptic view of the environment at the earth surface.

2. Data Analysis

Traditionally, the ability of the observer, whether scientist or poet, to acquire data has by far exceeded his ability to analyze and interpret data. The computer revolution of the past 25 years has provided a giant leap forward in the human capability to cope with the masses of data which are accumulated. Ruth Davis (1977), writing on the evolution of computers and computing, states: "Computers are properly cited as the first as well as the most important invention ever that significantly extends man's intellectual capabilities. Until the age of computers, inventions had primarily extended our muscular powers as well as certain of our sensory powers."

Davis predicts that the decreasing costs and decreasing size of computers and logical devices will put these scientific artifacts into the hands of large numbers of individuals. Further, man will continue to increase the number of "intelligent" tasks for computers faster than he does for himself.

The computers, or hardware, together with the computer language and analytical programs, or software, which have evolved within the past two decades place at our disposal a "never before" capability to store, retrieve, overlay, analyze, and interpret vast quantities of data. Perhaps this capability provides a new opportunity to explore the relationships between the many complex facets of global food production--physical, biological, chemical, cultural, economic, political, and social.

3. Information Dissemination

The technology of communication is another of man's activities which has undergone revolutionary changes during the past two decades. It is now possible to instantaneously transmit voices, images and large masses of data from any spot to any other place on the surface of the earth.

A development which integrates these three areas of technology is the Earth Resources Observation satellite program. The launch of Landsat 1 by the National Aeronautics and Space Administration (NASA) in July 1972 ushered in a new era of earth observations. Landsats 2 and 3 followed in January 1975 and March 1978, respectively. Landsat D, which will become Landsat 4 after a successful launch, is scheduled to be placed in polar orbit in 1982 followed by Landsat D' in 1983. Landsat 1, 2, and 3 are in near polar, sun synchronous orbit at an altitude of approximately 920 kilometers. The orbital and scanner designs are such that each satellite has the capability of scanning the surface of the earth every 18 days. After five years of successful data acquisition, Landsat 1 was retired from service in January 1978.

The satellites are equipped with return beam vidicon cameras (RBV) and multispectral scanners (MSS). Specifications for Landsats 1, 2, and 3 are summarized in Table 1.

TABLE 1--SPECIFICATIONS OF THE RETURN BEAM VIDICON (RBV) CAMERA AND THE MULTI-SPECTRAL SCANNERS (MSS) ON LANDSATS 1, 2 AND 3.

Landsat	Sensor	Spectral Bands (UM)	Description	Spatial Resolution (M)
1, 2	RBV	0.475 - 0.575	visible blue, green	80
		0.580 - 0.680	visible orange, red	80
		0.69 - 0.83	near infrared	80
3	RBV	0.505 - 0.750		38
1, 2, 3	MSS	0.5 - 0.6	visible green	80
		0.6 - 0.7	visible red	80
		0.7 - 0.8	near infrared	80
		0.8 - 1.1	near infrared	80
3		10.4 - 12.6	thermal infrared	240

Landsat D and D' will have a nominal orbital altitude of 705 km and will maintain a 16-day cycle of repetitive coverage. The MSS of Landsat D and the two on-board sensors (MSS and thematic mapper, TM) of D' will provide ground coverage of about 185 x 170 km per scene. The MSS will obtain data in the same four bands as those on previous Landsats and have the same instantaneous field of view (80 m). The TM, a line-scanning device also, will operate over seven bands and have an instantaneous field of view of 30 meters (Table 2).

TABLE 2--SPECIFICATIONS OF THE THEMATIC MAPPER OF LANDSAT D'

Spectral band (m)	Description	Spatial Resolution (m)
0.45 - 0.52	visible blue	30
0.52 - 0.60	visible green	30
0.63 - 0.69	visible red	30
0.76 - 0.90	near infrared	30
1.55 - 1.75	middle infrared	30
2.08 - 2.35	middle infrared	30
10.40 - 12.50	thermal infrared	120

Data from the Landsat sensors are transmitted to receiving stations in digital form. Receiving stations in operation as of May 1979 include the following:

United States of America (3 stations)

- Greenbelt, Maryland
- Goldstone, California
- Fairbanks, Alaska

Canada (2 stations)

- Prince Albert, Saskatchewan
- Shoe Cove, Newfoundland

Brazil - Cuiaba

Iran - Tehran

Italy - Fucino

Japan - Tokyo

Sweden - Kiruna

Receiving stations are under construction in Argentina, Australia, and India. The common reception radius of ground receiving stations is 2,780 km.

The products available from receiving stations include black and white single-band images, false color (multiband) images, and digital data on computer compatible tapes. These images can be analyzed and interpreted by visual methods or the digital data can be analyzed by computer-implemented pattern recognition techniques.

APPLICATIONS OF EARTH OBSERVATION SYSTEMS FOR ARABLE LAND ASSESSMENT

Since the launch of Landsat 1, agricultural scientists in many nations have used satellite data to inventory and monitor earth surface features related to agriculture production. For the purposes of this paper, the discussion in this section will be restricted to the use of remote sensing technology for assessment of arable land resources.

One of the most obvious agricultural applications is the identification and area measurement of cultivated crops (NASA, 1978). Equally important but somewhat more complex is the use of these techniques to

predict crop yields. An increasing research effort is being expended to use remotely sensed data as one of the inputs for improving the accuracy and updating of crop yield predictions.

During the 1970s scientists in increasing numbers have been exploring methods of using satellite-derived images for delineating meaningful soil boundaries and characterizing soil conditions. One of the important uses of Landsat images is as a base from which preliminary soil legends can be described and general soil differences can be mapped. A single satellite image has a particular advantage over aerial photography because it provides a synoptic view of a contiguous area covering 34,000 km^2. This synoptic view is valuable to the soil surveyor in correlating soils mapped in adjacent counties or political units by different surveyors at different times.

Visual interpretation of black and white and false color images produced from Landsat data were used by Westin and Frazee (1976) to produce general soil maps at scales of 1:250,000 or smaller with map units of 260 hectares or larger. Weismiller, et al. (1979) visually interpreted black and white and false color images produced from Landsat data to determine soil parent material boundaries in Jasper County, Indiana (Figure 1). Confirming these boundaries by field observations, they then digitized these boundaries and overlaid them onto the four Landsat MSS bands which had been adjusted to a scale of 1:15,840. Spectral maps delineating soil differences were then produced at this scale with map units as small as one hectare. These maps delineating more than 50 different spectral classes in six different parent material areas are being used by soil surveyors as an additional valuable tool for a detailed soil survey of Jasper County, Indiana (Figure 2).

The digital format of Landsat MSS data permits rapid and easy merging and/or recombination of spectral classes to produce a wide array of smaller-scale base maps for soil survey at different levels of generalization.

There is increasing evidence that Landsat data can be useful for mapping and monitoring land degradation caused by wind erosion, water erosion, salinization and flooding. A striking example of denudation and sand dune encroachment caused by wind action can be seen in an area along the Wadi Abu Habl in Western Sudan (Fig. 3). The same data from which the synoptic view of the area at a scale of 1:250,000 was produced, was also used to examine in detail, at a scale of 1:25,000, the characteristics of the cultivated areas of one of the sand dunes (Figure 4). The three spectral classes of the cultivated sands seemed to correlate well with the areas of millet, peanuts, and fallow.

Severe erosion caused by rainfall has been detected and separated spectrally in the humid temperature region of northern and central Indiana (Figure 5). In these cultivated soils, the exposure of subsoil resulting from severe erosion gives reflectance values measured by the satellite sensors which are considerably different from those of the less eroded surrounding soils.

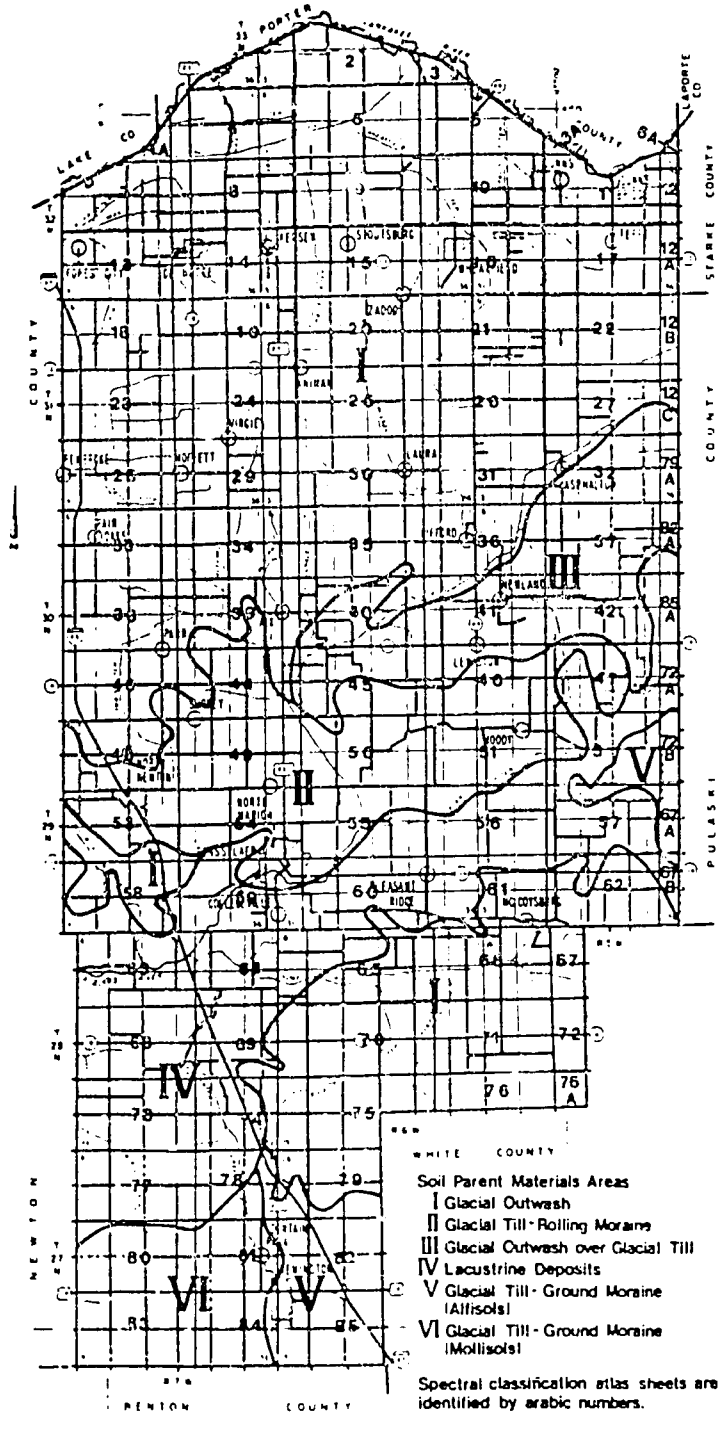
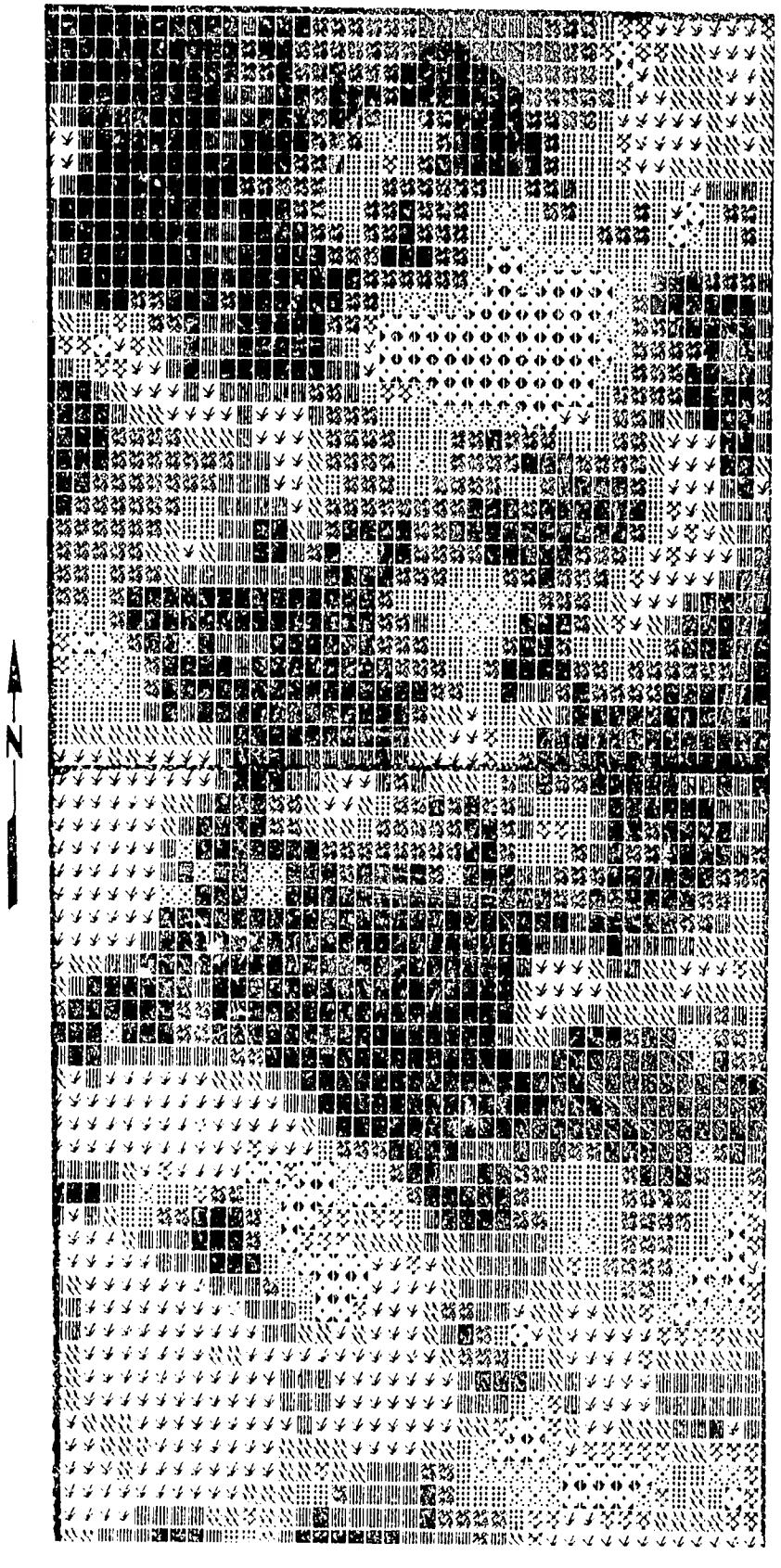


Figure 1. Parent material map of Jasper County, Indiana produced from visual interpretation of Landsat images. Original scale 1:125,000.



LEGEND

Class 1 - Excessively to well drained soils with significant inclusions of somewhat poorly drained soils. Very minor inclusions of very poorly drained soils also occur.

Class 2 - Somewhat poorly drained soils with significant inclusions of both excessively to well drained and very poorly drained soils.

Class 3 - Very poorly drained soils with significant inclusions of excessively to well drained and moderately well drained soils. S/V*

Class 4 - Very poorly drained soils with minor inclusions of excessively to well drained and somewhat poorly drained soils.

Class 5 - Very poorly drained soils with minor inclusions of somewhat poorly drained and excessively to well drained soils. S/V*

Class 6 - Very poorly drained soils with minor inclusions of somewhat poorly drained soils. Extremely small amounts of excessively to well drained soil inclusions occur.

Class 7 - Very poorly drained soils with very minor inclusions of somewhat poorly drained soils. S/V*

Class 8 - Very poorly drained soils with very minor inclusions of somewhat poorly drained soils.

Class 9 (Vegetation) - Predominantly very poorly drained soils. Significant inclusions of excessively to well drained, moderately well drained and somewhat poorly drained soils occur.

Figure 2. Spectral map delineating soil characteristics of an outwash area in Jasper County, Indiana. Scale 1:15,840

Key to prominent features in landscape:

1. Er Rahad (town)
2. Er Rahad Reservoir
3. Floodplain of Wadi Abu Habl
4. Jebel Ed Dair (granite hill)
5. Upland Clay Plain
6. Umm Ruwaba (town)
7. Sand Dunes
8. Villages

Figure 3. Landsat image showing denuded areas and dune encroachment along Wadi Abu Habl in Western Sudan. Original scale 1:250,000.

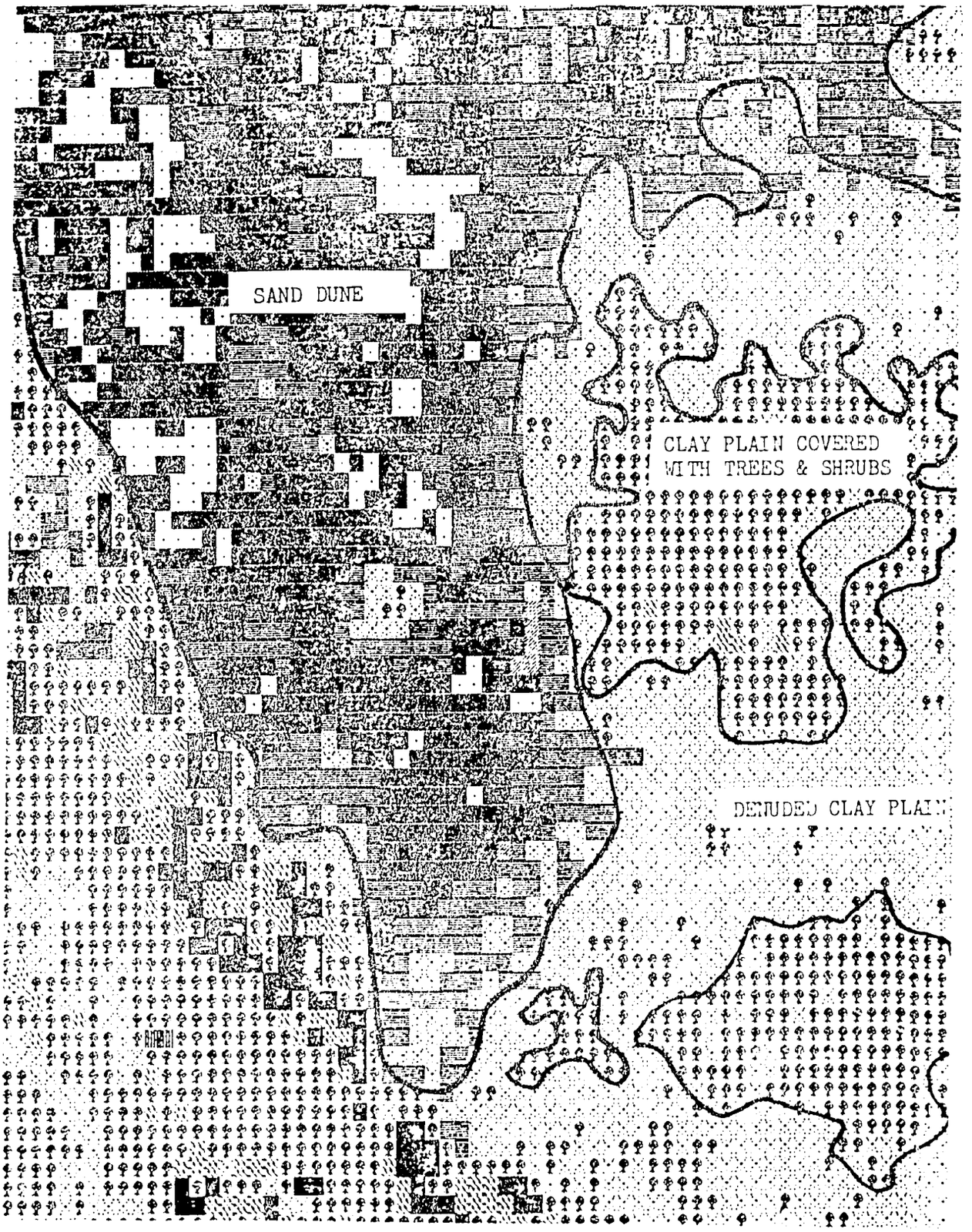


Figure 4. Detailed spectral map of dune area south of Wadi Abu Habl in Western Sudan. Scale 1:25,000

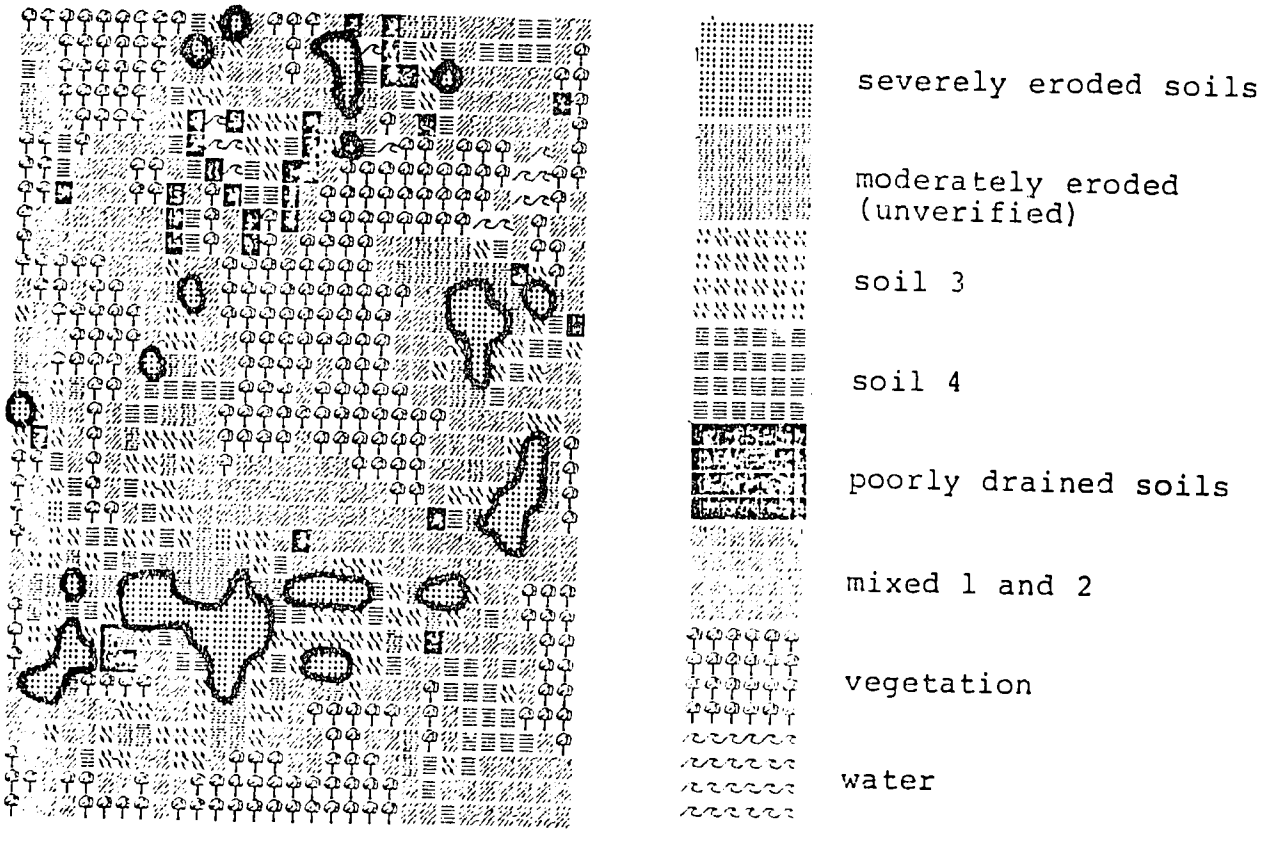
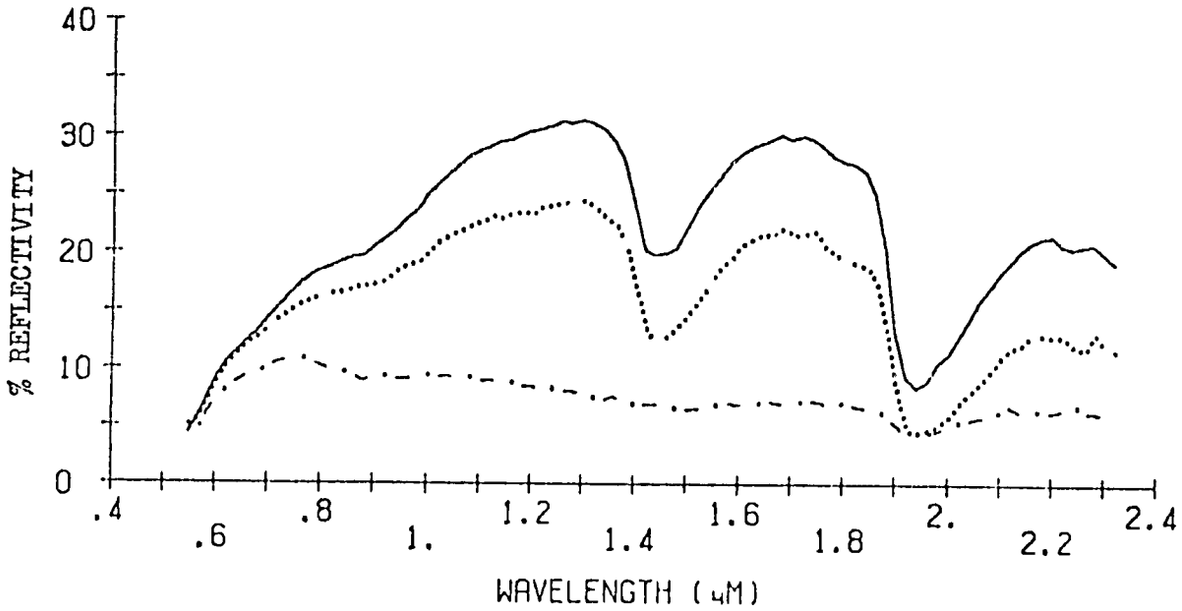


Figure 5. Spectral map units delineating severely eroded soils from other soil and vegetation classes. Scale 1:24,000.

Our ability to interpret spectral measurements obtained by multispectral scanners is greatly dependent upon our understanding of the spectral or reflectance properties of earth surface features--soils, crops, trees, water. Currently, several studies are being conducted to determine quantitative relationships between spectral and other propertie of soils. An example of the value of spectral analysis is the comparison of three different soils described by soil surveyors in the field as dark red and assigned Munsell color notations of 2.5 YR 3/6 (Figure 6). Although the differences in visible reflectance (0.4 - 0.7 μm) is not great, the differences in the near and middle infrared (0.7 - 2.5 μm) is dramatic. Similar spectral differences can be shown between severely eroded soils, non-eroded soils, and depositional soils among soils associated in an erosional sequence.

Here is a valuable tool to aid in the delineation of visually similar soils but with wide spectral differences which may be related to texture, internal drainage, water holding capacity, degree of weathering, fertility status, and potential productivity. A concerted research effort should be made to increase our knowledge of these relationships

so that remote sensing technology can be used more effectively in the assessment of arable lands and other resources.



Key to Soils Data

Soil	Curve	% Organic Matter	% Fe_2O_3
Dill (Oklahoma,USA)	——	0.6	0.87
Arroyo (Spain)	••••	1.28	2.00
Londrina (Brazil)	•-•-	2.28	25.6

Figure 6. Reflectance curve for three dark red surface soils having moist Munsell color notations 2.5 YR 3/6. (Stoner, 1979)

FUTURE APPLICATIONS IN ASIA AND THE PACIFIC

Although many countries in the Asia-Pacific region have applied remote sensing technology in a variety of ways to study their resources, its use is still quite limited. With the overriding purpose of extending our body of knowledge of the land resources and potential agricultural productivity and fertilizer needs of the Region, the author proposes the following research program to be conducted in the 1980s.

1. Objectives

a. To determine the degree to which Landsat multispectral scanner (MSS) and return beam vidicon (RBV) data can be used to delineate differences in the quantity and quality of land, vegetation, and water resources in Asia and the Pacific.

b. To examine and assess the use of Landsat MSS images as base maps for the inventorying of land, vegetation, and water resources at scales from 1:25,000 to 1:1,000,000.

c. To use sequential Landsat MSS data to make quantitative assessments of seasonal and yearly changes in the landscape (land use, arable lands, land degradation, wetlands, cultivated crops, forest resources, rangelands).

d. To define the desired specifications (spatial resolution, spectral bands, frequency) of sensor systems of future earth observation satellites to meet the data needs for the management of arable lands, forest lands, rangelands, and surface water resources in Asia and the Pacific.

2. Background and Justification

In many of the developing countries, the existence and/or ready availability of resource surveys is severely limited. In some countries which have received technical assistance from a variety of donor countries, as many as eight different soil classification systems at as many different scales and levels of mapping detail have been used to survey different areas. Case after case can be cited in extensive, costly development projects where critical decisions related to changes in land use had to be made with little or no detailed information about the soils and hydrologic characteristics of the projected areas. Such information is an essential ingredient in the prediction of the consequences of changing land use. In many instances, this lack of resource information has resulted in failure of the project, sometimes with disastrous effects.

Many areas of very high population density in Asia and the Pacific face critical decisions concerning changes designed to extract greater food resources from the land. Mass transfer of people from one area to a less densely populated area is in progress or is being contemplated by several developing countries. Unless accurate, useful, and timely information about the land, vegetation, and water resources to undergo change is available and is used wisely by the decision makers, serious unanticipated complications may lie ahead.

Conventional methods of inventorying and monitoring changes in earth resources are tedious and slow. In many areas under extreme population stress, there is insufficient time for conventional survey methods to provide the required resource information and to respond to the needs for basic data.

Even though the current Earth Observation Satellite program of NASA is still experimental in concept, many countries are using MSS images and data as a basis for surveying their land, vegetation, and water resources. Most of these maps are being prepared at scales of 1:100,000 or smaller and are being accomplished primarily by visual analysis. In many instances this scale is less than adequate for local and subnational planning.

Digital analysis techniques, even though they require a more sophisticated system of analysis, offer many benefits. Results are quantitative; a very wide range of spectral separations can be made rapidly; where the need arises, spectral classes can be combined or further divided into subcategories; tabular information related to areal measurements of specific classes can be quickly generated; digital data bases can be established and registered to other sources of data which can be related geographically to the addresses represented by the satellite data at scales as large as 1:25,000.

To date, the use of Landsat data in the digital format has been limited in the Asia-Pacific region. In the realm of earth resources data, the world is moving rapidly in the direction of digital data bases. With the launch of Landsat D in 1981, the flow of earth resources data transmission will increase from 1.1 million data points per second of Landsat 3 to more than 15 million data points per second from Landsat D. How can the nations of Asia and the Pacific take advantage of this valuable data source and extract from it a maximum of useful information?

A carefully designed research program must be conducted to determine the utility of Landsat data in identifying and characterizing features of interest in the landscape.

3. Approach

A study such as the one proposed could be approached at different levels. The approach suggested is a rather ambitious one and would require careful planning and coordination plus the commitment and cooperation of a number of scientists in the Asia-Pacific countries in which test sites are located. The general approach would be to obtain detailed agronomic, meteorological, and spectral data on small research plots of major crops at national agricultural experiment stations. Data would be obtained less intensively for larger sites of commercially grown crops and forest lands. A minimum project duration of five years would hopefully provide the possibility of obtaining cloud free multispectral data over the test sites on several different dates by both Landsat 3 (80 meter resolution) and Landsat D (30 meter resolution) scheduled for launch in 1981.

During the project, field observations and aircraft/satellite data could be acquired throughout at least three crop growing seasons at each test site. The final year of the project would be designated for intensive statistical analysis and interpretation.

a. Test sites. In the choice of test sites, several factors must be considered--political climate, availability of local experts, local institutional arrangements, experience in cooperative regional research, local interest in an in-depth assessment of land, crop, forest, and water resources by remote sensing techniques.

b. Agronomic data to be collected.

- o soils for each test site (Experiment Station)
  - site description (taxonomy, parent material, climatic regime)
  - profile description
  - chemical properties of surface soils (organic matter content, iron oxide content, mineralogy)
  - physical properties (color, % sand, silt, clay)
- o soils for extensive test sites (commercial fields, forest lands)
  - detailed soils map where possible
  - topographic map, 10 m or less vertical intervals (if available)
- o crop data (for all plots in Experiment Station test sites; sampling of extensive areas)
  - date of planting
  - general crop calendar
  - fertilizer treatments
  - cultivar
  - dates and amount of irrigation
  - plant measurements to be obtained every two weeks during growing season
    - height of plant
    - percent soil cover
    - leaf area index
    - biomass (above ground)
    - plant water content

c. Spectral, photographic data

- o laboratory/field spectroradiometer data
- o ground photography (color, color infrared)
- o air-borne spectroradiometer (low altitude aircraft or helicopter) data
- o aerial photography (color, color infrared)
- o multispectral scanner data from Landsats 1, 2, 3, and D
- o return beam vidicon data from Landsat 3

4. Organizational Arrangements

An effective administrative and implementation organization will have to be developed to make it possible to accomplish the objectives of this project. There must be a large component of coordination to assure the essential participation of and communication among scientists and policymakers from numerous national ministries and research institutes and international development organizations.

5. Project Personnel

The project objectives can be met by a staff consisting of a small overall administrative team, with a coordinator in each participating country in which test sites are located. Much of the field research, analysis, and interpretation could be done by graduate students from participating countries enrolled for graduate studies in crop physiology, statistics, forestry, soil science, ecology, geography, or some related field.

THE CHALLENGE

Several references have been made to the spatial resolution of the satellite sensors. That is, what is the smallest ground area identifiable in the satellite-derived data? In our research we often refer to temporal resolution, that is, the frequency of repetitive scanning of the same scene. We also speak of spectral resolution, meaning the number and width of wavelength bands measured by the sensors.

What has not been addressed may be clustered into a broad but very important category--the political/social/economic resolution. The potential benefits to the human family of a global earth resources information system are indeed exciting. The technology is with us and continues to develop at an accelerated rate.

But, perhaps the most important issues have yet to be resolved. What is the "resolution" of our political, social, and economic "scanners" as we attempt to design a global information system which will provide optimum benefits to the citizens of all nations? How do we internationalize such a system so that all nations may participate and reap the benefits? How do we effectively transfer the technology so that all

nations may be equipped to use the system? Can we have a global resource information system which does not erode the sovereignty or invade the privacy of nations? These and many more questions are yet to be resolved.

If we are to be prepared in the Asia-Pacific region to take full advantage of the developing resource information technology, it is of critical importance that sound research programs be conducted in this area to establish quantitative relationshps between those measurements obtained by aerospace sensors and important categories of ground information.

The challenge is before us. There is so little time and we have so much to do!

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ESTIMATING GLOBAL FERTILIZER REQUIREMENTS:

SOME TENTATIVE RESULTS

R. L. FOX and R. S. YOST*

Making accurate estimates of fertilizer requirements for specific crop-site combinations is fraught with many difficulties. A partial listing of factors that contribute to these difficulties should include: soil variability plant species and cultivar differences, a host of management variables, constraints on production from whatever cause, vagaries of weather, economic considerations, logistics of fertilizer supply and product disposal, labor availability, farmer acceptance of new ideas and techniques, and individual goals and pride of accomplishment. The list could be expanded to include factors peculiar to a region, a nation, or a community of nations.

It is unlikely that general estimates of fertilizer requirements will be useful for farm advisors and certainly they are of little use to individual farmers. Why then should we attempt to estimate fertilizer requirements on a global scale? A few reasons are:

1. Estimates of fertilizer needs are attention-getters. They emphasize the enormity of the need in relation to the facilities at hand to meet those needs.
2. Such estimates serve as guidelines for developing assistance programs that help in determining both the general nature of programs and where those programs should be implemented.
3. Estimates of fertilizer needs help to identify the more pressing problems; thus they are useful for developing relevant research programs.
4. Reasonable estimates of potential requirements for fertilizer provide essential background material for sensible resource development, resource management, and resource conservation.

Several different approaches could be used for estimating global fertilizer requirements. Some approaches are appropriate for one nutrient and some for another. Four approaches are recognized here:

1. A socio-economic approach applies past trends to present programs and market conditions to predict future fertilizer requirements.
2. A balance sheet approach is based on nutrient removal and seeks to restore to the soil the nutrients removed by cropping (perhaps also removal by leaching and erosion).
3. A soil approach is based on the requirements to bring soils to certain prescribed levels of nutrients. This approach is especially useful for estimating phosphate, potash and lime requirements.

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4. A recommended fertilizer rates approach for crops in selected areas can be extrapolated to include areas of the major crops of the area, as has been done for North America (Beaton and Tisdale, (1969) or for the entire world as will be illustrated in these proceedings by Saleem Ahmed.

All of these approaches can be used to estimate global fertilizer requirements; but first, one word of caution. The estimates presented result from a series of bold assumptions. We are "painting with a broad brush"; the data should be treated accordingly.

THE SOCIO-ECONOMIC APPROACH TO FERTILIZER REQUIREMENTS

An Economic Approach

Economists remind us that the appropriate question pertaining to fertilizing for increased crop production is not simply, "How much?," but also, "At what price?" In this view, the use of fertilizer during a time of adequate supply becomes an appropriate basis for establishing fertilizer requirements. This is the what-the-market-will-bear approach. Stangel (1976) has made fertilizer use in 1975 the starting point to predict fertilizer demand to the year 2000. The estimated 1980 demand is approximately as follows:

Fertilizer Material	Metric Tons
N	60×10^6
P_2O_5	30×10^6
K_2O	24×10^6

A strict economic approach makes no provisions for correcting inequities in the system; in fact, such an approach goes on compounding inequities. Serious inequities have been built into fertilizer use patterns already. Estimates of fertilizer requirements, if they are to be useful for making decisions about resource development, should make corrections for these inequities.

As Dr. Uehara says in his paper, "a poor man on infertile soil has little chance of extricating himself from poverty's grip"--to this I would add, "unless he has help." As was stated in an earlier paper (Fox and Kang, 1977), an "Operation Bootstraps" cannot succeed for a man who has no shoes. It is not enough to demonstrate that fertilizers increase yields or even that the economics are favorable, if there is no means to put into practice what has been demonstrated as possible in theory. That fertilizer could be the "shoes" for an "Operation Bootstraps" has been well stated by Richardson (1968), but to my knowledge this approach has never been seriously tried in developing countries.

A Sociological Approach

It is estimated that countries with 15 percent of the world's population utilize 70 percent of the fertilizer. It is simple mathematics to show that if the fertilizer demand by all countries is 114×10^6 tons, the requirement to put all people on an equal basis with developed countries is:

$$\frac{114 \times 10^6 \times .70}{.15} = 532 \text{ million tons}$$

Demand and requirement differs by a factor of 4.7.

Assuming that the ratio of fertilizer nutrients used remained as in 1975, the requirements would be:

	Tons (millions)
N	250
P_2O_5	150
K_2O	130

A Nutritional Approach

A modification of the sociological approach could be based on requirements for protein (about 30 g/person/day). Translated into nitrogen equivalents on a global basis (4×10^9 persons), this is 7×10^6 tons. The utilization of protein in developed countries is 90 g/person/day which, translated into N for the world, is 21×10^6 tons/year. Assuming 60 percent efficiency of the N fertilizer, a 70 percent partition of N into the harvested product, a 50 percent conversion to food of which 60 percent is utilized, gives a fertilizer requirement as follows:

$$21 \times 10^6 \div 0.60 \div 0.7 \div 0.5 \div 0.6 = 170 \text{ million tons}$$

This value may be high because no allowance has been made for conversion of plant protein (from by-products and waste) to animal protein as food. Nevertheless the agreement with the calculations based on equal use per capita is reasonably good.

These calculations have at least one serious flaw. They do not take into account a point made by another paper in these proceedings (Goro Uehara); soils that have the greatest nutrient needs tend to occur in the tropics. To bring these soils to the same state of productivity as in technically advanced countries will require greater inputs of fertilizer per unit production than is now being made in the temperate zone. This is especially true of the nutrient phosphorus. This problem must be dealt with in a different way.

A BALANCE-SHEET APPROACH TO FERTILIZER REQUIREMENTS

The balance sheet approach can be used to estimate N and K fertilizer requirements for maintenance if certain assumptions are made. The method does not make reasonable predictions about the need for P because start-up requirements for P are so great.

The N and K contents in the harvested portions of several classes of crops are presented in Table 1. The totals are 10 million tons of K and 33 million tons of N. Some assumptions were made about the quantities of N and K_2O that will be required to provide these quantities of N and K in the harvested product. These assumptions are presented in the footnotes to Table 1. Based on these assumptions, the N and K_2O requirements are calculated as follows:

$$N = 33 \div 0.5 \div 0.7 = 94 \text{ million tons}$$

$$K_2O = 10 \div .33 \times 1.2 = 36 \text{ million tons}$$

A SOILS APPROACH TO FERTILIZER REQUIREMENTS

Potassium

In making estimates of the potassium fertilizer requirements, we have assumed that 0.25 meq K/100 g soil (about 100 ppm K) represents a nearly adequate K supply for most crop-soil combinations (Table 2). For Andosols and Histosols, which are low bulk density soils, we assume that 0.5 meq/100 g is appropriate but in these cases we have also assumed that the quantity of soil being fertilized is 1 million kg/ha . Except as noted above, the K requirement for a particular soil is the deficit between exchangeable K^+ and 0.25 meq K/100 g soil.

Exchangeable K (meq/100 g) - 0.25 = K Required

Only negative values have been recorded since exchangeable soil K in excess of K required in one soil cannot compensate for a K deficit in another soil. The values recorded in Table 2 are means for various soil groups extended on a global scale and expressed as millions of metric tons. These calculations are based on the assumption that 20 percent of the land area represented by each soil group is under cultivation during a given year.

The calculated requirement is about 113 million tons K_2O, a value which exceeds the balance sheet estimate by a factor of about three. Since the balance sheet estimate is based on K in the entire crop, a considerable portion of which may be recycled in crop residues, we assume that this estimate of K requirement has a rather large start-up component of K in it. The cost of the start-up component can be amortized over several years unless leaching and erosion losses are severe. These considerations tempt us into making further approximations. Assuming that new fertilizer promotion schemes proceed at the rate of 10 percent of the cultivated land per year (probably an unrealistic goal), start-up would require 11.3 million tons per year but this addition

would eliminate (for that year) 3.6 from maintenance--a net increase in the fertilizer requirement of 7.7 million tons per year to a total of 44 million tons.

TABLE 1. Contents of Nitrogen and Potassium in the harvested portion of important food crops.

Crops	+World Production million metric tons	++Potassium in Harvested Portion %	++Nitrogen in Harvested Portion %	Amount of K in Harvested Portion --million metric tons--	Amount of N in Harvested Portion --million metric tons--
Cereals (except millets and sorghum)	1230	.41	1.86	5.0	23.
Roots and Tubers	550	.37	.52	2.0	3.0
Legumes	100	1.00	4.40	1.0	+++2.2
Millets and Sorghum	155	.36	1.83	.56	2.8
Fruits	205	.49	.75	1.0	1.5
Vegetables	65	.25	.56	.2	.4
Sugarcane sugarbeet	85	.31	.23	.2	.2
Total	2385			10	33

+Source: Harlan, 1976

++Source: Morrison, 1949; McDonald et al. (1974)

+++Assumed that 50% of the N contained in leguminous crops was derived from symbiotic N fixation.

Assumptions for calculation of the following maintenance requirements.

Nitrogen fertilizer requirement:

(1) $\frac{\text{N in harvested portion of crop}}{\text{N in plant}} = 0.7$

(2) $\frac{\text{N in crop}}{\text{N applied in fertilizer}} = 0.5$

(3) Assume that leaching losses in excess of those suggested in assumption (2) will be balanced by non-symbiotic N fixation and rainfall addition of N. Estimated maintenance requirement = 94 million metric tons

Potassium fertilizer requirement:

(1) $\frac{\text{K in harvest portion}}{\text{K in crop}} = .33$

Estimated maintenance requirement =30 million metric tons.

TABLE 2. Major soils of the world and estimates of their potassium fertilizer requirements.

Soils	+Area (million ha)	% of Total	++Exchangeable K Estimate ----meq/100 g--		‡Estimated K Requirement (million metric tons K)	
			(1)	(2)	(1)	(2)
Acrisols and Nitosols	1050	8.0	.16	0.15	15.0	16.0
Histosols	240	1.8	.36	.36		13.0
Ferralsols	1068	8.1	.15	.14	17.0	18.0
Podzols	478	3.6	.02	.02	17.0	17.0
Planosols	120	.9	.15	.15	2.0	2.0
Podzoluvisols	264	2.0	.22	.22	1.2	1.2
Luvisols	922	7.0	.43	.25	0.0	0.0
Cambisols	925	7.0	.16	.16	13.0	13.0
Andosols	101	.8	1.20	.39	0.0	4.4
Chermozens, Greyzems, Phaeozems	408	3.1	.84	.25	0.0	0.0
Xerosols and Kastanozems	896	6.8	1.10	.25	0.0	0.0
Yermosols	1176	8.9	1.45	.25	0.0	0.0
Solonchaks and Solonetz	268	2.0	2.20	.25	0.0	0.0
Cleysols	623	4.7	.25	.20	0.0	4.8
Fluvisols	316	2.4	.16	.16	4.4	4.4
Others (Regosols, Arenosols, Lithosols, Rendzinas, and Rankers, misc.)	4254	32.0	--	--	--	--
TOTAL					70 (K_2O = 113)	94

+Source: R. Dudal

++Estimates of exchangeable K levels obtained from Soil Taxonomy, 1975; North Central Regional Potassium Studies, N. Central Regional Publication No. 124; Selected Coastal Plain Soil Properties, Southern Cooperative Series Bulletin 148; Some Highly Weathered Soils of Puerto Rico III. Chemical Properties, R. L. Fox, Geoderma (in press). Values in Column 1 are means of all values of soils included in the estimate. Values in Column 2 are also means, however any value above 0.25 meq K/100 g are considered as 0.25.

‡Estimated K requirement based on: (1) the need to obtain 0.25 meq k/100 g, was used for Andosols and Histosols due to low bulk densities, (2) that one fifth of the area of each soil will be cultivated, and (3) conversion of ppm x 2 = kg/ha for all soils except Andosols where we assumed ppm = kg/ha. Estimated requirements in columns (1) and (2) are based on the estimates of exchangeable K in columns (1) and (2) respectively.

Phosphorus

Among the macro nutrients, phosphorus deserves special attention. Next to nitrogen, it is the nutrient most likely to be deficient for crop production; and, where biological nitrogen fixation is a major consideration, it is frequently the most deficient nutrient. Phosphorus uptake by crops in relation to the capacity of the soil to sorb P (or as a percentage of P in the labile pool) may be small; thus the balance sheet approach is not appropriate to short-term P fertilizer requirements.

The soils approach used here involves constructing phosphate adsorption curves of the type illustrated in Figure 1. Phosphorus adsorption by soils is concentration dependent--that is to say, the quantity of phosphorus required by a soil depends on the level of nutrition (concentration of P in solution) one wishes to establish. It is clear from Figure 1 that soils differ greatly in the quantity of phosphate required (P sorbed) to attain a given level of P in solution. Thus the Chernozem soils from Kazakstan, USSR have low requirements in comparison with the Oxisols from Brazil. We have found in field results, of the kind presented in Figure 2 that plants with low phosphorus requirements (sweet potato, cassava) make acceptable yields when solution P concentrations are about 0.008 ppm or even less; crops with intermediate requirements (cabbage, corn), Figure 3, require about 0.02 to 0.05 ppm while crops with high requirements (potatoes, tomatoes, lettuce) may require 0.2 ppm or more.

Phosphorus fertilizer requirements are determined by reading phosphate sorbed values from the P sorption curves at the concentration appropriate for the crop and the level of production desired. In the case of corn (Figure 3) maximum yield in Hawaii was attained at about 0.05 μg P/ml of soil solution. If one enters Figure 1 at 0.2 μg/ml, the P requirement for the Alabama Ultisols is about 100 μg P/g while for the Oxisols of Brazil the requirement is 2.5 times greater.

Table 3 is an extension of the P requirement values to areas of cultivated soils of various associations. We have assumed that one-fifth of the area within each association is cultivated. The order of arranging soils in Table 3 is approximately according to increasing standard P requirements. The requirements are as follows:

	Metric Tons P_2O_5
Low intensity	100×10^6
Medium "	270×10^6
High "	$1{,}000 \times 10^6$

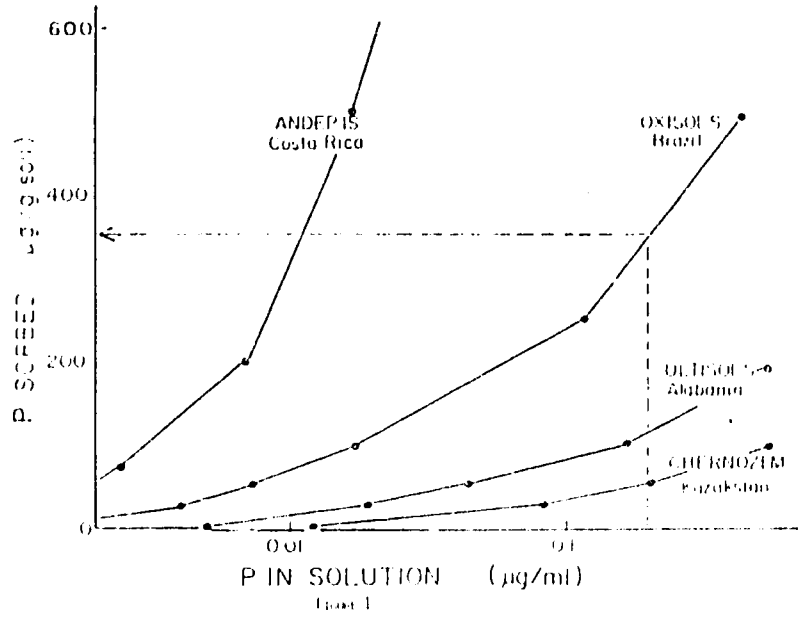

Fig. 1 Phosphate sorption by soils in relation to phosphate concentration in solution is illustrated for soils with different mineralogies. Andepts developed from volcanic ash; the Oxisols are kaolin clays with iron oxides. The Alabama Ultisols are mineralogically similar to the Brazilian Oxisols except that they contain a greater percentage in quartz sand.

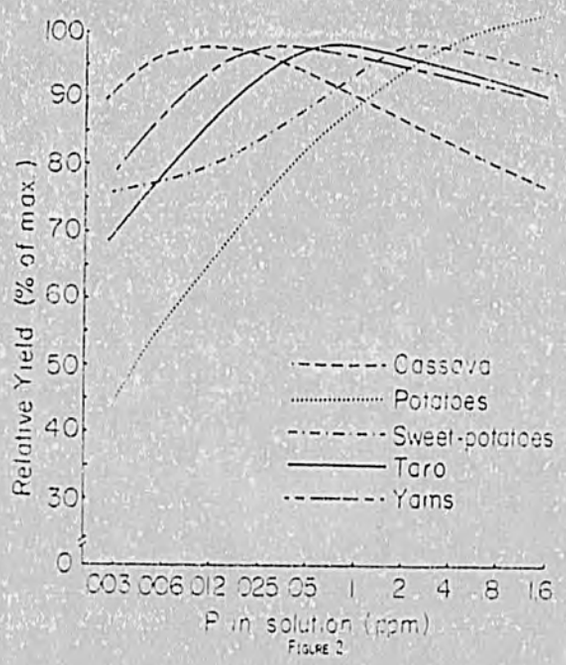

Fig. 2 Relative yield of five root crops in relation to levels of P established in soil solution. (From Vander Zaag, P., Ph.D. thesis, University of Hawaii, Dept. of Agronomy and Soils, 1979.)

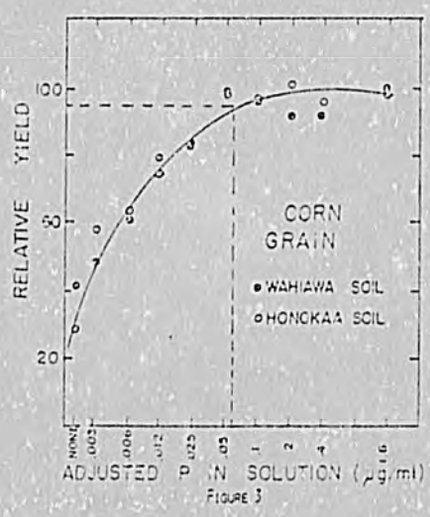

Fig. 3 Relative yield of corn growing on two soils in relation to adjusted levels of P in the soil.

TABLE 3. Estimated Initial Phosphate Requirements of the Major Agricultural Soils of the World.

Soil Association dominated by	Area		Mean standard P requirements to attain 3 levels of P in solution			Fertilizer P+ Required for for cultivated land for 3 classes of crops			Percentage of world's requirement		
			0.008 ppm	0.02 ppm	0.2 ppm	Low Requirement (Cassava, etc.)	Moderate Requirement (Corn, etc.)	High Requirement (tomatoes, etc.)	Low Requirement	Medium Requirement	High Requirement
	Million ha	%	---µg P/g soil---			---Millions of tons of P---			---%---		
Histosols	240	1.8	0	1	3	.0	.0	.1	.0	.0	.0
Xerosols	896	7.0	0	2	15	.0	.3	2.6	.0	.3	6
Solonchaks and Solinetz	268	2.0	4	7	20	.4	.7	2.0	.9	.6	.5
Chernozems, etc.	408	3.1	2	7	31	.3	1.1	4.8	.7	.9	1.1
Planosols	120	.9	2	16	82	.0	.4	1.9	.1	.3	.4
Gleysols	623	4.7	8	27	48	1.9	6.4	11.4	4.2	5.3	2.5
Luvisols	922	7.0	8	18	72	2.8	6.3	25.2	6.2	5.3	5.6
Podzols	478	3.6	5	13	80	.9	2.4	14.5	2.0	2.0	3.2
Fluvisols	316	2.4	7	25	102	.8	1.5	6.1	1.8	1.3	1.4
Cambisols	925	7.0	5	20	132	1.8	7.0	46.4	3.9	5.9	10.3
Podzoluvisols	264	2.0	0	13	220	0	1.3	22.1	.0	1.1	4.9
Vertisol	311	2.4	16	30	82	1.9	3.6	9.7	4.2	3.0	2.2
Acrisols and Nitosols	1049	8.0	15	36	123	6.0	14.3	51.0	13.2	11.9	12.1
Ferralsols	1068	8.1	61	161	535	24.8	65.2	17.1	54.5	54.4	48.2
Andosols	101	.8	198	486	1625	3.8	9.3	31.2	8.4	4.8	6.9
TOTAL	7678	58.4	--	--	--	45	120	446			

+Based on phosphate sorption curves from numerous sources, but mostly from unpublished data of R. L. Fox.

The disproportionate requirement of important soils in tropical and subtropical areas (e.g. Ferralsols) is evident from the presentation in Table 4. The very high requirements for these soils will set limits on their development for many years. Certainly these soils will not be extensively developed for phosphorus-demanding crops unless these crops are so high-valued that fertilizer costs become a minor consideration in the total cost of production.

TABLE 4. Disproportionate phosphate fertilizer requirements for important soils of the tropics and subtropics

Soils (Area) Considered	Area (1% of total)	Fertilizer P required	
		(%)	Tons P_2O_5 (millions)
Acrisols and Nitosols	8	12	32
Ferralsols	8	54	148
Andosols	1	8	21
Subtotal	17	74	201
(World)	100	100	272

For purposes of comparison, we have assumed that the maintenance requirement for medium intensity P is 10 percent that of the requirement for maintenance of N (The N: P ratio in plants is usually about 10:1). Assuming that the start-up requirement is one year at the full rate and four subsequent years at one-fourth the full rate, that 10 percent of the cultivated area is brought into a fertilization scheme each year, and that after five years the maintenance rate suffices, the requirement for medium intensity P nutrition on a global scale is 744 million tons for 14 years. This estimate does not allow for an increase in the area of cultivated land or for erosion losses or for the generally higher P requirements of subsoil materials that become surface soil as a consequence of erosion.

SUMMARY AND CONCLUSIONS

Several methods of estimating global fertilizer requirements have been examined for this report. They give widely different estimates of fertilizer requirements in absolute terms. Some interesting trends emerge and are summarized in Table 5. We believe that these estimates support the following conclusions:

TABLE 5. Estimated Fertilizer Requirements Based on Several Methods of Making the Estimates.

Approach used to make estimates	Fertilizer N		Required P_2O_5	K_2O
	--Million of tons--			
Socio-Economic				
Economic	60		30	24
Sociological	250		150	130
Human Nutrition	170		--	--
Balance Sheet (Maintenance)	94		21	36
Soils				
Low Intensity	--		100	--
Medium Intensity	--		270	113
High Intensity	--		1000	--
Maintenance - start up	94	mean	74[1]	44
		max	87	

[1] Assuming a 14-year program of bringing all soils to the medium intensity P level, a 4-year build up and a maintenance program.

1. Present utilization of fertilizers ($N + P_2O_5 + K_2O$) is approximately one-half of the quantity that should be used for long-term fertility buildup and fertility maintenance of existing cropland. This does not include fertilization of lands not in crops and it does not include new lands. Likewise, these estimates do not attempt to compensate for nutrient loss by erosion. These losses are very large. This is a serious problem but we do not know how it should be evaluated.

2. A higher proportion of the fertilizer used should be phosphate--until the level of phosphate in the highly weathered soils is built up. This is especially true if legumes are relied upon for a greater share of the N requirement.

3. If a modest program of fertility buildup is embarked upon, the requirement will be approximately 540 million tons P_2O_5 over and above requirements for maintenance. Assuming that this buildup takes place over a 20-year period the requirement during that time will be approximately 870 million tons, or 45 million tons per year. This is approximately 1.5 times the estimated 1980 consumption.

4. After a time of fertility buildup the requirements for phosphorus should decrease to about 20+ million tons per year for maintenance. The plus is for any additional buildup needed to attain a higher level of soil P. To attain a level adequate for near maximum

production of most vegetable crops will require an enormous investment--probably about four times the requirement for crops such as maize--and is not recommended as a goal for this generation or even the next.

5. The long-term requirements for potassium (after 20 years) may exceed the requirements for P unless more effective measures are devised to recycle plant nutrients in the soil.

6. To bring the whole of mankind to the same per capita level of fertilizer consumption that is currently employed in Europe and North America would require a five-fold increase in fertilizer manufacturing capacity.

7. As policy we should no longer advocate N nutrition of crops at the expense of soil organic matter--we should not, in general, deplete soil organic matter reserves any more than they have been depleted already. Therefore, the dependence on commercial N fertilizers will increase. However, if this N is more uniformly employed, if crops with low requirement for N are grown (for example, tropical root crop) where they are adapted, and if there is greater dependency on plant protein as food, the requirement for N fertilizer can be kept to a reasonable value. Our estimated requirement is about 60 percent greater than 1980 consumption.

8. The greatest problem soils for enhanced crop productivity through soil fertility buildup are the highly weathered soils of the tropics and subtropics. In the U.S. classification system these are the Oxisols and Ultisols. Developing these soils is a worthy challenge. Whether or not the task will be undertaken is no longer the question. Development has already been going on for years. We can expect the pace to accelerate. We need to understand the problems involved. The relevant questions are: (a) What will the priorities be for inputs? (b) What will be the rate of development? (c) Will some of the fundamental obstacles to development such as soil infertility be dealt with decisively or will we continue to expect that ill-equipped and under-supported settlers will accomplish the next-to-impossible-task of getting the last drop of blood out of these "turnips" while the sociological, economic, and political problems pile up?

It has been said that analogy is a poor teacher--just the same we would like to conclude with this reminder: exploiting the fertility of soils is like flying low-powered aircraft up blind canyons. One runs out of options very quickly and the results are often fatal. Likewise, exploiting the inherent fertility of highly weathered soils must inevitably lead to a state of infertility which is almost impossible to correct. The time for investing in corrective measures leading to enhanced soil fertility is now. We must not encumber a future, more destitute generation with the tasks we should have undertaken but did not.

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SOILS AND FUTURE FERTILIZER NEEDS

GORO UEHARA*

INTRODUCTION

During the last 20 years the percent increase in world population has outpaced the expansion of cultivated land by a ratio of four to one. Thus the world's growing food demand has largely been met by increased production on land already under cultivation. It is significant that during this period fertilizer use increased by 260 percent--from 24 million tons of plant nutrients in 1957 to 88 million tons in 1976-1977 (Dudal, 1978). The increased agricultural productivity was mainly achieved in the industrialized countries, which consumed 85 percent of the fertilizer.

Since most of the developing countries of the world are located in and near the tropics where there are few industralized nations, it follows that the greatest potential for increasing agricultural productivity through fertilizer use is in the tropics.

As I stated in an earlier paper (Uehara, 1976), a rich farmer can make infertilie land productive, and a poor farmer can become rich on fertile land, but a poor farmer on infertile land has little chance of extricating himself from poverty's grip.

Of the three cases, only the first and last are relevant today. There is only a remote possibility that a significant number of the world's poor farmers will be relocated to rich farm land. The situation is such that a disproportionate amount of the world's fertilizer supply is consumed by the large, profit-oriented farmer. On the other hand, in the tropics there is an abundance of poor farmers who subsist on impoverished land with little or no fertilizer.

For humanitarian reasons, as well as for the more pressing need to maintain world order, the industrialized countries of the world will continue their attempts to lessen the plight of the poor farmer. It is sufficient to say that fertilizer use is necessary but not sufficient to overcome the problems of the small farmer.

The purpose of this paper is to present a brief inventory of the soils of the world and to relate future fertilizer needs to soil requirements.

WORLD SOIL RESOURCE INVENTORY

Table 1 lists the major soils of the world and their areal extent (Dudal, 1976). The soil names are those used by the Food and Agriculture Organization of the United Nations (FAO, 1974).

About 10 percent of the world's land area is occupied by soils with high natural fertility. These soils are the Chernozems, Greyzems, Phaeozems, and Luvisols. However, limitations other than mineral deficiencies prevent their full utilization.

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Table 1. Distribution of the Major Soils of the World (Dudal, 1976)

Soil Associations dominated by	Area in 1000 ha	Percent
Fluvisols	316,450	2.40
Gleysols	622,670	9.73
Reyosols and Arenosols	1,330,400	10.10
Andosols	100,640	0.76
Vertisols	311,460	2.36
Solonchaks and Solonetz	268,010	2.03
Yermosols	1,175,980	8.83
Xerosols and Kastanozems	895,550	6.79
Chernozems, Greyzems, and Phaeozems	407,760	3.08
Cambisols	924,870	7.02
Luvisols	922,360	7.00
Podzoluvisols	264,120	2.00
Pdozols	477,700	3.63
Planosols	119,890	0.91
Acrisols and Nitosols	1,049,890	7.97
Ferralsols	1,068,450	8.11
Lithosols, Pendzinas and Rankers	2,263,760	17.17
Histosols	240,200	1.82
Miscellaneous land units (icefields, salt flats, rock debris, shifting sands, etc.)	420,230	3.19
Total world land area	13,180,390	100.00

Approximately 22.5 percent of the world's land area is occupied by soils which are seriously deficient in one or more essential plant nutrient. Mineral deficiency is still one of the easiest problems to correct, and the technology for accomplishing it is well known. Land utilization for crop production is more often restricted by other limitations. These limitations, expressed in terms of plant stresses, are summarized in Table 2.

Table 2. World Distribution of Soil-Related Plant Stress

Stress	Land Area (In billions of hectares)	Percent of Land Area
Mineral	2.96	22.5
Drought	3.70	27.8
Excess Water	1.61	12.2
Shallowness	3.19	24.2
Non-Soil	0.42	3.2
TOTAL	11.88	89.2

Since we have been asked to confine our discussion to fertilizer needs, a more detailed breakdown of the soils with mineral deficiencies is provided in Table 3. It is significant that the Ferralsols, Acrisols, and Nitosols, which constitute the bulk of mineral deficient soils, for the most part occur in the tropics. In the U.S. system of soil classification (Soil Taxonomy, 1975), the Ferralsols correspond to Oxisols and the Aerisols and Nitosols to Ultisols. Extensive areas with these soils occur in tropical South America, Africa, and Asia. With proper management and fertilizer inputs, these soils can be highly productive. The largest single tract of Ferralsols occurs in central Brazil surrounding the capital city of Brasilia. This region is undergoing rapid agricultural development.

Table 3. Soils with Severe Mineral Deficiencies

Soil	Land Area (In billions of hectares)	Percent of Land Area
Ferralsols	1,068,450	8.11
Acrisols)	1,049,890	7.97
Nitosols)		
Podzols	477,700	3.63
Podzoluvisols	264,640	2.00
Andosols	100,640	0.76
	2,960,800	22.47

FERTILIZER REQUIREMENT OF SOILS

It goes without saying that even the best of soils requires fertilizer. The soils listed in Table 3 are unique because they are naturally infertile and, in addition, require inordinate amounts of one or more nutrient element in order to render them productive. Furthermore, many of them are extremely acid and benefits from fertilizer are not realized until the excess acidity has been neutralized.

In the industrialized countries, fertilizer is added to replace annual losses due to plant removal, leaching, volatilization, and immobilization. Fertilizer is added at maintenance levels to soils which are already nutrient-rich compared to the soil cultivated by the subsistence farmer.

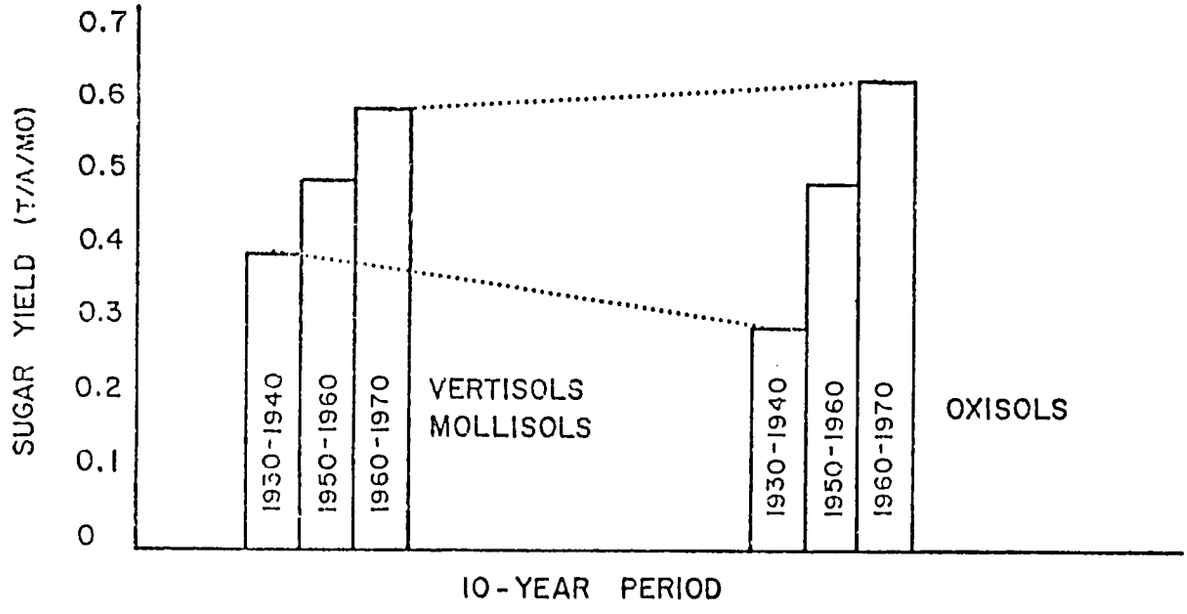
In order to raise the fertility level of his farmland to that of his counterparts in the industrialized countries, the subsistence farmer would first have to apply a heavy initial dose of one or more nutrient elements to correct mineral deficiencies. It is this initial cost that frequently discourages the development of the extensive impoverished and underutilized lands of the tropics. It might be useful to treat this initial expense as capital cost since it is not a recurring cost. It is, however, highly unlikely that national planners or farmers have sufficient information to assess the fertilizer requirements of their soils, much less estimates of the initial and maintenance fertilizer

needs. The next speaker (R. L. Fox) will emphasize the fact that fertilizer levels depend not only on soil requirements but also on crop requirements. In fact, the subsistence farmer manages with little or no fertilizer on impoverished soils because he has learned to accept low yields and to grow crops adapted to low fertility soils.

However, fertilizer use remains one of the most effective ways to produce more food on a given land area. In addition, the benefits of fertilizer use are often not immediately apparent. Figure 1 illustrates what has happened to sugar yields in Hawaii. The Vertisols and Mollisols are Hawaii's most fertile soils. They normally occur on the coastal plains of the older islands and are dark colored and rich in bases. The Oxisols on the other hand are highly weathered soils equivalent to the Ferralsols in Table 3. Forty to fifty years ago the highest sugar yields were obtained on Vertisols and Mollisols. Today yields on Oxisols equal or exceed those on Vertisols and Mollisols. Oxisols have excellent physical conditions so that when their fertility problem was eliminated by continued use of fertilizer they surpassed the Vertisols and Mollisols in performance.

The vast majority of the world's Oxisols (Ferralsols) are still performing at Hawaii's 1930 level. It is safe to say that it will take at least as long to rejuvenate the impoverished soils of the tropics.

Fig. 1. SUGAR YIELDS OVER 40-YEAR PERIOD ON SOME SOILS IN HAWAII



SUMMARY AND CONCLUSION

Fifteen percent of the world's supply of fertilizer is used by 70 percent of the world's people who live in the developing countries of

the tropics and subtropics. A disproportionate amount of the soils in and near the tropics suffer from nutrient deficiency.

The potential annual, per unit area fertilizer requirement is higher in the tropics than in the temperate zone for the following reasons:

1. Lower inherent nutrient level of soils in the tropics.
2. Lower inherent nutrient reserves in soils of the tropics due to a high degree of weathering and low content of weatherable minerals.
3. Higher immobilizing capacity of high sesquioxide tropical soils for one or more nutrient element.
4. Longer growing season and higher potential plant removal of nutrients under continuous cropping systems.

There is, however, a marked difference between fertilizer requirement and fertilizer demand. In the industrialized countries of the world, fertilizer requirement and demand are nearly alike; whereas in the developing nations, fertilizer requirement far exceeds demand.

In order to meet the fertilizer requirement of the soils already under cultivation, the world would need to at least double its fertilizer production. The technology of fertilizer use is well known. What is lacking is the knowledge and will to make fertilizer use economically feasible, socially desirable, environmentally sound, and politically acceptable.

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CALCULATING THE POTENTIAL ANNUAL GLOBAL FERTILIZER REQUIREMENT USING THE RECOMMENDED RATE METHOD: SOME TENTATIVE RESULTS

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The significant role of soil characteristics in influencing fertilizer requirements, particularly for phosphates and potash, has been highlighted by the two previous speakers on this panel (Uehara and Fox). In the determination of nitrogen requirements, however, soil characteristics assume a role secondary to one assumed by exogenous factors such as crop management practices, cropping history and crop rotation. Since reliance cannot be placed on soil characteristics in this case, other methods for estimating potential nitrogen requirements have to be sought. An alternative that we have adopted in the present study is the use of two major physical aspects of crop production, that is, crop areas planted and recommended levels of fertilizer use. This study is an attempt to use these two physical factors to arrive at an estimate of the plant nutrients that could potentially be used on a global basis. We should emphasize, as have the previous speakers, that we are not attempting to predict the quantities of plant nutrients that would be used at some future time but only what could be used by using the set of assumptions outlined below. Benton and Tisdale (1969) have used this method for calculating the potential fertilizer requirement for North America.

While focusing on an assessment of the potential annual global requirement for nitrogen, which as suggested earlier, is more neutral to pedological influences, we have also attempted to estimate P and K requirements at the same time.

Definition: The annual fertilizer requirement being estimated here is the theoretical requirement that would be needed should all crop area be fertilized at the recommended level. It is time-neutral and may, perhaps, never be achieved. These estimates are applicable as long as the current set of assumptions, outlined below, are valid.

Potential Annual Fertilizer Requirement, as used in this study, may therefore be defined as "the amount of N, P_2O_5, and K_2O that would be required if the area for the crops being considered were to be fertilized at the recommended rates being used."

Assumptions:

We would like to underscore the following assumptions being used in this study:

1. The area under the 18 crops being considered remains relatively unchanged over time, and the increases in such area brought about by

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bringing more land under cultivation and/or changing cropping patterns will be counterbalanced by decreases in cropped area due to soil degradation and/or urbanization. The area under various crops being used in this study has been obtained from the FAO Production Yearbook (1976).

2. Other inputs which influence fertilizer use--water, seeds, pesticides, labor--are available in quantities needed for the recommended rates of fertilizer application being considered, uniformly for the entire crop area.

3. The potential fertilizer requirement for crops other than the 18 considered, and for other agricultural uses of fertilizer (pasture crops, forests, etc.), will approximate 25 percent of the requirements arrived at for these 18 crops.

4. There are no constraints on product availability and distribution, and on the farmers' ability to purchase it.

Estimation of the Recommended Rates

A review of the literature reveals a multitude of recommended rates developed by various scientists for different crop varieties grown at specific locations in various countries. Many of these have been summarized by De Gues (1967) and Cooke (1975).

In view of our objectives, we have tried to generalize these recommended levels by averaging them out first at country levels and then at continent level (following FAO's practice, USSR has been considered separately along with the other six continents). Data has been more readily available for some regions (such as North and Central America) than for others. Similarly, within each region it has been more readily available for some countries (like Egypt in Africa, India in Asia, the U.S. in North-Central America) than for others. The generalizations which have been adopted may therefore be biased more toward the situations for countries for which such data have been available.

The recommended NPK levels that we have used for various regions are indicated in Table 1a for wheat, 1b for rice, 1c for maize, 1d for barley, 1e for cotton and 1f for some other crops.

In order to provide for greater latitude in the results that emerge from this study, we have considered three cases:

Case I: This represents the theoretical "maximum" annual fertilizer requirement for each crop under the set of assumptions that have been made. It has been formulated by putting together the maximum level of each of the three nutrients recommended in the literature for each crop and then applying it uniformly for all regions. Thus, for example, in the case of wheat; the N level has been obtained from an Egyptian source (Hamissa, 1979), and P and K from a U.S. source (Benton and Tisdale, 1969; see Table 1a). Case I therefore represents a situation where the inherent soil fertility level has been assumed to be an aggregation of the poorest levels for each nutrient separately. The NPK rate thus obtained has been used uniformly for all continents.

TABLE 1. FERTILIZER RECOMMENDATIONS USED
($N-P_2O_5-K_2O$, Kg/ha)

(figures in parentheses refer to references cited)

a. Wheat

Region	Case I	Case II	Case III	
Africa	180(1)-120(2)- 80(2)	144(1)- 40(1)- 40(3)	144(1)- 40(1)-40(3)	(For 50% of area)
			40(3)- 60(3)-40(3)	(For balance area)
N-C. America	" " "	125(4)-120(2)- 80(2)	65(5)- 45(5)-35(5)	
S. America	" " "	120(6)- 40(6)- 0(6)	120(6)- 40(6)- 0(6)	(For 50% of area)
			50(7)- 30(7)- 0(7)	(For balance area)
Asia	" " "	125(7)- 75(7)- 60(8)	120(6)- 40(6)-30(9)	(For 50% of area)
			50(7)- 30(7)- 0(7)	(For balance area)
Europe	" " "	180(10)- 40(10)- 40(10)	180(10)- 40(10)-40(10)	(For 50% of area)
			65(11)- 45(11)-45(11)	(For balance area)
Oceania	" " "	180(12)- 75(12)- 0(12)	180(12)- 75(12)- 0(12)	(For 50% of area)
			50(13)- 50(13)- 0(13)	(For balance area)
U.S.S.R.	" " "	125(14)-120(14)- 80(14)	65(15)- 45(15)-35(15)	

b. Rice

Region	Case I	Case II	Case III	
Africa	230(12)-170(12)-240(12)	144(1)- 40(1)- 40(16)	144(1)- 40(1)- 40(16)	(For 50% of area)
			50(9)- 25(9)- 0(9)	(For balance area)
N-C. America	" " "	150(17)- 60(17)- 60(17)	96(5)- 38(5)- 30(5)	
S. America	" " "	90(18)- 90(18)- 50(18)	90(18)- 90(18)- 50(18)	(For 50% area)
			75(9)- 25(9)- 25(9)	(For balance area)
Asia	" " "	175(9)-150(9)- 75(9)	150(9)-100(9)-100(9)	(For Japan & Korea)
			120(9)- 30(9)- 0(9)	(For China)
			150(7)- 75(7)- 30(19)	(For 50% of rest of Asia area)
			50(9)- 25(9)- 0(9)	(For balance area)
Europe Oceania & U.S.S.R.	" " "	200(20)-160(20)-120(20)	150(9)-100(9)- 50(9)	

TABLE 1. FERTILIZER RECOMMENDATIONS USED (contd)
($N-P_2O_5-K_2O$, Kg/ha)

(Figures in parentheses refer to references cited)

c. Maize

Region	Case I	Case II	Case III	
Africa	288(1)-120(21)-180(21)	288(1)- 80(22)- 40(22)	250(9)- 80(22)- 40(22)	(For 50% area)
			100(22)- 80(22)- 40(22)	(For balance area)
N-C. America	" " "	200(23)-120(2)-180(21)	120(5)- 65(5)- 70(5)	
S. America	" " "	90(24)- 90(24)- 90(24)	90(24)- 90(24)- 90(24)	(For 50% of area)
			50(9)- 50(9)- 50(9)	(For balance area)
Asia	" " "	125(7)- 75(7)-100(7)	125(7)- 75(7)-100(7)	(For 50% area)
			50(9)- 50(9)- 50(9)	(For balance area)
Europe	" " "	200(25)-120(25)-180(25)	120(25)- 65(25)- 70(25)	
Oceania & U.S.S.R.	" " "	200(25)-120(25)-180(25)	120(25)- 65(25)- 70(25)	

d. Barley

Region	Case I	Case II	Case III	
Africa	125(26)- 75(26)- 80(26)	75(9)- 50(9)- 50(9)	75(27)- 40(27)- 30(27)	(For 50% area)
			40(28)- 40(28)- 0(26)	(For balance area)
N-C. America	" " "	125(26)- 75(26)- 80(26)	55(5)- 45(5)- 30(5)	
S. America	" " "	75(29)- 50(29)- 50(29)	75(29)- 50(29)- 0(29)	(For 50% area)
			50(29)- 40(29)- 0(29)	(For balance area)
Asia	" " "	" " "	75(29)- 50(29)- 50(29)	(For 50% area)
			50(29)- 40(29)- 0(29)	(For balance area)
Europe, Oceania & U.S.S.R.	" " "	" " "	55(5)- 45(5)- 30(5)	

TABLE 1. FERTILIZER RECOMMENDATIONS USED (contd)
($N-P_2O_5-K_2O$, Kg/ha)

(Figures in parentheses refer to references cited)

e. Cotton

Region	Case I	Case II	Case III	
Africa	200(30)-100(30)-120(30)	144(1)- 70(9)- 0(9)	144(1)- 70(9)- 0(9)	(For 50% area)
			50(9)- 25(9)- 0(9)	(For balance area)
N-C. America	" " "	" " "	95(5)- 60(5)-60(5)	
S. America	" " "	" " "	40(31)- 60(31)-40(31)	
Asia	" " "	125(32)- 50(7)-50(32)	125(32)- 50(7)-50(32)	(For 50% area)
			75(7)- 50(7)- 0(9)	(For balance area)
Europe, Oceania & U.S.S.R.	" " "	" " "	95(5)- 60(5)-60(5)	

f. Other Crops (applicable to all regions and all cases unless otherwise stated)

Crop	Fertilizer Recommendations	
Sorghum	120(34)- 60(34)- 40(34)	
Millet	120(34)- 60(34)- 40(34)	
Pulses	20(34)- 60(34)- 30(34)	
Potato	200(7)-240(35)-250(35)	(Cases I & II, for all areas)
	115(5)-135(5)-120(5)	(Case III for all regions except Asia)
	200(7)-150(7)-150(7)	(Case III for Asia)
Sweet Potato	90(9)- 60(9)-200(9)	
Cassava	60(9)- 60(9)-120(9)	
Sugarcane	325(36)-150(36)-300(36)	
Sugarbeet	120(37)-200(37)-150(37)	
Soybean	40(9)- 60(9)- 80(9)	
Vegetables	250(9)-250(9)-250(9)	

Case II: This has been derived in the same way as the rates in Case I, but here the rates have been formulated by putting together the maximum rates obtainable for N, P, and K for each continent separately. We therefore see in Table 1a, for example, that the rates for all three nutrients used for North-Central America have been obtained from one U.S. source (Benton and Tisdale, 1969); for Africa, from one Egyptian source (Hamissa, 1979); etc. Thus variations will be observed in the NPK rates being used for different continents.

Case III: This may be considered as the "micro" level NPK rate of our study. It is based upon some averaging of the various NPK rates recommended for specific countries/locations within each region and then applying it to the region under consideration. In the case of the major crops (wheat, rice, maize, barley, and cotton), further refinement has been brought about by projecting the ultimate likely spread of high yielding, fertilizer responsive crop varieties. Higher rates of fertilizer applications are being used for these crops than for the more "traditional" crop varieties. It is being assumed that the balance area available will be used for these traditional varieties. In the case of North-Central America, the NPK rates for various crops in this case have been derived as an arithmetical average of the various rates listed by Benton and Tisdale (1969) for each U.S. state and Canadian province.

For regions for which relevant recommended NPK rates were not available for any of the Cases and/or for any of the crops, we have either used the same rates as for some other similar region or used our judgment in deriving one.

RESULTS AND DISCUSSIONS

The potential annual fertilizer requirements, calculated on the basis of the above-mentioned fertilizer recommended levels, are indicated in Tables 2(a-g), 3(a-i) and 4. These are indicated by crop for all regions in Tables 2(a-g), by regions for all crops in Tables 3(a-i), and as a world summary by regions in Table 4. The potential global annual fertilizer requirement for the three cases is summarized on Table 5. It is also illustrated by regions and for all three cases in Figure 1.

Assuming the estimates obtained for each nutrient in Case III as 100 percent, the figures in parentheses following each estimate in Cases I and II (Table 5) reflect the percentage change over the estimates for the same nutrient obtained in Case III. These changes are reflections of the nutrient levels we have assumed for these Cases. We see that the percentage change is greatest for potash and least for nitrogen, with phosphate occupying an intermediate place. This is in the reverse order of the actual quantities of the three nutrients currently used. This probably is a reflection of the fact that, unlike the current situation in which the quantities of P and K usually used are quite low, their potential demand in the future is relatively high. This is particularly indicated in the case of K where we see that its potential annual demand under Case I becomes even higher than that for P.

TABLE 2. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS REGIONS, BY CROP
(million metric tons)

a. Africa

Crop	Area x 10^6ha	Case I			Case II			Case III		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Wheat	8.9	1.60	1.07	0.71	1.28	0.37	0.37	0.83	0.45	0.36
Rice	4.6	1.06	0.78	1.10	0.66	0.18	0.18	0.45	0.15	0.09
Maize	19.6	5.64	2.35	3.53	5.64	1.57	0.78	2.73	1.24	0.62
Barley	4.7	0.59	0.35	0.38	0.35	0.23	0.23	0.80	0.19	0.07
Sorghum	13.9	1.67	0.83	0.57	1.67	0.83	0.57	1.67	0.83	0.57
Millet	16.3	1.96	0.98	0.65	1.96	0.98	0.65	1.96	0.98	0.65
Oats & Rye	0.4	0.05	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01
Potato	0.5	0.10	0.12	0.12	0.10	0.12	0.12	0.10	0.12	0.12
Sweet Potato	0.8	0.07	0.05	0.20	0.07	0.05	0.20	0.07	0.05	0.20
Cassava	6.1	0.37	0.37	0.74						
Pulses	11.9	0.24	0.71	0.36	0.24	0.71	0.36	0.24	0.71	0.36
Cotton	4.4	0.88	0.44	0.53	0.63	0.31	Neg	0.43	0.22	Neg
Sugarcane	0.8	0.26	0.12	0.24	0.26	0.12	0.24	0.26	0.12	0.24
Sugarbeet	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Soybean	0.2	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Vegetables	0.8	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Subtotal	93.9	14.69	8.40	9.36	13.09	5.69	3.92	9.76	5.27	3.49
Others		3.67	2.10	2.34	3.27	1.42	0.98	2.44	1.31	0.87
TOTAL		18.36	10.50	11.70	16.36	7.11	4.90	12.20	6.58	4.36

Neg = Negligible

TABLE 2. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS REGIONS, BY CROP (contd)
(million metric tons)

b. North-Central America

Crop	Area x 10^6ha	Case I			Case II			Case III		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Wheat	40.6	7.31	4.87	3.25	5.08	4.87	3.25	2.43	1.83	1.42
Rice	1.8	0.41	0.31	0.43	0.27	0.11	0.11	0.17	0.07	0.05
Maize	38.3	11.03	4.60	6.89	7.66	4.60	6.89	4.60	2.50	2.68
Barley	8.0	1.00	0.60	0.64	1.00	0.60	0.64	0.44	0.36	0.24
Sorghum	7.8	0.94	0.47	0.31	0.94	0.47	0.31	0.94	0.47	0.31
Millet	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Oats & Rye	8.2	1.02	0.62	0.66	0.61	0.41	0.41	0.32	0.20	Neg
Potato	0.8	0.16	0.19	0.20	0.16	0.19	0.20	0.16	0.19	0.20
Sweet Potato	0.2	0.02	0.01	0.04	0.02	0.01	0.04	0.02	0.01	0.04
Cassava	0.1	Neg	Neg	0.01	Neg	Neg	0.01	Neg	Neg	0.01
Pulses	3.5	0.07	0.12	0.06	0.07	0.12	0.06	0.07	0.12	0.06
Cotton	5.0	1.00	0.50	0.60	0.48	0.30	0.30	0.48	0.30	0.30
Sugarcane	2.7	0.88	0.41	0.82	0.88	0.41	0.82	0.88	0.41	0.82
Sugarbeet	0.6	0.07	0.12	0.09	0.07	0.12	0.09	0.07	0.12	0.09
Soybean	20.3	0.81	1.20	1.62	0.81	1.20	1.62	0.81	1.20	1.62
Vegetables	0.9	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Subtotal	138.8	24.95	14.25	9.85	18.28	13.64	14.98	11.62	8.01	8.07
Others		6.24	3.57	2.47	4.57	3.41	3.75	2.91	2.01	2.02
TOTAL		31.19	17.82	12.32	22.85	17.05	18.73	14.53	10.02	10.09

Neg = Negligible

TABLE 2. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS REGIONS, BY CROP (contd)
(million metric tons)

c. South America

Crop	Area x 10^6ha	Case I N	Case I P_2O_5	Case I K_2O	Case II N	Case II P_2O_5	Case II K_2O	Case III N	Case III P_2O_5	Case III K_2O
Wheat	12.3	2.21	1.48	0.98	1.48	0.49	Neg	1.13	0.45	Neg
Rice	7.8	1.79	1.33	1.87	0.70	0.70	0.70	0.64	0.45	0.30
Maize	16.5	4.75	1.98	2.97	1.48	1.48	1.48	1.17	0.17	1.17
Barley	1.1	0.14	0.08	0.09	0.08	0.06	0.06	0.12	0.10	Neg
Sorghum	2.4	0.29	0.14	0.10	0.29	0.14	0.10	0.29	0.14	0.10
Millet	0.2	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Oats & Rye	1.1	0.14	0.08	0.08	0.08	0.05	0.05	0.06	0.03	Neg
Potato	1.0	0.20	0.24	0.25	0.20	0.24	0.25	0.20	0.24	0.25
Sweet Potato	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Cassava	2.6	0.16	0.16	0.32	0.16	0.16	0.32	0.16	0.16	0.32
Pulses	2.4	0.29	0.14	0.10	0.29	0.14	0.10	0.29	0.14	0.10
Cotton	2.9	0.58	0.49	0.35	0.58	0.49	0.35	0.58	0.49	0.35
Sugarcane	3.4	1.10	0.51	1.02	1.10	0.51	1.02	1.10	0.51	1.02
Sugarbeet	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Soybean	7.1	0.28	0.42	0.57	0.28	0.42	0.57	0.28	0.42	0.57
Vegetables	0.6	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Subtotal	61.4	12.08	7.20	8.85	6.87	5.03	5.15	6.17	3.45	4.33
Others		3.02	1.80	2.22	1.72	1.26	1.29	1.55	0.87	1.09
TOTAL		15.10	9.00	11.07	8.59	6.29	6.44	7.72	4.32	5.42

Neg = Negligible

TABLE 2. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS REGIONS, BY CROP (contd)
(million metric tons)

d. Asia

Crop	Area x 10^6ha	Case I			Case II			Case III		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Wheat	78.2	14.08	9.38	6.27	9.78	5.86	4.69	6.65	2.73	1.17
Rice	127.1	29.23	21.61	30.50	22.24	19.07	9.53	13.75	5.93	1.77
Maize	28.5	8.21	3.42	5.13	3.56	2.14	2.85	1.50	1.78	2.13
Barley	24.4	3.05	1.83	1.95	1.83	1.22	1.22	1.53	1.00	0.61
Sorghum	19.0	2.28	1.14	0.76	2.28	1.14	0.76	2.28	1.14	0.76
Millet	53.2	6.83	3.19	2.13	6.83	3.19	2.13	6.83	3.19	2.13
Oats & Rye	3.9	0.49	0.29	0.31	0.29	0.20	0.20	0.19	0.11	0.11
Potato	5.5	1.10	1.32	1.38	1.10	1.32	1.38	1.10	1.32	1.38
Sweet Potato	13.5	1.22	0.81	2.70	1.22	0.81	2.70	1.22	0.81	2.70
Cassava	2.8	0.17	0.17	0.34	0.17	0.17	0.34	0.17	0.17	0.34
Pulses	40.9	0.82	1.23	0.62	0.82	1.23	0.62	0.82	1.23	0.62
Cotton	15.8	3.16	1.58	1.90	2.00	0.79	0.79	1.59	0.79	0.40
Sugarcane	5.5	1.79	0.82	1.64	1.79	0.82	1.64	1.79	0.82	1.64
Sugarbeet	0.8	0.10	0.16	0.12	0.10	0.16	0.12	0.10	0.16	0.12
Soybean	16.2	0.65	0.97	1.30	0.65	0.97	1.30	0.65	0.97	1.30
Vegetables	4.1	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Subtotal	439.4	74.20	48.94	58.07	55.68	40.11	31.29	41.19	23.17	16.20
Others		18.55	12.24	14.52	13.92	10.03	7.83	10.30	5.80	4.05
TOTAL		92.75	61.18	72.59	69.60	50.14	39.12	51.49	28.97	20.25

Neg = Negligible

TABLE 2. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS REGIONS, BY CROP (contd)
(million metric tons)

e. Europe

Crop	Area x 10^6ha	Case I			Case II			Case III		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Wheat	26.7	4.81	3.20	2.14	4.81	1.07	1.07	3.29	1.15	1.01
Rice	0.4	0.09	0.07	1.00	0.08	0.06	0.05	0.06	0.04	0.02
Maize	11.7	3.37	1.40	2.11	2.34	1.40	2.11	1.40	0.76	0.82
Barley	18.6	2.32	1.40	1.49	1.40	0.93	0.93	1.02	0.84	0.56
Millet	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Oats & Rye	11.7	1.46	0.88	0.94	0.88	0.58	0.58	0.64	0.53	0.35
Potato	6.2	1.24	1.49	1.55	1.24	1.49	1.55	1.24	1.49	1.55
Sweet Potato	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Cassava	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Pulses	3.6	0.07	0.12	0.06	0.07	0.12	0.06	0.07	0.12	0.06
Cotton	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Sugarcane	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Sugarbeet	4.0	0.48	0.80	0.60	0.48	0.80	0.60	0.48	0.80	0.60
Soybean	0.3	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Vegetables	2.9	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Subtotal	86.1	14.56	9.28	10.61	12.02	7.17	7.67	8.92	6.45	5.69
Others		3.64	2.32	2.66	3.01	1.80	1.92	2.23	1.62	1.43
TOTAL		18.20	11.60	13.27	15.03	8.97	9.59	11.15	8.07	7.12

Neg = Negligible

TABLE 2. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS REGIONS, BY CROP (contd)
(million metric tons)

f. Oceania

Crop	Area x 10^6ha	Case I			Case II			Case III		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Wheat	9.0	1.62	1.01	0.72	1.62	0.67	Neg	1.04	0.57	Neg
Rice	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Maize	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Barley	2.3	0.29	0.17	0.18	0.17	0.11	0.11	0.13	0.10	0.07
Sorghum	0.5	0.06	0.03	0.02	0.06	0.03	0.02	0.06	0.03	0.02
Millet	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Oats & Rye	1.1	0.14	0.08	0.09	0.08	0.06	0.06	0.06	0.05	0.03
Potato	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Sweet Potato	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Cassava	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Pulses	3.6	0.07	0.12	0.06	0.07	0.12	0.06	0.07	0.12	0.06
Cotton	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Sugarcane	0.3	0.09	0.04	0.09	0.09	0.04	0.09	0.09	0.04	0.09
Soybean	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Vegetables	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Subtotal	16.8	2.27	1.45	1.16	2.09	0.97	0.34	1.45	0.91	0.27
Others		0.57	0.37	0.29	0.53	0.25	0.08	0.37	0.23	0.07
TOTAL		2.84	1.82	1.45	2.62	1.22	0.42	1.82	1.14	0.34

Neg = Negligible

TABLE 2. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS REGIONS, BY CROPS (contd)
(million metric tons)

g. U.S.S.R.

Crop	Area x 10^6ha	Case I			Case II			Case III		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Wheat	59.5	10.71	7.14	4.76	7.44	7.14	4.76	3.87	2.68	2.08
Rice	0.5	0.12	0.08	0.12	0.10	0.08	0.06	0.08	0.05	0.02
Maize	3.3	0.95	0.40	0.59	0.66	0.40	0.54	0.40	0.21	0.23
Barley	34.2	4.28	2.57	2.74	2.57	1.71	1.71	1.88	1.54	1.03
Sorghum	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Millet	3.0	0.36	0.18	0.12	0.36	0.18	0.12	0.36	0.18	0.12
Oats & Rye	20.3	2.54	1.52	1.62	1.52	1.01	1.01	1.12	0.91	0.61
Potato	7.1	1.42	1.70	1.78	1.42	1.70	1.78	1.42	1.70	1.78
Sweet Potato	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Cassava	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Pulses	5.2	0.10	0.15	0.08	0.10	0.15	0.08	0.10	0.15	0.08
Cotton	2.9	0.58	0.29	0.35	0.58	0.29	0.35	0.58	0.29	0.35
Sugarcane	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Sugarbeet	3.8	0.46	0.76	0.57	0.46	0.76	0.57	0.46	0.76	0.57
Soybean	0.8	0.03	0.04	0.08	0.03	0.04	0.08	0.03	0.04	0.08
Vegetables	0.4	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Subtotal	141.0	21.65	14.93	12.91	15.34	13.56	11.14	10.40	8.61	7.05
Others		5.41	3.74	3.23	3.84	3.39	2.79	2.60	2.16	1.77
TOTAL		27.06	18.67	16.14	19.18	16.65	13.93	13.00	10.77	8.82

Neg = Negligible

TABLE 3. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS CROPS BY REGIONS
(million metric nutrient tons)

a. Wheat

Region	Area x 10^6ha	Case I			Case II			Case III		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Africa	8.9	1.60	1.07	0.71	1.28	0.37	0.37	0.83	0.45	0.36
N-C. America	40.6	7.31	4.87	3.25	5.08	4.87	3.25	2.43	2.83	1.42
S. America	12.3	2.21	1.48	0.98	1.48	0.49	0.00	1.13	0.45	Neg
Asia	78.2	14.08	9.38	6.27	9.78	5.86	4.69	6.65	2.73	1.17
Europe	26.7	4.81	3.20	2.14	4.81	1.07	1.07	3.29	1.15	1.01
Oceania	9.0	1.62	1.01	0.72	1.62	0.67	Neg	1.04	0.57	Neg
U.S.S.R.	59.5	10.71	7.14	4.76	7.44	7.14	4.76	3.87	2.68	2.08
TOTALS	235.5	42.34	28.15	18.83	31.49	20.47	14.14	19.24	9.86	6.04

b. Rice

Region	Area x 10^6ha	Case I			Case II			Case III		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Africa	4.6	1.06	0.78	1.10	0.66	0.18	0.18	0.45	0.15	0.09
N-C. America	1.8	0.41	0.31	0.43	0.27	0.11	0.11	0.17	0.07	0.05
S. America	9.8	1.79	1.33	1.87	0.70	0.70	0.39	0.64	0.45	0.30
Asia	127.1	29.23	21.61	30.50	22.24	19.07	9.53	13.75	5.93	1.77
Europe, Oceania & U.S.S.R.	1.0	0.23	0.17	0.24	0.20	0.16	0.12	0.15	0.10	0.01
TOTAL	142.2	32.72	24.20	34.14	24.07	20.22	10.33	15.16	6.70	2.22

Neg = Negligible

TABLE 3. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS CROPS BY REGIONS (contd)
(million metric nutrient tons)

c. Maize

Region	Area x 10^6ha	Case I			Case II			Case III		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Africa	19.6	5.64	2.35	3.53	5.64	1.57	0.78	2.73	1.24	0.62
N-C. America	38.3	11.03	4.60	6.89	7.66	4.60	6.89	4.60	2.50	2.68
S. America	16.5	4.75	1.98	2.97	1.48	1.48	1.48	1.17	1.17	1.17
Asia	28.5	8.21	3.42	5.13	3.56	2.14	2.85	1.50	1.78	2.13
Europe	11.7	3.37	1.40	2.11	2.34	1.40	2.11	1.40	0.76	0.82
Oceania & U.S.S.R.	3.3	0.95	0.40	0.59	0.66	0.40	0.54	0.40	0.21	0.23
TOTAL	118.0	33.95	14.15	21.22	21.34	11.59	14.65	11.80	7.56	7.65

d. Barley

Region	Area x 10^6ha	Case I			Case II			Case III		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Africa	4.7	0.59	0.35	0.38	0.35	0.23	0.23	0.80	0.19	0.07
N-C. America	8.0	1.00	0.60	0.64	1.00	0.60	0.64	0.44	0.36	0.24
S. America	1.1	0.14	0.08	0.09	0.08	0.06	0.06	0.06	0.06	Neg
Asia	24.4	3.05	1.83	1.95	1.83	1.22	1.22	1.53	1.00	0.61
Europe	18.6	2.32	1.40	1.49	1.40	0.93	0.93	1.02	0.84	0.56
Oceania	2.3	0.29	0.17	0.18	0.17	0.11	0.11	0.13	0.10	0.07
U.S.S.R.	34.2	4.28	2.57	2.74	2.57	1.71	0.71	1.88	1.54	1.03
TOTAL	93.4	11.16	7.00	7.47	7.40	4.86	4.90	5.92	4.13	2.65

Neg = Negligible

TABLE 3. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS CROPS BY REGIONS (contd)
(million metric nutrient tons)

e. Cotton

Region	Area x 10^6ha	Case I N	Case I P_2O_5	Case I K_2O	Case II N	Case II P_2O_5	Case II K_2O	Case III N	Case III P_2O_5	Case III K_2O
Africa	4.4	0.88	0.44	0.53	0.63	0.31	Neg	0.43	0.22	Neg
N-C. America	5.0	1.00	0.50	0.60	0.48	0.30	0.30	0.48	0.30	0.30
S. America	2.9	0.58	0.49	0.35	0.12	0.17	0.12	0.12	0.17	0.12
Asia	15.8	3.16	1.58	1.90	2.00	0.79	0.79	1.59	0.79	0.40
Europe, Oceania & U.S.S.R.	3.2	0.64	0.32	0.38	0.30	0.19	0.19	0.30	0.19	0.19
TOTAL	31.3	6.26	2.33	3.76	3.53	1.76	1.40	2.92	1.67	1.01

f. Sorghum/Millet/Pulses

Region	Area x 10^6ha	Sorghum N	Sorghum P_2O_5	Sorghum K_2O	Area x 10^6ha	Millet N	Millet P_2O_5	Millet K_2O	Area x 10^6ha	Pulses N	Pulses P_2O_5	Pulses K_2O
Africa	13.9	1.67	0.83	0.57	16.3	1.96	0.98	0.65	11.9	0.24	0.71	0.36
N-C. America	7.8	0.94	0.47	0.31	Nil	Nil	Nil	Nil	3.5	0.07	0.12	0.06
S. America	2.4	0.29	0.14	0.10	Neg	Neg	Neg	Neg	5.1	0.10	0.15	0.08
Asia	19.0	2.28	1.14	0.76	53.2	6.38	3.19	2.13	40.9	0.82	1.23	0.62
Europe	Neg	Neg	Neg	Neg	Nil	Nil	Nil	Nil	3.6	0.07	0.12	0.06
Oceania	0.5	0.06	0.03	0.02	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
U.S.S.R.	Neg	Neg	Neg	Neg	3.0	0.36	0.18	0.12	5.2	0.10	0.15	0.08
Total	43.9	5.24	2.61	1.76	72.8	8.70	4.35	2.90	70.4	1.40	2.48	1.24

Neg = Negligible

TABLE 3. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS CROPS BY REGIONS (contd)
(million metric nutrient tons)

g. Potato/Sweet Potato & Cassava

Region	Potato				Sweet Potato				Cassava			
	Area x 10^6ha	N	P_2O_5	K_2O	Area x 10^6ha	N	P_2O_5	K_2O	Area x 10^6ha	N	P_2O_5	K_2O
Africa	0.5	0.10	0.12	0.12	0.8	0.07	0.05	0.20	6.1	0.37	0.37	0.74
N-C. America	0.8	0.16	0.19	0.20	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
S. America	1.0	0.20	0.24	0.25	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Asia	5.5	1.10	1.32	1.38	13.5	1.22	0.81	2.70	2.8	0.17	0.17	0.34
Europe	6.2	1.24	1.49	1.55	Neg	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Oceania	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
U.S.S.R.	7.1	1.42	1.70	1.78	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
TOTAL	21.1	4.22	5.06	5.29	14.9	1.29	0.86	2.90		11.6	0.70	1.40

h. Soybean/Vegetables

Region	Soybean				Vegetables			
	Area x 10^6ha	N	P_2O_5	K_2O	Area x 10^6ha	N	P_2O_5	K_2O
Africa	0.2	Neg	Neg	Neg	0.8	0.20	0.20	0.20
N-C. America	20.3	0.81	1.20	1.62	0.9	0.23	0.23	0.23
S. America	7.1	0.28	0.42	0.57	0.6	0.15	0.15	0.15
Asia	16.2	0.65	0.97	1.30	4.1	1.02	1.02	1.02
Europe	0.3	Neg	Neg	Neg	2.9	0.72	0.72	0.72
Oceania	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
U.S.S.R.	0.8	0.03	0.04	0.06	0.4	0.10	0.10	0.10
TOTAL	44.9	1.77	2.63	3.55	9.6	2.42	2.42	2.42

Neg = Negligible

TABLE 3. ESTIMATED FERTILIZER REQUIREMENTS FOR VARIOUS CROPS BY REGIONS (contd)
(million metric nutrient tons)

i. Sugarcane/Sugarbeet

Region	Sugarcane Area x 10^6ha	Sugarcane N	Sugarcane P_2O_5	Sugarcane K_2O	Sugarbeet Area x 10^6ha	Sugarbeet N	Sugarbeet P_2O_5	Sugarbeet K_2O
Africa	0.8	0.26	0.12	0.24	Neg	Neg	Neg	Neg
N-C. America	2.7	0.88	0.41	0.82	0.6	0.07	0.12	0.09
S. America	3.4	1.10	0.51	1.02	Neg	Neg	Neg	Neg
Asia	5.5	1.79	0.82	1.64	0.8	0.10	0.16	0.12
Europe	Neg	Neg	Neg	Neg	4.0	0.48	0.80	0.60
U.S.S.R.	Nil	Nil	Nil	Nil	3.8	0.46	0.76	0.57
TOTAL	12.7	4.03	1.86	3.72	9.4	1.11	1.84	1.38

TABLE 4. ESTIMATED WORLD POTENTIAL ANNUAL FERTILIZER REQUIREMENTS, BY REGION
(million metric tons)

SUMMARY

Region	Area x 10^6ha	Case I N	Case I P_2O_5	Case I K_2O	Case II N	Case II P_2O_5	Case II K_2O	Case III N	Case III P_2O_5	Case III K_2O
Africa	93.9	18.36	10.50	11.70	16.36	7.11	4.90	12.20	6.58	4.36
N-C. America	138.8	31.19	17.82	12.32	22.85	17.05	18.73	14.53	10.02	10.09
S. America	61.4	15.10	9.00	11.07	8.59	6.29	6.44	7.72	4.32	5.42
Asia	439.4	92.75	61.18	72.59	69.60	50.14	39.12	51.49	28.97	20.25
Europe	86.1	18.20	11.40	13.27	15.03	8.97	9.59	11.15	8.07	7.12
Oceania	16.8	2.84	1.82	1.45	2.62	1.22	0.42	1.82	1.14	0.34
U.S.S.R.	141.0	27.06	18.67	16.14	19.18	16.65	13.93	13.00	10.77	8.82
TOTAL	977.4	205.50	130.59	138.54	154.23	107.43	93.13	111.91	69.87	56.40

Neg = Negligible

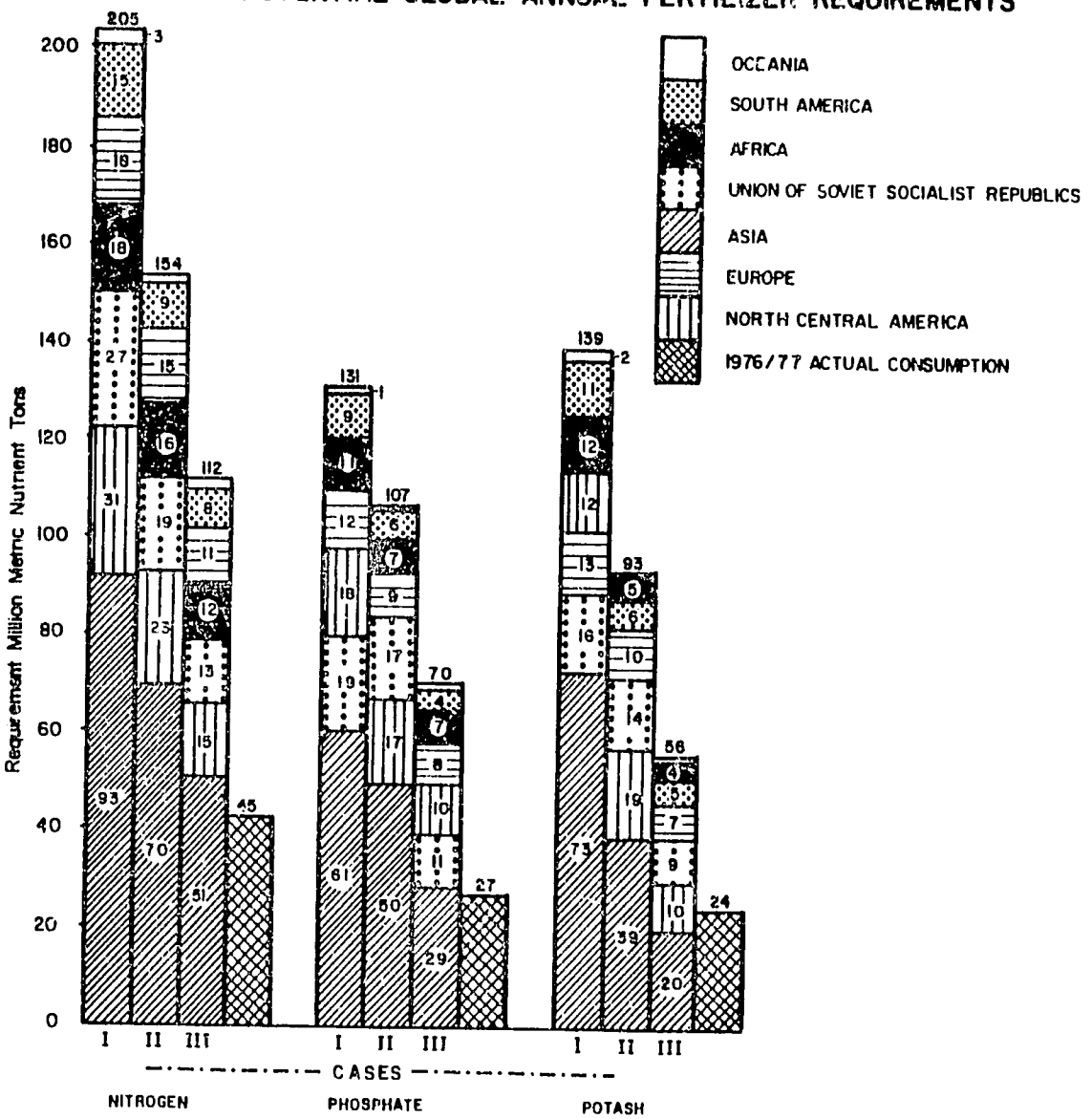
TABLE 5. POTENTIAL GLOBAL FERTILIZER REQUIREMENT
(million metric nutrient tons)

SUMMARY

	Case I	Case II	Case III
N	205.50 (184%)	154.23 (138%)	111.91 (100%)
P_2O_5	130.59 (187%)	107.43 (154%)	69.87 (100%)
K_2O	138.54 (246%)	93.13 (165%)	56.40 (100%)
Total all Nutrients	474.63 (199%)	354.79 (149%)	238.18 (100%)

Fig. 1

POTENTIAL GLOBAL ANNUAL FERTILIZER REQUIREMENTS



Our estimates compare with the following estimates derived by Fox and Yost using their different approaches:

Approach used to make estimate	Fertilizer Required (million metric tons) N	P_2O_5	K_2O
Economic	60	30	24
Sociological	250	150	130
Human nutrition	170	-	-
Balance sheet (for maintenance)	94	21	36
Soils:			
Low intensity	-	100	-
Medium intensity	-	270	113
High intensity	-	1,000	-
Maintenance-startup	94	min. 74 max. 87	44

We find that in Case I, our estimates for all three nutrients approximate closely with those calculated by them using the sociological approach. In Case II, our N estimate approximates that obtained by their nutrition approach, while P and K approximate their estimates derived by using the soil approach (at low and medium intensities, respectively). In Case III, our N estimate approximates their estimate derived by using the balance sheet approach, while P and K estimates approximate their maintenance-startup approach. The variations that we see in the estimates derived by using their and our approaches are within what we would consider to be reasonable limits, keeping in mind the crude approximations being used.

Benton and Tisdale (1969), using the recommended NPK rates for the major crops grown in each state of the U.S. and each province of Canada, have estimated the potential annual fertilizer requirement for North America as follows:

N	14.55	million	metric	nutrient tons
P_2O_5	11.33	"	"	"
K_2O	8.85	"	"	"

These come remarkably close to our own estimates for North-Central America derived through Case III, although our estimates are based upon an arithmetic averaging of NPK recommendations for each state and province (Table 2b). Their N and P estimates are higher than ours by approximately 1 percent and 11 percent, respectively, while our K estimates are higher than theirs by 12 percent. It should be pointed out that our estimates, being for North and Central America, cover a cropped area approximately 13 percent bigger than the area under their consideration.

CURRENT CONSUMPTION VERSUS POTENTIAL REQUIREMENT

Table 6 compares the 1976-1977 estimated global NPK consumption reported by USDA (1978) with the potential annual fertilizer requirement,

as estimated in Case III. This comparison is also provided in Figure 1.

At the outset, we would like to point out that there may be slight discrepancies between the actual areas represented in the two sets of figures. In Case III, the region we have used is North-Central America, while USDA's figures are for North America only. Similarly, since USDA does not give a breakdown for Asia, we have assumed this region to be represented by their "Near East" plus "Far East" plus "Communist Asia" plus "Other Developed Market Economies." Finally, we have combined their "Eastern Europe" (minus U.S.S.R.) and "Western Europe" to represent our "Europe" region. The estimated figures for U.S.S.R. were derived from another USDA publication (1979).

An analysis of the figures indicates that, as expected, "developing' areas are currently using a much smaller fraction of their potential than the "developed" areas. On one end of the scale, we have Africa where the current consumption is between only 4 percent and 7 percent of estimated potential. In Asia, it is between 10 percent and 20 percent; while in Latin America, it is between 20 percent and 30 percent. In the developed areas on the other hand, it is mostly over 50 percent.

Two peculiar situations are notable:

In Europe, the current use is above what has been estimated to be their potential. This highlights the fact that the average NPK recommended rates we have used for Case III are on the conservative side for this region.

In Oceania, while P_2O_5 use is nearly at its potential level, the N rate is only at about 13 percent. The explanation provided for the European situation above most probably would also account for the P_2O_5 situation here; some of this discrepancy perhaps may also be explained by the fact that the current N usage in Australia is very low due to its high reliance on pasture legumes as a source of nitrogen.

SUMMARY AND CONCLUSIONS

We have attempted to estimate the potential annual global fertilizer requirement using the two physical factors of current crop areas and the recommended rates of NPK applications as determinants. Depending upon assumptions used, the potential requirements for NPK are estimated to range as follows:

N	111 to 206	million	metric	nutrient	tons
P_2O_5	69 to 131	"	"	"	"
K_2O	56 to 139	"	"	"	"

It is seen that these figures approximate within reason those estimated by Fox and Yost. Our Case III estimates are also seen to be remarkably close to those developed by Benton and Tisdale for North America.

TABLE 6. CURRENT WORLD FERTILIZER CONSUMPTION vs. ESTIMATED POTENTIAL REQUIREMENT

Region	1976/77 Consumption* (million metric tons)			Case III Potential Requirement (million metric tons)			Present Consumption as % of Potential Requirement		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Africa	0.52	0.42	0.21	12.20	6.58	4.36	4.3	6.4	4.8
North-Central America	10.26	5.64	5.54	14.53	10.02	10.09	70.6	56.3	54.9
South America	2.27	1.89	1.11	7.72	4.32	5.42	29.4	43.8	20.5
Asia	11.47	4.94	2.15	51.49	28.97	20.25	22.3	19.0	10.6
Europe	12.45	8.41	8.24	11.15	8.07	7.12	111.7	104.2	115.7
Oceania	0.23	1.13	0.25	1.82	1.14	0.34	12.6	99.1	73.5
U.S.S.R.	7.25	4.06	5.58	13.00	10.77	8.82	55.8	37.7	63.3
TOTAL	44.45	26.49	23.08	111.91	69.87	56.40	39.7	37.9	40.9

* Source: USDA (1978)

As a futuristic exercise, therefore, we can conclude that the method of using recommended NPK rates to project potential requirement has some merit. Its effectiveness will, of course, increase with more reliable estimates of what the recommended rates should be for use in various areas.

Our estimates confirm the generally held belief that most of the growth in future fertilizer consumption will come from developing areas.

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13. Based on No. 4.

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15. Estimates for N-C. America also used here.

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PART 3

FERTILIZER COMMERCE

FERTILIZER SCENE IN INDIA: 2000 A.D.

N.M. VACHHRAJANI*

ABSTRACT

The need is highlighted for massive use of chemical fertilizers to make production meet the food requirements of a population of nearly 935 million by the year 2000 in India. Based on past trends and taking into account the resource constraints, both monetary and infrastructural, as well as the problems connected with feedstock which is mainly petroleum based, the country needs to concentrate on successful implementation of the two coal-based plants under commission and to further develop and improve technology in order to produce chemical fertilizers from coal.

Even these will not fulfill the total need for chemical fertilizers. Therefore, it is suggested that the alternative use of organic wastes enriched with N and P be tried on a large scale.

INTRODUCTION

The most redeeming feature of India's present economy is the achievement of self sufficiency with respect to foodgrain production. The productivity levels achieved in recent years have not only been adequate to feed the 645 million population but have also generated surpluses, although in a modest way. As recently as 1976, India's import bill for foodgrains was a staggering figure of nearly Rs.1,000 crores ($1250 million). This achievement therefore cannot be considered insignificant. (Production imports and availability of foodgrain during the last decade in India are given in Appendix I.)

By the turn of this century, India's population is expected to reach a figure of 935 million. The minimum foodgrain requirement will be about 230 million tons, which implies almost doubling the present output of about 130 million tons within 20 years. Considering that the foodgrain production in India doubled between 1951 and 1975, a span of 25 years, increasing the present production to twice its present level by the year 2000 may not, prima facie, appear formidable. Since no scope exists for harnessing fresh cultivable land on the one hand (see Appendix II for growth of India's cultivable land), and given the risks and uncertainties associated with the management of agriculture in a predominantly tropical country like India, the task ahead calls for sustained, intensive, and concerted efforts on the part of the government, the fertilizer industry, and the farming community. The only possible alternative lies in better farm management for achieving growth vertically. And the key to success lies in providing an adequate amount of chemical fertilizers, improved seed, and modern farm management techniques. Among these inputs, it is well known that chemical fertilizers have a dominant role to play.

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CONSUMPTION OF FERTILIZERS IN INDIA

There are two important milestones in the history of fertilizer consumption in India, namely the years 1966 and 1973. The first date is important as a landmark for the advent of high yielding seed and the second for the energy crisis. Apart from these, several changes in the pricing and other policies in the country affected the system. During 1978-1979 a total of 5.1 million tons of plant nutrients were distributed in India, of which nitrogen (N) accounted for 3.41 million tons, phosphate (P) 1.1 million tons, and potash .59 million tons. The contribution of domestic producers to this total was 2.93 million tons and the balance was met through imports. Similar statistics relating to the years 1961-1962 to 1977-1978 are given in Appendix III.

Fertilizer consumption in 1966-1967 increased by nearly 300 percent when compared to the year 1961-1962. Growth was comparatively greater for P and K than for N. In the subsequent five-year period the overall growth of the three primary nutrients was about 240 percent. However compound growth during the decade 1961-1962 to 1971-1972 averaged around 23 percent per annum, or about an eight-fold increase on the whole. The details are given in Table 1.

TABLE 1-- GROWTH OF CONSUMPTION OF N, P, AND K, 1961-1962 to 1971-1972

Unit: 1,000 tons

YEAR	N	P	K	N+P+K
1961-1962	249.8	60.5	28.0	338.3
1966-1967	737.8	248.6	114.2	1,100.6
1971-1972	1,798.0	558.3	300.0	2,666.3
Increase per year compound growth rate in 1971-1972 over 1961-1962.	21.8	24.8	26.8	22.8

Source: Fertilizer Situation in India, FAI, New Delhi.

In the following two years, 1972-1973 and 1973-1974, although the demand was great, growth was barely 2-3 percent, or far below the spectacular achievment of 23 percent during the previous decade. Principal factors arresting this growth were:

- Indigenous production was much below target, and
- Inadequate imports due to limited exportable surplus in world markets and spiraling prices.

These factors not only arrested growth but caused a drop in 1973-1974 compared to the preceding year.

It was at this time that the energy crisis gripped the world economy, and India, too, suffered heavily. Fertilizer prices went up steeply, so much so that for the first time in the history of fertilizer consumption, all three nutrients registered a negative growth rate. Although nitrogen recovered from the trauma in the next year, P and K continued to lag behind. When the farmer is under a compulsion to reduce fertilizer application, it is K and P that get discarded from the list, in that order. Details of the yearly growth of N-P-K consumption from 1972-1973 to 1978-1979 are given in Appendix IV. This alarming phenomenon not only precipitated a reverse trend in respect to P and K, but eroded the already existing imbalance in the N-P-K consumption ratio. In spite of better availability, the situation was getting worse. The government, industry, and all concerned reacted quickly. Many drastic steps were taken to remedy the situation, including reduction in the price of N-P-K in general. Inducement to consumption by way of reduced excise duty, subsidies, and intensification of product promotion efforts were undertaken. Potential consumption areas were identified and micro level programs organized. All these measures brought a boost to fertilizer consumption and the desired recovery occurred. The highest ever level of consumption of 4,286 thousand tons of N-P-K was recorded for the year 1977-1978; and in the year just ended (1978-1979), consumption reached 5,100 thousand tons.

In effect, the compound growth during the period 1972-1973 to 1978-1979 averaged around 10.50 percent per annum. The details may be seen in Table 2.

TABLE 2-- GROWTH OF FERTILIZER CONSUMPTION IN INDIA 1961-1962 to 1978-1979 Unit: 1,000 tons

	1961-1962	1966-1967	1971-1972	Growth rate %	1972-1973	1978-1979	Growth rate %
N	249.8	737.8	1,798.0	21.8	1,839	3,410	11
P	60.5	248.6	558.3	24.8	581	1,100	11
K	28.0	114.2	300.0	26.8	347	590	9
Total	338.3	1,100.6	2,656.3	22.8	2,767	5,100	10.5

Source: Fertilizer Situation in India, FAI, New Delhi.

At this stage it is worthwhile to analyze per hectare consumption in India compared with that of the world generally and certain other countries specifically.

In spite of the spectacular growth as judged from conditions in the country, the per hectare consumption in India is one of the lowest as may be seen from Table 3.

TABLE 3-- FERTILIZER CONSUMPTION PER HECTARE OF ARABLE LAND DURING 1976-1977

Unit: Kg/ha

COUNTRY	N	P	K	TOTAL
India	14.5	3.8	1.9	20.2
Bangladesh	17.7	6.5	1.5	25.7
Pakistan	25.8	6.3	0.2	32.3
New Zealand	23.7	459.4	160.7	643.8
Fiji	39.0	6.1	9.5	54.5
Japan	146.3	146.8	137.4	430.5
World Total	30.3	17.8	15.5	63.6

Source: Annual Fertilizer Review 1977, FAO Rome, as reproduced in Fertilizer Statistics 1977-78, Page III-9 FAI. New Delhi

The above picture reflects the national averages. However, there are areas even in India which consume up to 350 percent more than the national average Data on typical disparities are given in Table 4.

TABLE 4-- STATEWISE CONSUMPTION OF NUTRIENTS DURING 1977-78

Unit: Kg/ha

STATE	N	P	K	TOTAL
Punjab	51.1	16.7	4.6	72.4
Tamil Nadu	36.7	10.1	12.2	59.0
Assam	1.5	0.1	0.2	1.8
Madya Pradesh	4.7	2.3	0.5	7.5

Source: Fertilizer Statistics 1977-78, FAI, New Delhi

This indicates the vast potential available for development and also the extent to which promotion is needed.

The desirable N-P-K consumption ratio for Indian soils and crops is considered to be 4:2:1. All these years efforts were directed toward achieving this ratio by monitoring fertilizer promotion, distribution, pricing policies, etc. Progress achieved during the last two decades has been quite encouraging, as may be seen from Table 5.

TABLE 5-- N:P:K RATIO IN INDIA

YEAR	N	P	K
1961-1962	8.9	2.2	1
1966-1967	6.5	2.2	1
1971-1972	6.0	1.9	1
1972-1973	5.3	1.7	1
1973-1974	5.1	1.8	1
1974-1975	5.3	1.4	1
1975-1976	7.7	1.7	1
1976-1977	7.7	2.0	1
1977-1978	5.8	1.7	1
1978-1979	5.8	1.9	1
Asia	5.6	2.2	1
Oceania	0.9	4.5	1
World, 1976-1977	1.9	1.1	1

Source: FAI for data on India and Annual Fertilizer Review 1977, FAO, Rome, for other countries and world.

An alarming feature in Indian agriculture is the low productivity of Indian soil as compared to other countries of the world. This is reflected in Table 6.

TABLE 6-- YIELD PER HECTARE, 1976-1977

Unit: 1,000 kg

	PADDY	WHEAT	MAIZE
India	1.9	1.4	1.1
Australia	5.8	0.9	2.7
Japan	6.2	2.7	2.7
China	3.5	1.3	3.0
USA	4.9	2.1	5.7

Source: Fertilizer Statistics 1977-78, FAI, New Delhi.

Here also the national averages do not give a correct picture, since when different areas in India are compared, the productivity range per hectare is high, as data in Table 7 would substantiate.

Significant improvement in the productivity level of soils should be an important objective if India is to have sustained food production. This becomes all the more significant when it is realized that only marginal additions to the cultivable land are possible.

It would appear that the key to sustained agricultural development lies in the use of chemical fertilizers only. Every addition of one

TABLE 7-- PRODUCTIVITY OF CROPS IN INDIA IN SELECTED STATES, 1976-1977

Unit: 1,000 kg/ha

STATE	RICE	WHEAT	MAIZE
Punjab	2.5	2.4	1.1
Tamilnadu	2.1	-	1.1
Uttar Pradesh	.9	1.3	.75
Andhra Pradesh	1.3	.6	1.0
Assam	1.0	1.1	.56
Madhya Pradesh	.6	.7	1.1

kilogram of N to India's 164 million hectares of crop area would call for one fertilizer plant with about 330,000 tons of urea. This would mean Rs.150 crores ($187 million) investment, at current prices. Can the country afford such high levels of application in a short span of time with meager financial and material resources? The answer is obvious. Keeping these realities in mind, future targets cannot be much different from those of the past or present--however optimistic the country might be. Therefore, the projections considered for this discussion are based upon past experience.

In this context, some of the time series projections are made by the association of domestic producers called Fertilizer Association of India (FAI). An assessment of the projections done by FAI in the past shows that their forecast figures closely approximate the actual (Table 8). FAI has made use of time series analysis for projection of future demand by extrapolation of quadratic relationship. Such projections are available for the years 1979-1980 to 1987-1988 (see Appendix V). It will be seen from those projections that during the period 1985-1986 to 1987-1988 the growth rates for N, P, and K average around 9 percent and 8 percent per annum. The author feels that the same trends would continue at least up to 1990-1991. From that high base, thereafter, it is presumed that annual growth rate would be around 5 percent, 4 percent, and 3 percent respectively, up to the year 2000.

TABLE 8-- COMPARISON OF FAI'S ESTIMATES WITH ACTUAL FIGURES

Unit: 1,000 tons

	N	P	K
1976-1977			
FAI Proj.	2,466	679	400
Actuals	2,457	635	319
1977-1978			
FAI Proj.	2,826	740	448
Actuals	2,913	867	506
1978-1979			
FAI Proj.	3,329	959	551
Actuals	3,410	1,100	590

Source: Fertilizer Situation in India, FAI, New Delhi.

Based on these assumptions, the author has projected the demand for N-P-K up to the year 2000 (details are given in Appendix VI). A summary of the projections made is shown in Table 9.

TABLE 9-- PROJECTION OF N-P-K CONSUMPTION IN INDIA 1980-1981 to 2000

Unit: 1,000 tons

YEAR	ESTIMATED CONSUMPTION			
	N	P	K	TOTAL
1980-1981	4,260	1,172	691	66,123
1985-1986	7,135	1,801	1,113	10,049
1990-1991	11,010	2,530	1,650	15,190
1999-2000	17,080	3,610	2,160	22,850

Data used for projections are time series from 1961-1962 to 1977-1978.

Credibility of these projections increases further when viewed again in UNIDO's projections for the regions of the world, as given in Table 10.

TABLE 10-- FERTILIZER DEMAND FORECAST-GROWTH RATE, BY NUTRIENT AND REGION
(All figures in percentages)

REGION	1976/1982			1982/1987			1987/2000		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Developed countries									
Market economies	3.2	2.3	3.5	3.2	1.7	3.5	2.8	1.8	3.2
Centrally planned economies	7.6	9.2	5.2	5.7	3.3	6.4	4.6	5.3	4.6
Total developed countries	4.9	4.9	4.3	4.2	5.6	4.8	3.7	2.4	3.9
Developing countries									
Africa	6.8	7.6	10.3	9.3	6.2	7.3	5.2	5.3	4.9
Latin America	10.3	8.8	9.4	7.3	7.3	8.9	5.2	5.4	5.0
Near East	8.8	6.8	8.1	8.9	7.0	6.6	5.2	5.8	5.8
Far East	10.2	11.8	11.6	8.1	7.3	7.2	5.8	4.9	5.0
Total market economies	9.8	9.2	10.0	8.1	7.2	8.0	5.5	5.3	5.0
Asian centrally planned economies	6.8	8.3	8.1	6.1	7.0	4.8	4.6	4.8	8.1
Total developing countries	8.7	8.9	9.9	7.5	7.2	7.5	5.2	5.2	4.9
Total world	6.2	5.9	5.0	5.4	6.0	5.2	4.3	3.2	4.1

Source: Second World-wide Study on the Fertilizer Industry, 1978-2000, UNIDO, September, 1978.

Having thus accepted the forecast figures to be reasonably realistic, two basic questions remain to be answered. The first is:

Within 10 years we wish to more than double the present level of consumption, and by the end of the century to triple it. Is this possible? And if so, under what conditions? The author's answer is an emphatic "yes" to the first part of the question. This optimism stems from the analysis of historical data on consumption of N-P-K during the years 1951-1952 to 1978-1979. It will be seen that the periodicity or doubling is much less (about five years) except when the system was affected adversely during the seventies (the reasons for which have already been traced in detail), when it took eight-ten years. Therefore, even in the event another crisis occurs, the growth envisaged appears feasible. Moreover, currently about 55 districts out of 380 (14%) account for 75 percent of total fertilizer consumption, bringing into sharp focus the vast potential. In regard to the conditions that would be necessary for conducive growth, the following are important:

- Further intensification of agro-promotional activities. This has to be carried out on a village-to-village, farmer-to-farmer basis. The inspiration and the model for this should be somewhat along the lines of the Indo-German Fertilizer Educational Program conducted in West Bengal and a similar project recently undertaken in Madya Pradesh with the help of the U.K. government.
- Strengthening of distribution outlets--at present the country has about 100 thousand selling points.
- Improved warehousing, credit disbursal.
- Pragmatic policies for support prices for foodgrains so as to ensure a favorable benefit cost ratio to the farmer.
- Relaxation of controls on distribution and pricing.
- Ensuring adequate, if not unlimited, availability of not only fertilizers but all related inputs like pesticides, water, seed, and management techniques.
- Identification of potential areas for development and organizing specific programs for area development.

The second is:

It is recognized that all these measures would require large-scale investments. Could the country afford it? And if so, to what extent? These are the factors needing a deeper analysis which is not attempted here. But the adequacy of availability factor among the list given above would lead to the second question: Can we ensure adequate availability? To answer this question, we shall now examine the fertilizer production scene in India.

FERTILIZER PRODUCTION IN INDIA

Fertilizer manufacturing in India which commenced in a humble way in 1906 has come of age today. The capacity for N production at the end

of December 1950 was just 16,700 tpa and that of P was about 20,500 tpa. By the end of the fifties another 100,000 tons of N was added to this when P capacity also increased to nearly 100,000 tons. These capacities nearly doubled by about 1964-1965. The year 1966 forms a watershed in the history of domestic capacity growth in India when a new policy was evolved by the Government of India. Up to October 1966, fertilizer marketing was characterized by the dominance of the state in respect to production, distribution, and selling prices. The policy referred to above had sought for gradual decontrol, which resulted in the salutory effect of bringing in private investment in a major way. Within a decade the N capacity recorded a growth of nearly 667 percent and P capacity a growth of 380 percent. As of October 1978, India's capacity for N production stood at 3,295,000 tons and that for P at 1,278,000 tons. Historical data on the growth of production are given in Appendix VI

There is no production of potash in India, due to the absence of viable deposits, and this situation is expected to continue for a long time.

The domestic production of N contributed 63 percent and P, 71 percent of the total consumption during 1978-1979 as shown in Table 11.

TABLE 11-- SHARE OF DOMESTIC PRODUCTION, IMPORTS IN CONSUMPTION OF N-P-K IN 1978-1979 IN INDIA

Unit: Million tons

PARTICULARS	N	P	K
Consumption	3.41	1.10	0.59
Domestic Supply	2.17	0.78	-
Gap (filled through imports)	1.24	0.32	0.59

The gaps were filled by importing the fertilizers. The rapid increase in fertilizer demand far outstripped the supply from the domestic units; in fact, the dependence on imports increased almost commensurately with demand. Details of consumption of N, P, and K, domestic production, and imports during the last two decades are given in Appendix III.

Despite the spectacular growth achieved in domestic production, there is no relief from the heavy import bills.

As of October 1978, capacity for N and P was about 3,295,000 tons and 1,277,000 tons, respectively. To this another 2,071,000 tons of N and 101,000 tons of P will be added by the projects currently under implementation between now and 1982-1983. The projects approved in principle and those likely to come on stream between 1982-1983 and 1984-1985 will add 2,308,000 tons of N and 450,000 tons of P. Thus, the total capacity so far planned will amount to 7,674,000 tons of N and 1,828,000 tons of P by 1984-1985 as shown in Table 12.

TABLE 12-- TOTAL CAPACITY FOR N & P IN INDIA		Unit: 1,000 tons
STATE	N	P
Existing	3.296	1,277
Under implementation	2,071	101
Approved in principle	2,308	450
TOTAL	7,674	1,828

Source: Fertilizer Statistics 1977-1978, page I.7.

Taking this into account, a demand-supply balance is computed by FAI up to 1987-1988. It shows that dependence on imports would continue. (Details are given in Appendix VIII.) In fact, there will be no further increase in the production of N and P achieved by 1985-1986. A similar position for the years beyond 1988-1989 up to the year 2000 is given in Appendix IX.

To sum up, large-scale gaps exist between demand and supply for N, P, and K throughout the century, as may be seen from Table 13.

TABLE 13-- GAPS IN DEMAND-SUPPLY IN INDIA			Unit: 1,000 tons
YEAR	N	P	K
1985-1986	1,152	762	1,113
1990-1991	5,027	1,481	1,650
1999-2000	11,097	2,561	2,160

The above figures reveal that if India is to meet the entire demand by 1985-1986 there is need for at least five plants each of 228,000 N and 150,000 P. The investment requirements at the current rates would be about Rs.2400 crores ($3,000 million) for these ten plants. Between 1985-1986 and 1990-1991, the country would need to double this amount; and during the nineties the investment requirements would be an astronomical figure, at least from Indian standards, that is, a cumulative investment of the order of Rs.24,000 crores ($30,000 million) at current prices. As of 1978 the cumulative investment in the fertilizer industry was nearly Rs.5,000 crores ($6,250 million). In the next 20 years we will require Rs.24,000 crores--where will be money come from? Or is there another alternative?

First, the domestic fertilizer industry has hardly any scope to generate investment funds. Prices are controlled, and any increase in the consumer price will upset the low benefit cost-ratio which is very sensitively being balanced now by imposing a ceiling on the price on the one hand and providing a support price to the farmer on the other. Data on benefit-cost ratio for important crops in India are given in Table 14.

TABLE 14-- BENEFIT-COST RATIOS* IN INDIA

Unit: Kg

	Wheat		Rice	
	N	P	N	P
1971-1972	3.78	2.45	2.64	1.71
1972-1973	3.65	2.41	2.64	1.75
1973-1974	4.00	2.65	3.68	2.44
1974-1975	2.90	2.52	2.04	1.07
1975-1976	3.32	1.76	2.34	1.24
1976-1977	3.68	2.21	2.74	1.54
1977-1978	4.01	2.26	3.03	1.70

*Incremental response ratio kg. of extra product for additional kg. of nutrient application.

Source: Fertilizer Situation of India, FAI, New Delhi.

Even at the existing price levels, the Indian farmer pays a much higher rate than his counterparts in the neighboring countries or elsewhere. Relevant data are given in Appendix X.

The only feasible way is for the state to divert the investable surpluses from other sectors, since the likelihood of foreign entrepreneurs' interest in fertilizers is ruled out within the framework of the existing government policy. A two digit inflation and the threat of another traumatic shock by OPEC make the state's capability doubtful.

The existing plants should be revamped and the capacity utilization improved so as to generate additional production. The operating ratio, which has been only in the vicinity of 45 to 66 percent, can at best improve by another 15 percent. This again is a swim against the current when viewed in the light of recent history! (Table 15)

TABLE 15-- OPERATING RATIOS OF FERTILIZER PLANTS IN INDIA 1973-1974 to 1977-1978

Unit: 1,000 tons

YEAR	INSTALLED CAPACITY		PRODUCTIVITY		OPERATING RATIOS %	
	N	P	N	P	N	P
1973-1974	1,939	531	1,060	323	55	61
1974-1975	2,196	592	1,185	327	60	58
1975-1976	2,676	742	1,508	320	63	45
1976-1977	3,064	1,042	1,857	478	64	56
1977-1978	3,221	1,042	2,000	670	65	66

Source: Fertilizer Situation in India, FAI, New Delhi.

The third alternative that can be thought of is to harness the other sources for plant nutrients. One such possible way is to utilize the organic sources for N-P-K. According to a leading agricultural scientist, there is vast untapped potential in urban wastes, farmyard manure, and crop residuals which can offer a viable alternative source for N, P, and K. Related data are given in Table 16.

TABLE 16-- POTENTIAL OF ANNUAL AVAILABILITY OF ORGANIC WASTES WITH PLANT NUTRIENTS

MATERIAL	QUANTITY AVAILABLE (1,000,000 tons)	Nutritional content			
		N	P_2O_5	K_2O	TOTAL
City garbage	15.0	0.23	0.15	0.23	0.61
Sewage and sullage	292,000.0	0.036	0.007	0.022	0.065
Rural compost*	600.0	3.00	3.00	3.00	9.00
Cattle dung (wet)	960.0	1.92	0.96	1.44	4.32
Cattle urine	370.0	2.22	0.04	1.85	4.11
Sheep, goat, and pigdung	14.1	1.00	0.45	0.90	2.35
Poultry droppings	3.4	0.30	0.26	1.40	1.96
Night soil and urine (dry)	7.0	2.00	0.50	0.50	3.00
Agro-industries wastes**	44.6	0.32	0.16	0.11	0.59
TOTAL	294,014.1	11.026	5.527	9.452	26.005

*Crop wastes and other organic wastes inclusive.

**Including animal wastes.

Source: Organic manures for higher harvests
Dhua, Dr. S.P., Science Today, p. 15, February 1979.

It has been pointed out by Dr. Dhua that the organic manures not only supplement the costly chemical fertilizers but also have the capacity to increase the efficiency of the plant uptake of the chemical fertilizers. This has, therefore, a double benefit. In addition, organic manures work as soil conditioners. The extent to which it is possible to utilize N, P, and K out of organic manures will determine the ability to meet the challenge of achieving self-sufficiency.

In the past energy crisis period, the topic of optimal fertilizer use in the context of limited availability was a subject of great interest worldwide. At a topical seminar held in India in 1974 and jointly sponsored by FAI and FAO, several interesting conclusions emerged. Some salient ones are reproduced below:

1. To increase the utilization efficiency of urea, the seminar recommended production of urea in suitable physical forms; coating it with shellac, sulphur, etc., and blending it with indigenously available nitrification-inhibiting materials like Neem-cake and Karanj-cake.

2. The seminar noted that 25 to 30 percent of the applied nutrients are taken up by weeds, particularly during the early stages (7-21 days of crop growth in kharif season) and recommended that suitable weed control measures be identified for different conditions and be widely practiced.

3. The seminar noted that there is an urgent need for increasing the organizational efforts to mobilize all resources for the production of organic manures, namely-- (a) urban composts, (b) rural composts, (c) Gobar Gas Plants, and (d) urban sewage/sullage utilization. The seminar recommended that the fertilizer industry should suitably stimulate interest in the projects for the exploitation of organics.

4. The seminar noted that despite the great potential of Gobar Gas Plants and the administrative approval to launch a large number of Gobar Gas Plants, progress in this direction had been slow. The constraints appeared to be finances and lack of technical personnel.

5. The seminar noted that there is considerable scope for direct application of suitable types of rock phosphate, after beneficiation if necessary, as a phosphatic fertilizer as well as an amendment wherever conditions permit; for instance: (a) in the cultivation of lowland rice and legumes and (b) in acid soils.

6. The seminar recommended that use of rock phosphate suitably ground with organic manures, for example, dung manure compost and activated sludge, be widely practiced. This will make the phosphate available in a relatively short time and the manures more balanced.

The above recommended measures are even more relevant now than they were in 1973 and hence need urgent implementation.

It will be imperative for the country to tap the organic wastes not only to improve the soil fertility but also to bridge the gap between demand and supply of chemical fertilizers as such. To the extent this is made possible, the country can progress toward the achievement of targets of production set before it.

CHOICE OF FEEDSTOCK

In view of the energy crisis in India, the alternative feedstock, that is, coal, will have to be used for fertilizer production. Two large coal-based plants with a capacity of 228,000 tons of nitrogen each are in advanced stages of commissioning in India. The country should concentrate on making this process successful so that vast reserves of coal available in the country are used to manufacture chemical fertilizers which will reduce dependence on petroleum-based feedstock and also so that the indigenous resources will get properly exploited and economically utilized.

SUMMARY AND CONCLUSION

India has to plan for production of massive quantities of nitrogen and P_2O_5 in the next 21 years. The investment required for this at current prices is estimated to be about Rs.24,000 crores. It is doubtful it will have the monetary resources and adequate quantities of feedstock to meet the projected requirements of N and P. Even if the necessary money could be managed, technical manpower poses another serious constraint.

An alternative feedstock, coal, has to be extensively used and the country needs to concentrate on making a success of two coal-based plants currently under various stages of commissioning. This will remove dependence on petroleum-based feedstock. This route for ammonia production, while utilizing the indigenous resources, will generate employment opportunities within the country.

In view of the near impossibility of producing or acquiring massive quantities of nitrogen and P_2O_5 required by the year 2000 in their entirety, concentration on utilizing city garbage and other organic wastes will be a prudent measure. The potential available for N, P, and K from this source is very large, and the mobilization of even 20 to 30 percent of this quantity in usable form will help in achieving the targets.

A new technology to enrich this organic waste with N and P to economize on the cost of transportation is a direction which the country must adopt.

The time span left, that is, 20-21 years, is not commensurate with the magnitude of the task ahead, and therefore the country would require concentrated efforts by the government in various directions to supplement the use of chemical fertilizers.

Although difficult, the target of feeding a population of 935 millions by the year 2000 is not an impossible one. In the past, fertilizer consumption has been doubling in a span of five years, and it should be possible to do so in the future. However, considering that the base in the past was low, doubling of consumption in the future, even over a decade, and particularly in the last decade, that is, the nineties, will require enormous effort by all: government, industry, and the people.

FOOD GRAIN PRODUCTION IMPORTS AND AVAILABILITY IN INDIA DURING 1978-79

Year	Cereals (thousand tons) Net production	Net imports	Net availability	Pulses net availability (thousand tons)
1951	40,087	4,801	44,299	8,047
1952	40,670	3,926	43,978	7,983
1953	45,456	2,035	47,974	8,605
1954	53,553	834	54,185	9,730
1955	51,705	596	53,047	10,109
1956	50,426	1,389	52,417	10,225
1957	52,768	3,626	55,538	10,626
1958	49,458	3,216	52,943	8,836
1959	57,388	3,858	60,754	11,558
1960	57,096	5,127	60,820	10,376
1961	60,893	3,493	64,551	11,135
1962	61,851	3,639	65,845	10,236
1963	60,190	4,551	64,763	10,853
1964	61,788	6,263	69,294	8,813
1965	67,335	7,447	73,719	10,853
1966	54,603	10,336	64,802	8,676
1967	57,648	8,665	66,573	7,298
1968	72,581	5,687	76,223	10,574
1969	73,145	3,846	76,529	9,094
1970	76,834	3,579	79,297	10,197
1971	84,528	2,027	83,987	10,341
1972	82,315	(-) 491	86,518	9,707
1973	76,230	3,590	80,129	8,668
1974	82,825	4,830	88,059	8,757
1975	78,586	7,387	80,414	8,762
1976 *	94,236	6,440	90,049	11,493
1977	125,600	-	125,600	*
1978	130,000	-	130,000	*

*Included in cereals.

Source: Up to 1976 Bulletin on Food Statistics Directorate of Economics and Statistics, Ministry of Agriculture and Irrigation, New Delhi 1977-78--FAI, New Delhi.

GROWTH OF INDIA'S CULTIVATED LAND (1951-52 to 1975-76)

Unit: 1,000 hectares

Year	Area sown			Area irrigated			Gross area under HYV	Share of gross irrigated to gross sown area
	Gross	Net	More than once	Gross	Net	More than Once		
1951-52	133,234	119,400	13,834	23,180	21,049	2,131	-	17.4
1956-57	149,492	130,848	18,644	25,707	22,533	3,174	-	17.2
1961-62	156,209	135,399	20,810	28,460	24,884	3,576	-	18.2
1966-67	157,355	137,232	20,123	32,683	26,907	5,776	1,886	20.8
1971-72	165,154	140,223	24,931	38,431	31,546	6,885	18,170	23.3
1975-76	171,160	142,245	28,915	42,944	34,453	8,491	31,888	25.1

Source: Primary - Directorate of Economics & Statistics, Ministry of Agriculture and Irrigation.

Secondary - Fertilizer Statistics, III-43, FAI, New Delhi 1977-78.

PRODUCTION, IMPORTS, DISTRIBUTION, AND CONSUMPTION OF FERTILIZERS--1960-61 to 1978-79

Unit: 1,000 tons

Year	Nitrogenous (N)				Phosphatic (P_2O_5)			
	Produced	Imported	Distributed	Consumed	Produced	Imported	Distributed	Consumed
1960-61	112.0	399.0	211.7	211.7	53.7	-	53.1	53.1
1961-62	154.3	307.0	291.5	249.8	65.4	-	63.9	60.5
1962-63	194.2	244.0	360.0	333.0	88.3	10.0	81.4	82.8
1963-64	219.1	228.0	407.0	376.8	107.8	13.0	116.7	116.5
1964-65	243.2	232.0	434.5	555.2	131.0	12.0	147.7	148.7
1965-66	237.9	326.0	547.4	574.8	118.8	14.0	132.2	132.5
1966-67	309.0	632.0	838.7	737.8	145.7	148.0	248.6	248.6
1967-68	402.6	867.0	1051.8	1034.6	207.1	349.0	422.1	334.8
1968-69	563.0	844.0	1254.9	1208.6	213.2	138.0	318.8	382.1
1969-70	730.6	667.0	1040.2	1356.0	223.7	94.0	234.9	416.0
1970-71	832.5	477.0	1310.0	1479.0	228.1	32.0	305.1	541.0
1971-72	949.2	481.0	1652.7	1798.0	290.3	248.0	473.6	558.2
1972-73	1054.5	665.0	1742.1	1839.0	330.3	204.0	534.3	581.3
1973-74	1049.9	659.0	1613.0	1829.0	324.5	213.0	541.1	649.7
1974-75	1186.6	884.0	1845.2	1765.7	331.2	286.0	497.4	471.5
1975-76	1508.0	996.0	1908.7	2148.6	319.7	361.0	373.6	466.8
1976-77	1862.4	750.1	2351.7	2457.1	478.3	22.8	643.5	635.3
1977-78	1999.8	758.1	2802.1	2913.0	669.9	163.9	756.6	866.6
1978-79	2168.0	1240.0		3410.0	776.0	320.0		1100.0

NUTRIENTWISE CONSUMPTION OF FERTILIZERS
1972-73 to 1978-79

(Unit: 1,000 tons)

Nutrient	1972-73	1973-74	1974-75	1975-76	1976-77	1977-78	1978-79
N	1,839	1,829	1,766	2,149	2,457	2,913	3,410
Change over previous year (percent)	2.3	-0.6	-3.5	21.7	14.4	18.6	17.0
P_2O_5	581	650	471	467	635	867	1100
Change over previous year (percent)	4.1	11.9	-27.5	-0.8	36.1	36.5	26.9
K_2O	347	360	336	278	319	506	590
Change over previous year (percent)	15.7	3.7	-6.7	-17.2	14.5	58.6	16.6
Total	2,767	2,839	2,573	2,894	3,411	4,286	5,100
Change over previous year (percent)	4.2	2.6	-9.4	12.5	17.9	25.7	19.0

Source: Fertilizer Statistics, FAI, New Delhi, pages I-178

Appendix V

ESTIMATES OF CONSUMPTION OF N, P_2O_5 & K_2O

1979-80 to 1987-88

Unit: 1,000 tons)

Year	Nitrogen	Percent over previous year	Phosphate P_2O_5	Percent over previous year	Potash (K_2O)	Percent over previous year	$N+P_2O_5+K_2O$	Percent over Previous year
1979-80	3,779	13.5	1,125	10.8	619	12.3	5,461	12.9
1980-81	4,260	12.7	1,272	10.4	691	11.6	6,123	12.1
1981-82	4,772	12.0	1,287	9.8	767	11.0	6,826	11.5
1982-83	5,315	11.4	1,407	9.3	847	10.4	7,569	10.0
1983-84	5,890	10.8	1,533	9.0	932	10.0	8,355	10.4
1984-85	6,497	10.3	1,664	8.5	1,020	9.4	9,181	9.3
1985-86	7,135	9.8	1,801	8.2	1,113	9.1	10,049	9.5
1986-87	7,804	9.4	1,943	7.9	1,210	8.7	10,957	9.0
1987-88	8,505	9.0	2,090	7.6	1,312	8.4	11,907	8.7

Source: Fertilizer Situation in India, FAI, New Delhi

Appendix VI

PROJECTION OF NPK REQUIREMENTS IN INDIA

1988-89 to Year 2000

Unit: 1,000 tons

Year	N	P	K
1988-89	9,270	2,260	1,420
1989-90	10,100	2,440	1,530
1990-91	11,010	2,530	1,650
1991-92	11,560	2,640	1,700
1992-93	12,140	2,740	1,750
1993-94	12,750	2,850	1,800
1994-95	13,390	2,960	1,860
1995-96	14,760	3,210	1,910
1996-97	14,760	3,210	1,970
1997-98	15,500	3.340	2,030
1998-99	16,270	3,470	2,090
1999-2000	17,080	3,610	2,160

Source: Author's projections

LICENSED CAPACITY OF FERTILIZERS NUTRIENTWISE IN INDIA FROM 1950 TO 1978

Unit: 1,000 tons

	As on	N	P_2O_5
1.	December 31, 1950	16.7	20.5
2.	December 31, 1951	88.7	27.7
3.	December 31, 1952	88.7	31.7
4.	December 31, 1953	88.7	31.7
5.	December 31, 1954	88.7	34.6
6.	December 31, 1955	88.7	43.2
7.	December 31, 1956	88.7	43.2
8.	December 31, 1957	88.7	49.6
9.	December 31, 1958	88.7	53.5
10.	December 31, 1959	148.6	80.8
11.	December 31, 1960	162.2	95.6
12.	December 31, 1961	246.3	107.2
13.	August 31, 1962	246.3	107.2
14.	July 31, 1963	326.7	146.5
15.	September 30, 1964	324.0	175.1
16.	September 30, 1965	324.0	187.5
17.	September 30, 1966	524.9	263.5
18.	September 30, 1967	632.4	316.4
19.	September 30, 1968	904.5	431.2
20.	September 30, 1969	1,136.4	431.2
21.	September 30, 1970	1,349.3	433.5
22.	September 30, 1971	1,514.7	532.0
23.	September 30, 1972	1,471.2	502.6
24.	November 1, 1973	1,933.5	534.2
25.	November 1, 1974	2,162.1	666.2
26.	November 1, 1975	2,625.1	737.6
27.	November 1, 1976	3,024.1	927.5
28.	October 1, 1977	3,068.8	1,198.6
29.	October 1, 1978	3,295.8	1,277.5

Source: Fertilizer Statistics 1977-78, pages I-19.

Appendix VIII

PRODUCTION AND CONSUMPTION FOR N AND P_2O_5

FOR THE YEARS 1979-80 to 1987-88

Unit: 1,000 tons

Year & Nutrient	Production	Consumption	Gap
1979-80			
N	2,980	3,779	- 799
P_2O_5	835	1,003	- 228
1980-81			
N	3,577	4,260	- 683
P_2O_5	959	1,172	- 213
1981-82			
N	3,972	4,772	- 800
P_2O_5	984	1,287	- 303
1982-83			
N	4,427	5,315	- 888
P_2O_5	1,014	1,407	- 393
1983-84			
N	5,558	5,890	- 332
P_2O_5	1,014	1,533	- 519
1984-85			
N	5,904	6,497	- 593
P_2O_5	1,029	1,664	- 635
1985-86			
N	5,983	7,135	-1,152
P_2O_5	1,039	1,801	- 762
1986-87			
N	5,983	7,804	-1,821
P_2O_5	1,049	1,943	- 894
1987-88			
N	5,983	8,505	-2,522
P_2O_5	1,059	2,090	-1,031

Source: Fertilizer Situation in India, FAI, New Delhi

Appendix IX

ESTIMATED PRODUCTION, CONSUMPTION & GAP FOR N & P DURING 1988-89 TO YEAR 2000

Unit: 1,000 tons

Year	Production	Consumption	Gap
1988-89			
N	5,983	9,270	- 3,287
P	1,049	2,260	- 1,211
1989-90			
N	5,983	10,100	- 4,117
P	1,049	2,440	- 1,391
1990-91			
N	5,983	11,010	- 5,027
P	1,049	2,530	- 1,481
1991-92			
N	5,983	11,560	- 5,577
P	1,049	2,640	- 1,591
1992-93			
N	5,983	12,140	- 6,157
P	1,049	2,740	- 1,691
1993-94			
N	5,983	12,750	- 6,767
P	1,049	2,850	- 1,801
1994-95			
N	5,983	13,390	- 7,407
P	1,049	2,960	- 1,911
1995-96			
N	5,983	14,060	- 8,077
P	1,049	3,080	- 2,031
1996-97			
N	5,983	14,760	- 8,777
P	1,049	3,210	- 2,161
1997-98			
N	5,983	15,500	- 9,517
P	1,049	3,340	- 2,291
1998-99			
N	5,983	16,270	- 10,287
P	1,049	3,470	- 2,421
1999-2000			
N	5,983	17,080	- 11,097
P	1,049	3,610	- 2,561

RELATIVE POSITION OF WHEAT, RICE, AND FERTILIZERS N, P_2O_5 & K_2O IN DIFFERENT COUNTRIES 1976-77

Country	Price per kg. in U.S. cents					Kg. of wheat required to buy 1 kg of nutrient			Kg. of rice required to buy 1 kg. of nutrient		
	Wheat	Rice	N (S.A.)	P_2O_5 (Sup-phos.)	K_2O (MOP)	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Austria	17.4	-	60.4	67.3	39.6	3.47	3.87	2.28	-	-	-
Brasil	-	26.0	-	54.5	18.6	-	-	-	-	2.10	0.72
Egypt	-	12.9	33.0	26.6	11.5	-	-	-	2.56	2.10	0.89
France	14.0	-	38.2	49.7	17.6	2.73	3.55	1.26	-	-	-
India	13.2	17.2	-	42.7	16.7	-	3.24	1.27	-	2.48	0.97
Iraq	14.4	-	-	-	-	-	-	-	-	-	-
Italy	26.2	-	35.3	41.6	22.7	2.18	2.57	1.40	-	-	-
Korea	-	60.0	69.0	23.7	14.5	-	-	-	1.15	0.39	0.24
Mexico	13.3	-	-	-	-	-	-	-	-	-	-
Pakistan	11.4	-	32.1	23.7	12.9	2.82	2.08	1.13	-	-	-
Philippines	-	23.4	67.1	17.8	23.1	-	-	-	2.87	0.76	0.99
Thailand	-	18.5	30.3	52.5	26.1	-	-	-	1.64	2.84	1.41
Turkey	-	31.0	20.9	14.8	-	-	-	-	-	-	-
U.S.A.	8.0	33.2	53.5	56.8	17.8	6.08	6.46	2.02	1.61	1.71	0.54

Source: (1) Foodgrain prices (wholesale): FAO Production Year Book, 1977, Vol 31, FAO Rome

(2) Fertilizer prices: Annual Fertilizer Review 1977, FAO, Rome
Secondary Source: Fertilizer Statistics 1977-78, pages III-29.

PAKISTAN: PROJECTED FERTILIZER DEMAND TO THE YEAR 2000

A.M. Shah*

ABSTRACT

Projections of any commodity utilization, based on accurate and adequate data of its past behaviour with specific reference to the controlling constraints, is a basic necessity for the effective planning of any country's economy. The anticipated level of consumption thus determined is by no means a measure of the potential demand in the country, but is merely indicative of the level likely to be achieved taking into account all the known constraints.

Agriculture is the dominant sector of Pakistan's economy, contributing approximately 1/3rd to the GNP, with crop production as the major sub-sector constituting about 70 percent of the agriculture sector. The performance of the crop production sector is dependent largely on the quantity of fertilizer applied. Accurate projection of fertilizer consumption is therefore very necessary for Pakistan's economic planning.

FERTILIZER CONSUMPTION

Chemical fertilizer was first introduced in Pakistan in 1952. Following an introductory phase lasting about a decade, its consumption registered a phenomenal increase. Over a period of twenty-seven years, the consumption increased from a mere 1,000 nutrient tons to about 880,000 nutrient tons last year (Table 1 and Fig. 1). In spite of this encouraging growth trend, the fertilizer consumption per hectare of cultivated land continues to be very low.

STRATEGY

With worldwide inflation, introduction of HYV in 1966 helped change the nature of agriculture. From strictly traditional, agriculture took on a progressive and commercially-oriented approach. With growing emphasis on research, soil testing and efforts to achieve higher productivity, the future strategy for determining fertilizer demand has been modified to take into consideration the following factors:

1) Increase in water availability.

2) Continued promotion of seed-water-fertilizer technology.

3) Incentive price strategy assuring attractive benefit:cost ratio (3-4:1) to the farmers.

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Table 1

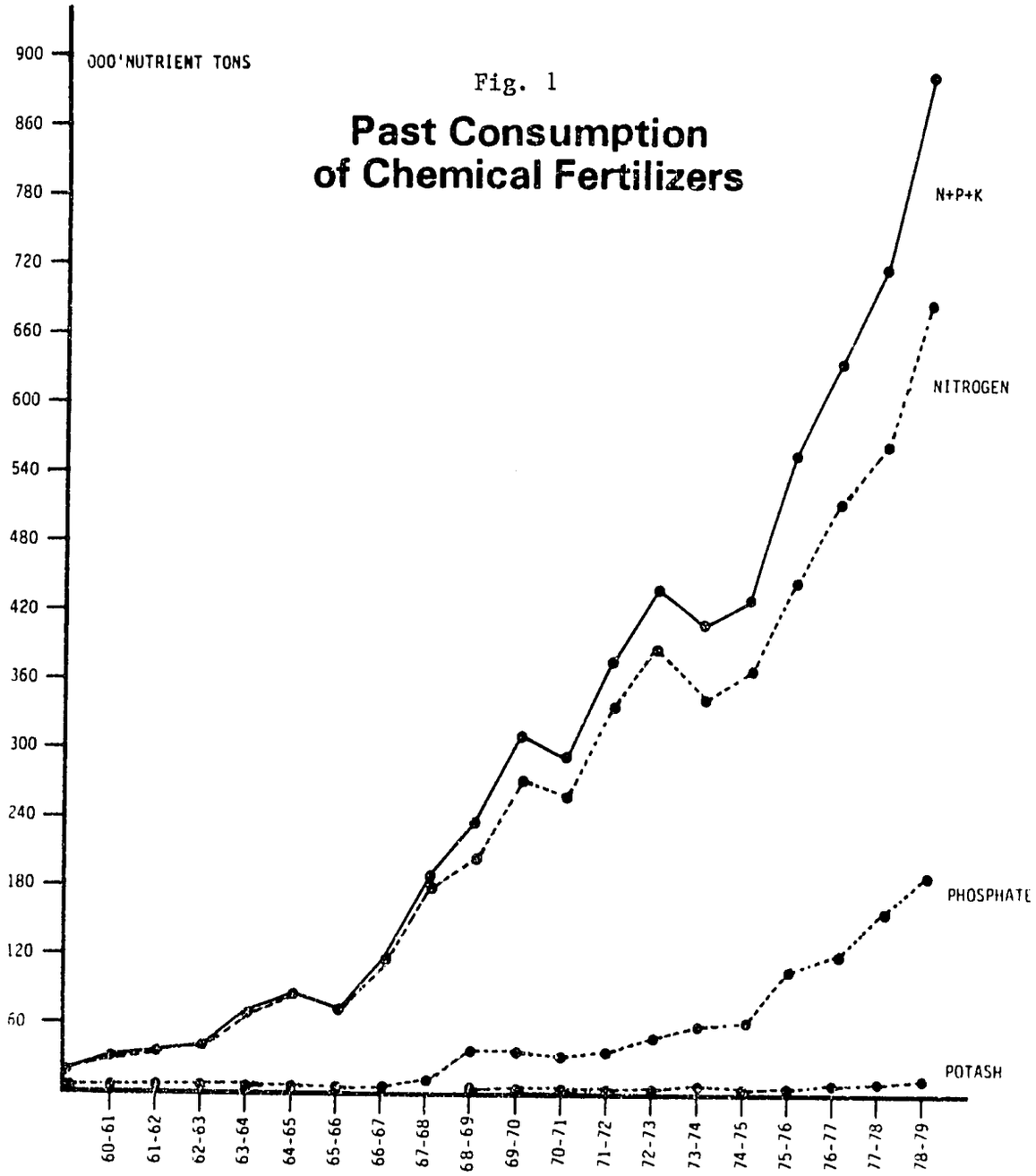
CONSUMPTION OF CHEMICAL FERTILIZERS IN PAKISTAN

('000 Nutrient Tons)

Year	N	P	K	Total
1952-53	1.0			1.0
1953-54	14.8			14.8
1954-55	14.1			14.1
1955-56	6.6			6.6
1956-57	9.0			9.0
1957-58	16.4			16.4
1958-59	18.0			18.0
1959-60	19.3	0.1		19.4
1960-61	31.0	0.4		31.4
1961-62	37.0	0.4		37.5
1962-63	40.0	0.2		40.2
1963-64	68.0	0.7		68.7
1964-65	85.0	2.2		87.2
1965-66	69.8	1.2		71.0
1966-67	112.3	3.9		116.2
1967-68	177.7	11.3	0.2	189.2
1968-69	204.5	38.9	3.0	238.9
1969-70	273.5	35.5	1.4	310.4
1970-71	257.1	30.7	1.3	289.1
1971-72	336.4	36.4	0.7	373.5
1972-73	386.4	48.6	1.4	436.5
1973-74	341.9	58.0	7.0	406.9
1974-75	363.3	60.6	2.1	426.0
1975-76	443.4	108.6	2.8	554.8
1976-77	511.0	117.9	4.9	633.8
1977-78	550.76	156.36	5.99	713.11
1978-79	684.21	187.87	7.58	879.66

Fig. 1

Past Consumption of Chemical Fertilizers



4) State monopolization of agricultural produce trade in providing definite support price of commodities to farmers in cash and food crops.

5) Extensive improvements in production and distribution of quality seeds, plant protection and farm mechanization.

6) Measures to strengthen and expand support infrastructure, particularly credit, extension, marketing and fertilizer distribution.

FUTURE TREND

1981-1985

It is anticipated by agricultural scientists and policy makers that by next year or at the latest by 1981, all farmers in irrigated areas will be using some quantity of fertilizer. Increase in fertilizer consumption for the next five years would mainly come from higher dosages per acre in the irrigated areas and through more coverage of cropped area under rainfed agriculture. While continuing its efforts in the irrigated areas, the government is investing heavily in the development of rainfed agriculture, water management, control of waterlogging and salinity, and farm mechanization. Despite these efforts, it is expected that the growth rate will slow up during this period for the following reasons:

The optimum response from increased fertilizer application may become limited due to inadequate plant protection measures particularly in case of cotton, rice and sugarcane.

The deficiency of potassium in case of sugarcane and maize and that of zinc in case of rice may start limiting the response to N and P.

High level of salinity, poor water and soil management practices, may impose a limit on optimum fertilizer dosages much below the recommended dosages.

The growth rate in this period will be 7.58 percent (Tables 2 and 3, and Fig. 2).

1986-1990

The main effort of the government will be to maintain the momentum of developments and implementation of projects initiated in the previous five years. Other plans include provision of extensive and adequate plant protection and popularizing use of potassium and minor elements.

During this period, the growth rate is expected to be 5.0 percent.

1991-1995

It is expected that by the early 90's a reasonable sophistication in the agriculture sector will have been developed at least with respect to the use of fertilizer. Farmers will be using increased amounts of different fertilizers recommended. Development of quality seeds, maximization of irrigation facilities, and extensive and effective plant protection will

Table 2

FERTILIZER DEMAND PROJECTIONS 1980-1981 TO 1999-2000

(All Nutrients) (000 Nutrient Tons)

	N			P			K		
1980-1981	825	8%		268	15%		12	20%	
1981-1982	875	6%		300	12%		15	25%	
1982-1983	919	5%	6%	324	8%	10%	20	34%	31%
1983-1984	965	5%		350	8%		25	25%	
1984-1985	1013	5%		371	6%		30	20%	
1985-1986	1054	4%		390	5%		35	17%	
1986-1987	1096	4%		410	5%		45	29%	
1987-1988	1140	4%	4%	426	4%	4%	60	33%	30%
1988-1989	1186	4%		443	4%		80	33%	
1989-1990	1233	4%		461	4%		110	38%	
1990-1991	1283	4%		480	4%		145	32%	
1991-1992	1334	4%		514	7%		174	20%	
1992-1993	1437	7%	6%	565	10%	9%	235	35%	34%
1993-1994	1527	7%		627	11%		334	42%	
1994-1995	1649	8%		709	13%		468	40%	
1995-1996	1781	8%		801	13%		585	25%	
1996-1997	1923	8%		913	14%		731	25%	
1997-1998	2096	9%	9%	1023	12%	12%	899	23%	22%
1998-1999	2306	10%		1136	11%		1079	20%	
1999-2000	2537	10%		1250	10%		1240	15%	

Table 3

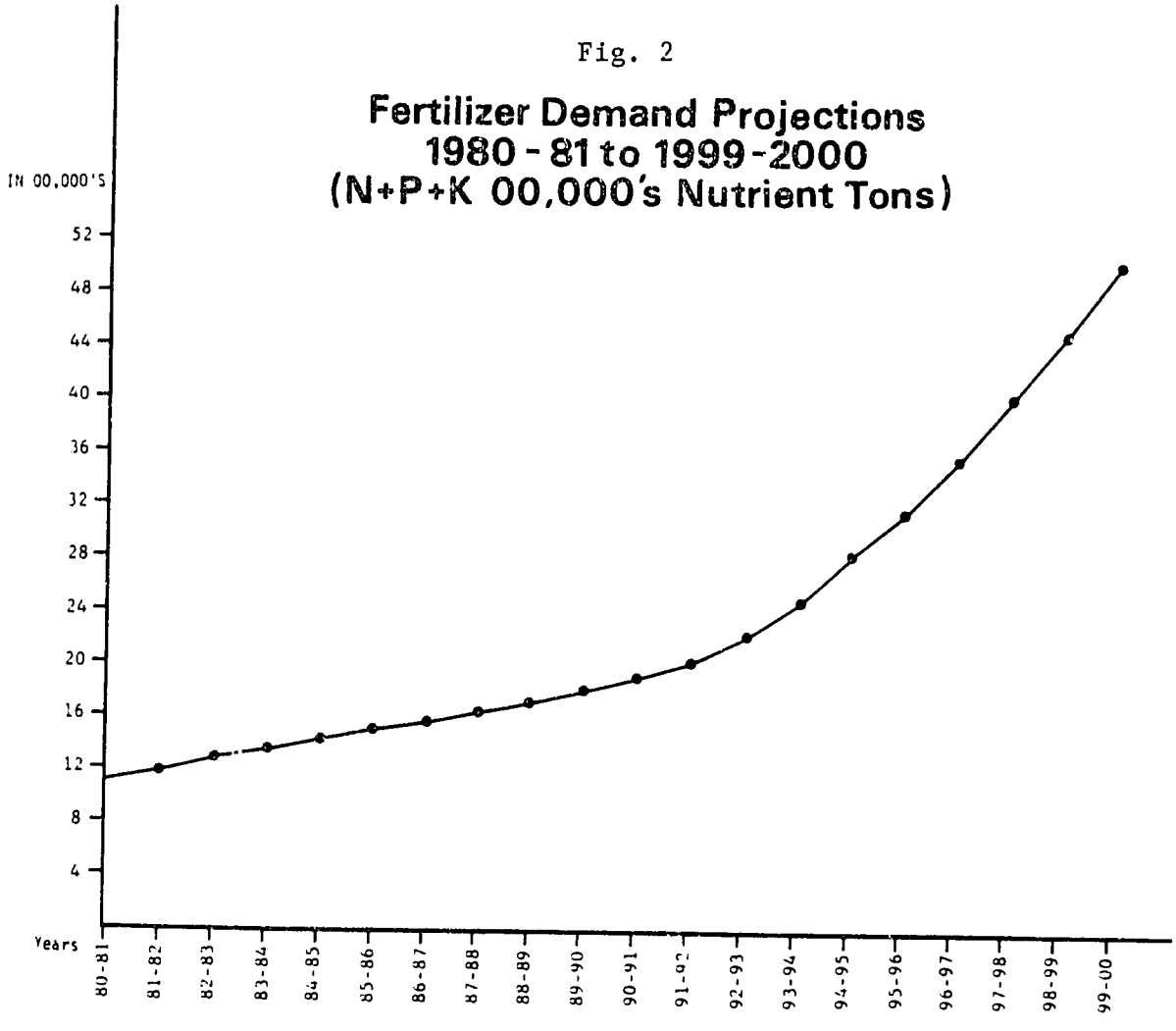
FERTILIZER DEMAND PROJECTIONS 1980-81 TO 1999-2000

(All Nutrients Combined)

(000 Nutrient Tons)

YEAR	N+P+K		
1980-1981	1105	12.5	
1981-1982	1190	7.7	
1982-1983	1263	6.1	7.58%
1983-1984	1340	6.1	
1984-1985	1414	5.5	
1985-1986	1479	4.6	
1986-1987	1551	4.9	5.0%
1987-1988	1626	4.8	
1988-1989	1709	5.1	
1989-1990	1804	5.6	
1990-1991	1908	5.8	
1991-1992	2022	6.0	9.41%
1992-1993	2227	10.1	
1993-1994	2488	11.7	
1994-1995	2826	13.6	
1995-1996	3167	12.1	
1996-1997	3567	12.6	12.2%
1997-1998	4018	12.6	
1998-1999	4521	12.5	
1999-2000	5027	11.2	

Fig. 2


Fertilizer Demand Projections
1980 - 81 to 1999-2000
(N+P+K 00,000's Nutrient Tons)
IN 00,000'S
52
48
44
40
36
32
28
24
20
16
12
8
4
Years
80-81
81-82
82-83
83-84
84-85
85-86
86-87
87-88
88-89
89-90
90-91
91-92
92-93
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94-95
95-96
96-97
97-98
98-99
99-00

be emphasized. The major thrust of the government would be towards intensifying agriculture.

The growth rate in this period is likely to be around 9.41 percent.

1996-2000

This period is expected to witness a major surge in two areas of agricultural activity. First, there will be an increasing turn towards export-based crop production. This will in turn lead to multiple cropping and adoption of intensive farming methods. The second area will be the development of agro-based and affiliated industries. These areas of activity are already in evidence in Pakistan today but their full maturity will come about towards the end of the century and they will collectively affect fertilizer consumption in this period.

The growth rate is expected to be 12.2 percent, bringing the annual consumption in the year 2000 to approximately 5,027,000 nutrient tons.

INCREASING EFFECTIVENESS OF FERTILIZER USE--
REPORT OF THE ADAPTIVE PRODUCTION SYSTEMS WORKSHOP

Panelists: Filomena Campos, H.P.M. Gunasena and M.R. Hamissa*

The Adaptive Production Systems Workshop, serving as the Final Review Meeting of the INPUTS project, brought to a successful conclusion a 5-year coordinated international research effort directed towards finding some innovative ways to reduce nitrogen (N) losses from fields. Over 100 field agronomic studies were conducted under the project in Australia, Bangladesh, Egypt, Guam, India, Japan, Korea, Nigeria, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, U.S.A. and Western Samoa by a team of over 150 scientists, technicians and students, in some 40 national and 5 international organizations. These scientists collectively planned, implemented and evaluated some specific studies aimed at:

- Reducing N losses from paddy fields
- Evaluating the efficiency of intercropping cereal with legume
- Evaluating the efficiency of using locally available organic materials

Research materials and treatments used evolved over the three research cycles that were completed under the project, on the basis of findings of the previous cycle. Experimental designs used and results obtained during each research cycle are reported in the proceedings of the four international review meetings that took place under the project. These are cited under references. Highlights of the findings are summarized below:

1. Urea supergranule (USG) was found to be superior to conventional urea for paddy grown under water-saturated conditions. A savings of approximately 20 to 25 percent in N use was obtained for the same level of paddy production by using USG in place of urea. Reduction in denitrification losses due to deep USG placement is attributed to be the main reason for this increased N use efficiency.

   Using current labor costs in cooperating countries and an assumption that USG price will be about 10 percent higher than urea (based on communication from the International Fertilizer Development Center, U.S.A.), preliminary economic analysis of the data indicates USG to be more profitable than urea for paddy production at most locations.

   Considering the millions of hectares under paddy production in the world--particularly in Asia--the potential use of USG and, therefore, of its likely impact on the fertilizer situation, can be significant.

   The Adaptive Production Systems meeting has recommended that further studies be conducted to confirm previous findings.

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Research on socio-economic aspects of USG's adoption by farmers and its marketing by village-level fertilizer retailers also need to be undertaken.

2. Intercropping maize with soybean, cowpea, mungbean and other legumes was found to be generally more profitable than growing it alone. Land Equivalent Ratio (LER) increased to 1.3 to 1.5 under intercropping, indicating increased advantage of this system of crop management. The use of fertilizer and other inputs also was more efficient, thereby increasing the profitability of this system. Also, risks associated with crop production--measured by stability analysis--were found to be much lower with intercropping.

   The Adaptive Production Systems meeting has recommended that studies on intercropping should be continued, with particular attention to plant populations of the respective components of the intercrop system, as well as to their spatial arrangements.

Treatments, layout plans and other details of the recommended studies are given in the proceedings of the Final INPUTS Review Meeting (4).

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FARMER DECISION MAKING IN TECHNOLOGY ADOPTION: FERTILIZERS

MOHAMMAD ASHRAF*, TAMRONG CHOMAITONG* and

SALEEM AHMED*

INTRODUCTION

Agriculture continues to be the mainstay in the economic development of a large number of countries, particularly in the developing world. With the rising population in these countries, however, food production has been barely able to keep pace with local demands. To extricate themselves from this vicious cycle, it has been the stated policy of a number of these countries to control population growth on the one hand, and to make an all-out effort to increase food production on the other.

With the amount of potentially arable land rapidly declining, most of the growth in agricultural production has to be derived from increased yields per hectare. In fact, currently over 80 percent of the recent increase in agricultural production has been due to increased yields per hectare and less than 20 percent can be attributed to increase in area under cultivation (FAO, 1972).

In a situation such as this the importance of inputs responsible for increasing yields per unit area cannot be overemphasized. Among those, fertilizers can certainly be classed as the most important factor. Depending upon agroclimatic and pedologic conditions and crop variety being grown, one kg of nitrogen, for example, has been found to produce over 40 kg of foodgrain in some cases. The average grain production:fertilizer use ratio for wheat and rice for Bangladesh, Egypt, India, Philippines, and USA/Canada has been recently reported to be over 15 for farmers' fields and over 30 for experimental stations (Ahmed, et al., 1979).

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In spite of these impressive statistics, however, per hectare fertilizer use, although gradually increasing, is still quite low in many developing countries, ranging from 5 kg to 30 kg nutrients per hectare. In view of this, an analysis of factors which influence farmers' decision-making in fertilizer use is essential so that relevant recommendations may be developed for policy consideration, for purposes of bringing about improvements in the amount of fertilizer used per unit area.

A socioeconomic study on farmers' decision-making in fertilizer use was therefore proposed at the First Review Meeting of the INPUTS project (Ahmed and Sadiq, 1976). Specific objectives of this study were:

1. The identification of important socio-economic factors influencing farmers' decision-making regarding level of fertilizer use.

2. The identification of the significance of each of these factors in decision-making and also the possible interrelations among the various factors.

3. The identification of areas where the existing farming efficiency could be improved through measures at the farm level.

4. The analysis of factors, in particular those which have potential for policy consideration.

5. The development of cross-cultural and cross-national correlations to the extent possible.

The study was undertaken initially at seven locations in six countries: Bangladesh, Pakistan, Philippines, Sri Lanka, Thailand, and the United States (Hawaii). Except in Pakistan and Hawaii, this research concentrated primarily on rice farms. In Pakistan, wheat farms were also studied. In Hawaii (on the island of Maui), a small sample of vegetables and taro was studied. A total of 680 farmers was interviewed in 37 villages. Country-wise breakdown is as follows:

Country	Number of villages	Crops surveyed	Number of farmers interviewed
Bangladesh	2	Rice	103
Pakistan	30	Rice (242) Wheat (130)	372
Philippines	3	Rice	105
Thailand	2	Rice	100
TOTAL	37		680

This report does not include analysis of data for Sri Lanka and Hawaii, but focuses on the other four. Preliminary results were presented earlier (Ahsan, et al., 1978).

STUDY LIMITATIONS

The study was conducted in the various countries during different time periods. Farm surveys were undertaken and supervised by different levels of people from different disciplines and different types of organizations. Farmers from different countries operate under different farm situations, different price ratios and price mechanisms, different socioeconomic and institutional conditions; they thus face a different nature of constraints and facilities. The data, therefore, were analyzed on a country-by-country basis to interpret results within common socio-economic environments and farming characteristics in each country. The results of each country were then presented for comparison.

The efficiency of research results is dependent on each step of the multi-step procedure from farm survey to analysis. The steps in between include recording farmers' responses, verifying correctness and completeness of the survey questionnaires, coding and transforming data appropriately, representing the individual variables properly, selecting appropriate analytical techniques and employing appropriate testing procedures. As pointed out before, the results presented here are not free from weaknesses, and so the findings of this study should not be considered absolute or conclusive but rather as guidelines for continuing future studies.

Another weakness is that since average "representative" villages were surveyed, those representing non-typical environmental conditions were not included; thus the results are not generalizable.

SAMPLING METHODOLOGY

The Fertilizer Adoption Study utilized a standardized farm survey questionnaire developed by the INPUTS socio-economic team composed of social and biological scientists from cooperating countries and agencies. The survey questionnaire was pretested in all the locations and, based on field experiences, was finally modified and improved at a workshop held at Chiang-Mai, Thailand in May 1977. In most of the countries, a two-stage, randomized sampling technique was followed in the process of farm selection.

METHODS OF ANALYSIS

Identical analyses were done for each country. The analysis was done to determine the relationship of different socio-economic factors to the level of fertilizer use on the surveyed farms using simple techniques of Pearson correlation, chi-square statistics and rank correlation, depending on the nature and characteristics of the variables used in analysis. In addition, attempts were made to employ alternative analytical techniques to determine the best fit of data. The variables included in hypothesized relationships were:

$F = f(x_1, x_2 \ldots\ldots\ldots\ldots\ldots\ldots x_n)$ where, n = 15 and

F = amount of fertilizer/nitrogen used per hectare (kg)

x_1 (+) = Farmers' past experience in fertilizer use (# of years)

x_2 (+) = Farmers' expected price of survey crop ($/kg)

x_3 (+) = Degree of commercialization (proportion of survey crop produce sold)

x_4 (+) = Nonfarm income ($)

x_5 (-) = Fertilizer price ($/kg)

x_6 (-) = Time required for other work in conflict with survey crop cultivation (number of days)

x_7 (+) = Formal education (number of schooling years)

x_8 (-) = Distance from market (km)

x_9 (+) = Size of farm (ha)

x_{10}(+) = Quality of soil

x_{11}(+) = Availability of irrigation (on the farm)

x_{12}(+) = Ownership status of farm (owner/tenant)

x_{13}(+) = Variety of the survey crop (improved/local)

x_{14}(+) = Farmers' exposure to information sources related to fertilizer use

x_{15}(+) = Purchase of fertilizer on credit

The signs (+ or -) represent the direction of relationships hypothesized in the model. The null hypotheses in all the cases means that there is no relationship.

The variables x_1-x_9 are quantitative in nature, whereas x_{10}-x_{15} are represented in scores for which dummy variables have been employed to determine the relationship.

Analytical Methods

A. Multiple Linear Regression

In order to test the hypothesized relationships, multiple linear regression procedure was followed. Great care was taken to make the model very comprehensive in order to avoid the specification error. However, after preliminary editing and analysis of data some variables could not be used in each country. Therefore, it was difficult to pool all countries' data for a general model.

Linear relationship was found to be appropriate, which is also easier for analysis and interpretation of results.

In order to get unbiased results of OLS (ordinary least square), conditions of Gaus-Markov's theorem have to be satisfied. Multicollinearity, an obvious problem, was minimized by transformation of the relevant variable on a per unit ba. .s.

B. Probit Model

Dependent Variable: 0 - if do not use fertilizer
1 - if use fertilizer

$I - XA$ A = a vector.

The probit model is a transformation of the x coefficient matrix from linear relation ($I = XA$) to a nonlinear relation within a range of 0-1 by the use of the cumulative normal distribution. The probability values method of calculation is MLE.

The model is very useful in case the dependent variable is a lineary variable. However, if OLS is employed to fit a regression to the model where its dependent variable is the binary variable, then the OLS estimates will be biased and inconsistent, even though a constrained linear OLS method is used to force the regression coefficients within a range of 0-1.

However, the intuitive feeling is that the probit model may not be appropriate for the data because the dependent variables are not simply the "qualitative" dummy variables--but it is the continuous variables with lower limited value (i.e., "0"). This is called "truncated normal" if the dependent variable is distributed normally but with the limited value of "0" or lower. Therefore, to predict the demand for fertilizer, the "TOBIT" model should be used.

C. Tobit Model

The model works as follows:

1. We transform the X coefficient matrix linearly into an index I by a transformation vector A.

   $I = XA$ A = normalized coefficients vector.

2. Then we use the normal density function and the cumulative normal distribution to transform the index I into a predicted limited dependent variable, i.e., we transform the normalized coefficient vector A into the regression coefficient vector B by multiplying all elements of A by the estimated standard error of estimate.

3. A MLE estimation procedure is used. So the hypothesis testing of each (or of any combination) of the coefficients of the independent variables can be done with a likelihood ratio test λ or equivalently with an F-test (See Theil, 1971).

4. If a likelihood ratio test (λ) is used, we can transform λ into 2 loge, which is distributed as a chi-square with γ degrees of freedom--where γ is the number of restrictions.

Therefore, the 't' values in the printout must not be used as a definite test. However, as the appropriate testing procedures are very expensive and time consuming e.g., if we want to test whether or not the price of fertilizer is significantly different from zero, we have to estimate the model twice--one with the price of fertilizer as the independent variable, and the other without the price.

Then we compute $\lambda = \frac{L\ (\theta) \text{ with constraint}}{L\ (\theta) \text{ without constraint}}$ where

L (θ) is the likelihood function obtained from the printout.

D. Tobit Model for Thailand

D.1 Dependent Variables are either:

QFKG = total amount of fertilizer (gross weight including N-P-K and other components) per hectare used, or

QFN = total amount of nitrogen per hectare used.

D.2 Independent Variables

1. Farmers' education (OWNED) in years--should have positive effect on the amount of fertilizer.

2. Farmers' exposure to information about fertilizer use (EXPOS = index range 0 to 7)--should have positive effect.

3. Per capita income from surveyed crop (RINCOMEP)--should have positive effect since higher income may induce farmers to use more fertilizer.

4. Per capita non-farm income (NONFARMY) may have positive effect because more non-farm income means risk from using fertilizer can be compensated for by non-farm income.

5. Farmers borrow money to buy fertilizer (0 if do not borrow)

   (If borrow - BORROW)--should have positive effect because it reflects an ease of credit availability and also credit worthiness of the farmers themselves

6. Price of fertilizer--

   PRICEF = price of gross weight of fertilizer per kg
   PEN = price of nitrogen per kg.

The price effect should be negative according to the theory of demand.

7. Price of rice

SALEP = farmers' expected price of rice in the next year

$$PRI = \frac{\text{farmers' expected lowest price + highest price}}{2}$$

PR2 = last year sale price of rice.

Its effect should be positive because if price of rice is high, derived demand for fertilizer should increase, ceteris paribus. This will increase the amount of fertilizer used.

RESULTS

1. FREQUENCY DISTRIBUTION:

Some major frequency distributions are summarized in Tables 1-7.

Percentage of Farmers Using Fertilizer (Table 1):

A fairly high level of farmers surveyed used fertilizers on the survey crop in Pakistan and Philippines (89% and 96% respectively); in Thailand it was about one-half. In the case of Bangladesh villages, however, 100 percent of the farmers surveyed indicated that they used fertilizer for the surveyed crop. This is because the villages selected in Bangladesh were "model" villages where all farmers use fertilizers.

Table 1.

PERCENTAGE OF FARMERS USING FERTILIZER

COUNTRY	NO. OF FARMERS	PERCENT TOTAL
Bangladesh	103	100
Pakistan	331	89
Philippines	101	96
Thailand	46	46

Reasons for Non-use (Table 2)

:op management practices conducive to enriching the soil :re considered to be the reasons for not using fertilizer; :op rotation was cited as a reason by 27 percent of farmers,

leaving field fallow by 42 percent, and use of organic manures by 29 percent. As opposed to this, nearly one-half of the non-users (49%) indicated financial limitations to be the main reason. Lack of knowledge/erroneous conceptions about effects of fertilizer also received some mention in Pakistan.

Table 2.

REASONS FOR NOT USING FERTILIZERS
(PERCENTAGE OF NON-USERS)

REASONS	PAKISTAN	THAILAND
Practice crop rotation	2	27
Leave fields fallow	-	42
Use organic manures/rich soil	17	29
Fertilizer not available	7	-
Don't know how/what to use	15	-
Fertilizer expensive/shortage of funds	49	2
Fertilizer harmful to crops	7	-
Miscellaneous	39	-

Means of Transportation for Fertilizers (Table 3)

The modes of transport used for carrying fertilizer from the market to the farm varied considerably among the countries: In Bangladesh, it was primarily on foot (79%); in Pakistan, by animal power (70%); in the Philippines and Thailand by motor power (96% and 85%, respectively). This could probably represent the stage of the country's development.

Table 3.

MEANS USED FOR FERTILIZER TRANSPORTATION
(% OF USERS)

MEANS	BANGLADESH	PAKISTAN	PHILIPPINES	THAILAND
On foot	79	3	-	-
On tricycles	-	-	48	-
Bullock/horse/carts/pack animals	5	70	4	15
Bus/truck/tractor/trolley	16	19	48	85
Combination of means	-	8	-	-

Ease of Fertilizer Availability (Table 4)

A vast majority of farmers (70% and above) in all countries indicated that it was not difficult to obtain fertilizers. Of those who found it difficult to obtain fertilizers, the major reason given in Bangladesh was that the shops were usually

closed (35%); in Pakistan, it was shortage of supplies (53%); in the Philippines and Thailand, it was difficulty in obtaining credit (25% and 90%, respectively).

Table 4.

EASE OF FERTILIZER AVAILABILITY
(% OF TOTAL RESPONDENTS)

	EASILY AVAILABLE	DIFFICULT TO OBTAIN
Bangladesh	86	14
Pakistan	79	21
Philippines	84	16
Thailand	91	9

Fertilizer Purchase on Credit (Tables 5 and 6)

Except in the Philippines, over 70 percent of farmers in all the countries stated that they did not purchase fertilizers on credit. High interest rates, time required to obtain credit, lack of a credit source, and preference for paying in cash were some of the main reasons advanced for not purchasing fertilizer on credit.

Table 5.

FERTILIZER PURCHASE ON CREDIT
(% OF TOTAL RESPONDENTS)

	PURCHASED ON CREDIT	DID NOT PURCHASE ON CREDIT
Bangladesh	29	71
Pakistan	22	78
Philippines	63	37
Thailand	21	79

Table 6.

REASONS FOR NOT PURCHASING FERTILIZER ON CREDIT
(% OF NON-CREDIT USERS)

	BANGLADESH	PAKISTAN	PHILIPPINES	THAILAND
Prefer cash payment	5	29	20	36
No credit source	7	25	11	58
High interest rates	46	12	2	2
Procedure time consuming & complicated	41	25	33	2
Lack of collateral	1	-	20	2

Source of Credit (Table 7)

An interesting and contrasting picture is seen: The commercial bank was the most important source of credit in Bangladesh and the Philippines; in the other two countries, it was not so significant. The landlord was the most important source of credit in Pakistan, while no one in Thailand used this source. Cooperative was the most important in Thailand, whereas it was not mentioned by anyone in Pakistan and the Philippines.

Table 7.

CREDIT SOURCE
(% CREDIT USERS)

	BANGLADESH	PAKISTAN	PHILIPPINES	THAILAND
Commercial bank	36	16	54	10
Cooperative	14	-	-	90
Money lender	14	5	27	-
Landlord	14	70	5	-
Fertilizer Dealer	-	3	-	-
Grain merchant	-	6	2	-
Friends and relatives	7	-	12	-
Other	15	-	-	-

2. RESULTS OF REGRESSION ANALYSIS

Several alternative models were tried with some variation for each of the countries (Table 8). Results of each model are slightly different due to interaction between the variables. Tobit analysis was only possible for Thailand and Pakistan since other countries' sample had a few or no fertilizer non-using farmers. The findings of these analyses are discussed separately.

Price of Fertilizer

Fertilizer price shows a significant relationship with fertilizer use in all the countries except for Thailand. It does not imply that farmers in Thailand do not respond to fertilizer prices, but the reason for nonsignificance of price coefficient in this case is lack of much price variation between the two villages as well as the farmers in each village. It is mainly because there was only one fertilizer brand available, and more or less from the same source of supply.

In the case of Pakistan our sample includes farmers growing high yielding wheat (Mexican), high yielding rice (IR-6, IR-8), and local rice. It is found that when farmers grow improved varieties which respond well to higher doses of fertilizer than the local one, they use more fertilizer. This result

helps to confirm that demand for fertilizer has increased with the introduction of high yielding varieties of wheat and rice crops.

Table 8.

SUMMARY OF REGRESSION RESULTS

	PAKISTAN	THAILAND	PHILIPPINES	BANGLADESH
Fertilizer price	***	NS	***	**
Past experience	***	NS	NS	NS
Exposure to information	***	**	NS	*
Soil Quality	**	NS	*	NS
Availability of irrigation	**	-	NS	NS
Degree of commercialization	**	NS	-	NS
Level of education	***	**	NS	NS
Expected price of rice	NS	NS	NS	NS
Distance from market	NS	NS	**	NS
Conflicting time demand	NS	-	-	-
Farm size	**	-	-	-
Tenancy	***	-	-	-
Crop variety	***	-	-	-
Nonfarm income	-	NS	**	NS
Credit availability	*	**	NS	NS

*** Statistically significant at .01 level
** Statistically significant at .05 level
* Statistically significant at .10 level
NS Statistically non significant
- Not included

Past Experience

Farmers' past experience in fertilizer use appears to have no relationship to the level of fertilizer used in all the countries except Pakistan, where the regression coefficient is statistically significant at the .01 level. The adoption of innovations starts from the initial trial, and if successful its use continues to some desirable level. It is quite conceivable in the case of fertilizer that after some time its use may not increase unless it is stimulated by some complementary factor such as new crop variety or better irrigation facilities.

Exposure to Information Sources on Fertilizer Use

In the case of Pakistan and Thailand, it is evident from the significant coefficients of regression that the higher the exposure of farmers to different sources of information the higher the fertilizer use. However, results are not significant in the case of Bangladesh and the Philippines. Apparently our analysis could not pick up the effect of this variable, mainly because of missing data.

Quality of Soil and Fertilizer Use

Coefficients of regression are nonsignificant for all countries except for Pakistan. It indicates that farmers do not take the chance of applying more fertilizer on very poor soils where they may not expect better returns. In the case of Bangladesh, the Philippines, and Thailand, a few villages from each country were selected in the sample, and therefore farms represent a very narrow range of variation in soil quality which is probably the reason for non-significant results.

Availability of Irrigation Water

Better availability of irrigation, either by supplementary means, for example, tubewells or whatever other source is available, induces the farmers to use more fertilizer. This assertion is confirmed in the case of Pakistan and Bangladesh. Sample farmers in the Philippines and Thailand did not indicate water as a constraint, and thus this variable was not used in the models of these countries.

Degree of Commercialization

The degree of commercialization has positive relation with fertilizer use in Pakistan. It means that if the crop is produced for selling in the market and not mainly for home consumption, this induces farmers to use more fertilizer. Data from the other countries do not show a significant relationship.

Level of Education

In the case of Pakistan and Thailand, the coefficient of this variable is positive and significant. Coefficients for Bangladesh and Philippines are not significant.

Expected Price of Crop

In all the countries expected price shows no relation to fertilizer use. It may be because of a very small range of expected price of survey crop due to the government's control of prices in Pakistan and the relatively small sample in other countries.

Distance from the Market

Distance from the market was used as a proxy for ease in obtaining fertilizer. It is not significant in all countries except the Philippines. Even in the case of the Philippines it has reverse relationship to that anticipated, which may be due to the better condition of the roads and relatively easier means of transport. The majority of the farmers in all countries report no difficulty in obtaining fertilizer.

Conflict in Demand for Time

There was not sufficient data about the involvement of farmers in conflict with the farming operation except Pakistan. Even in the case of Pakistan it did not indicate a significant effect.

Farm Size and Tenancy

Most of the farmers in all countries were small farm operators. The range of cultivated area under survey crop in Pakistan was quite high. The area under survey crop was used as one of the explanatory variables. It indicated positive relationship to the level of fertilizer use. Moreover, type of tenancy was used as another variable, which showed a negative significant relationship. It is contrary to the common assumption that owner farmers are likely to invest more on their farms since they have incentive to get full benefit. Explanation for such a result is that big landlords have scores of small tenants. Farm inputs were usually arranged by the landlord and then distributed among the tenants. Under such circumstances it may not be up to the farmer alone to decide whether to use or not use or even how much to use an input. It is for this reason that tenants used more fertilizer as compared to small owner farmers.

Availability of Credit

Farmers who could obtain credit indicate a higher level of fertilizer application in Thailand (significant at .05 level) and Pakistan (significant at .10 level). It did not show any effect in Bangladesh and the Philippines. The question is whether access to credit is a sufficient condition. Fleckenstein (1971) found that farmers' attitude toward borrowing was overwhelmingly negative for many reasons, such as fear of losing collateral and borrowing as a sign of poverty. However, the buying of fertilizer on credit is viewed differently from borrowing money. Therefore it is not only the easy availability of credit at a reasonable cost but its social acceptability.

3. RESULTS OF TOBIT ANALYSIS

Price of fertilizer, which is not significant* in the OLS regressions, becomes significant in the Tobit model. This reflects that Tobit is a more appropriate technique to estimate the parameters of the demand for fertilizer in case we are dealing with both fertilizer users and nonusers.

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*As mentioned above, the legitimate test of the coefficients in the Tobit model must be performed by using either the likelihood ratio test or the F-test. However, these have not been done because of time constraint. The significance of each variable is based on the ratio of the coefficient and the standard error of estimate.

Degree of exposure and a dummy variable which assumes a value cf 1 if a farmer borrows money to buy fertilizer are significant and of anticipated signs.

However, price of rice, farmer's education, per capita income from surveyed crop, and per capita non-farm income are not significant. Insignificance of income may be due to the problem of measurement. First, the number of family members were not exactly known. So we have to assume that the number of family members are the farmer, his wife, and his children. This clearly underestimated the actual family size. Second, the total incomes were probably not measured accurately.

Price of rice is not significant, partly because the sample came from two homogeneous villages with a small variation in farm size, socio-economic characteristics, etc. Moreover, the amount of fertilizer used may be related to last year's price of rice, not next year's price.

CONCLUSIONS

It is generally agreed that farmers respond to economic incentives, that is, pricing policies of both inputs and outputs. It is also generally agreed that most of the governments in the countries surveyed influence the market prices of wheat and rice in one way or the other. Our sample data, however, could not pick up enough variation both in price of fertilizer and price of survey crop except for Pakistan. This in a way reinforces the notion of governments' role in price stabilization. Such price incentives or controls should not, however, be overemphasized since several other factors such as farmers' own learning by doing (both in the use of fertilizer and participation in the market), their ability to comprehend new methods, their physical environments suitable for new technology adoption such as satisfactory supply of irrigation, improvements in soil condition by leveling, and easy access to input and output markets, have a significant effect on their decision making in using fertilizer. Furthermore, farmers are responsive to new ideas/information. Fellow farmers play a leading role, followed by governments' extension programs through field staff, field experiments, and agricultural programs on the radio. These findings are suggestive of areas requiring governments' efforts. Television is still in its infancy in regard to telecasting such ideas for the farmers in our survey area.

We find that farmer cooperatives play an important role in this regard in Thailand, and to some extent in Bangladesh. Newspapers and other printed material are still not of much importance as information sources for farmers in these countries.

We find that our conclusions are generally in agreement with those of other researchers.

SUGGESTED RECOMMENDATIONS FOR POLICY CONSIDERATION

Based on our findings, it would be appropriate to emphasize that governments should re-examine allocation of resources being used in

providing price subsidies as an economic incentive to farmers. This is the case in many of the countries under study. Furthermore, we would like to suggest the following:

- Key farmers in various areas should be tapped as demonstrators of new ideas/technologies, since they can be a resource for other farmers.
- The agricultural extension service should be improved in order to enable them to communicate new information to farmers more effectively and promptly.
- Radio, and later on, television programming should be re-examined to make these mass media more appealing to farmers. These can be used as cost-effective techniques for influencing farmer decision making.
- Improvements in physical infrastructure should command high priority to link the farmers with the market and be geared toward meeting farmers' needs.
- To improve farmers' attitudes toward purchasing fertilizer on credit, procedures for obtaining credit should be simplified, and a simultaneous campaign should be launched to enhance the "credibility" of credit-providing agencies.

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APPENDIX 1

REGRESSION RESULTS

DEFINITIONS OF VARIABLES

For Bangladesh, Philippines and Thailand

A. Independent variables

1. $PRICEF = \sum_{i=1}^{n} F \times PSi \;/\; \sum_{i=1}^{n} FQi$

   = price of fertilizer

2. $PFN = \sum_{i=1}^{n} \frac{EXPSi}{(Ni + Pi)} \;/\; \sum_{i=1}^{n} FQi * Ni$

   = Avg. price of N.

3. $PFP = \sum_{i=1}^{n} \frac{EXPSi}{(Ni + Pi)} \;/\; \sum_{i=1}^{n} (FQi * Pi)$

   $1 > N, P \geq 0$ (= Avg. price of P)

4. PFT = (PEN.QFN + PFQ.QFP)/(QFP.QFN)

   = Ave. price of N + P

5. SALEP = sale price of rice

6. RELPF1 = PRICEF/SALEP

7. RELPFT1 = FPT/SALEP

8. RELPFN1 = PFN/SALEP

9. RELPFP2 = PFP/SALEP

10. RINCOMEP = (total sales from rice)/(family size)

11. BORROW- dummy variable, for credit purchase BORROW = 1, otherwise = 0

12. COMMER1 = (value of paddy kept for seed + value sold + value for loan payment + value for barter)/yield. = degree of commercialization

13. EXPOS = exposure to sources of information: summation of index of intensity form government services, radio, TV, newspaper, cooperatives, and fertilizer distributors

14. NONFARMY = nonfarm income/family size

15. Y = RINCOMEP + NONFARMY

16. DISTKM = distance from farm to fertilizer distributor in kilometers

17. QSOIL = soil quality: good and very good = 1, otherwise = 0

18. EXPPERT = experience in fertilizer use in years.

19 OWNED = farmer's own education in years.

20. WATER = availability of water; enough = 1, otherwise = 0.

B. Dependent variables

1. $QFKG = \sum_{i=1}^{3} FQi/CL$

2. $QFN = \sum_{i=1}^{3} FQi * Ni \quad /CL$

3. $QFP = \sum_{i=1}^{3} FQi * Pi \quad /CL$

4. QFT = QFN + QFP

FERTILIZER SUPPLY TO 2000 IN REFERENCE TO THE ASIA AND PACIFIC REGION

FERNANDO C. ANGULO*

ABSTRACT

The evolution of the fertilizer industry which used to follow recognizable cyclical patterns was jolted in 1973-1974 by the sudden quadrupling of prices for petroleum and phosphate rock. It created apprehensive buying and increased splitting of the industry between manufacturers of fertilizer products and producers of fertilizer intermediates. Fast-rising transport costs deepened the process and have become the main trade barrier for low analysis fertilizer products and raw materials.

This paper presents an overview of the chemical fertilizer supply situation in the Asia and Pacific region up to the year 2000 within this changed context.

INTRODUCTION

The important role fertilizers play in increasing agricultural output, as well as the close interrelationships existing between nutrition, food, agricultural systems, and fertilizers, has been highlighted in the recent Second World-Wide Study on the Fertilizer Industry: 1975:2000 (UNIDO/ICIS.81, 11 September 1978). This paper presents an overview of the chemical fertilizer supply situation up to the year 2000 in the Asia and Pacific region. In 1977-1978 the region produced 20.86 percent of the world's nitrogen, 15.29 percent of phosphate, and 1.24 percent of potash fertilizers--despite having over half the world's population.

In order to gain insight into the possibilities and constraints of fertilizer production and flows within this region, three main subregions are considered: Japan and Oceania, Far East and Polynesia, and Asian centrally planned economies. The regional country classification is that of FAO.

The past evolution of the fertilizer industry has been characterized by longer periods of oversupply alternating with shorter periods of scarcity. Moreover, there have been cyclical mismatchings between fertilizer capacity and fertilizer intermediates capacities reflecting the realities of the market orientation in the former and the raw material orientation in the latter.

The splitting of this industry between fertilizers and intermediates has become more pronounced since late 1973 after the sudden quadrupling of prices for petroleum and phosphate rock. At the present time and in the medium-term, there is a substantial ammonia excess capacity over

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nitrogenous fertilizer capacity, while phosphoric acid capacity is more evenly matched to phosphate fertilizer capacities. The recent oil price increases and the growing consensus at OPEC to limit exportable oil output within the next few years will sharply affect both transport costs and oil-based nitrogren producers. Currently, transport costs are already a major barrier to the economic flow of bulk raw materials and low analysis fertilizers.

METHODOLOGY

Any planning undertaken to estimate future fertilizer supply in the region should be based on reliable historical data and projections of future demand. Consequently, FAO consumption and production figures up to 1977-1978 were used. Thereafter, forecasts made by the UNIDO/FAO/World Bank Working Group on Fertilizers in June 1979 were incorporated. Lastly, the longer-term projections for 1999-2000 were estimated at UNIDO based on the most recent figures and the methodological approach used in its previous Second World-Wide Study on the Fertilizer Industry: 1975-2000 (UNIDO/ICIS.81, 11 September 1978).

Plant capacity data for fertilizer intermediates from 1973-1974 to 1983-1984 are those of the Working Group on Fertilizers, while the longer-term projections were made at UNIDO. The Working Group on Fertilizers usually publishes its figures in FAO's current situation and outlook reports to FAO's Commission on Fertilizers.

Concerning consumption, a distinction is made between forecasts and projections. The former involves policy, economic, and commercial judgment on the medium-term estimates, while the latter passes economic and policy judgment on the statistically calculated long-term estimates. Consumption in this context refers to apparent demand.

Regarding production, separate data are presented on fertilizers and intermediates. The former includes only medium-term forecasts in terms of maximum supply capabilities estimated under both concrete information (existing fertilizer capacities and new projects under construction or firmly committed) and assumptions (such as capacity phasing-in factors, plant operating rates, and loss factors).

No attempt is made to estimate long-term fertilizer supply in the region for two reasons: (1) in general, practically all fertilizers derive mainly from the three chief fertilizer intermediates: ammonia, phosphoric acid, and potassium chloride, which also account for the bulk of investment; (2) choices for fertilizer production involve taking stock from several production systems, a large selection of straight and compound fertilizers, and a range of policy options from fertilizer raw materials to crops.

Consequently, assumptions aiming at simplifying and rationalizing this selection process may become either simplistic or extremely complicated, both of which are outside the scope of this paper. However, estimates of long-term fertilizer intermediates supply in the region give a useful picture of production possibilities and flows within the

region that may spur cooperative fertilizers/intermediates schemes. The specific assumptions to estimate long-term intermediates capacities are given in more detail in the analysis by nutrient that follows.

Yearly nameplate capacities of ammonia and phosphoric acid plants are obtained by multiplying the daily capacity by 330 days for all countries except North America which has 340 operating days. Potash nameplate capacity is estimated at 300 working days except for Canada which has 320 operating days. The differences in the subregional effective capacity are accounted for through varying plant operation rates.

NITROGEN FERTILIZERS

The Asia and the Pacific region consumed 26.5 percent of total nitrogen demand in 1977-1978 and is expected to increase its consumption to 32 percent of the world total by 1999-2000.

Table 1 gives consumption and production figures for nitrogenous fertilizers from 1965-1966 to 1999-2000, for the world and the three subregions under study. From the Table it can be ascertained that the region as a whole attained 81.62 percent self-sufficiency in 1977-1978 and may reach 85.07 percent in 1983-1984. At the sub-regional level, Japan and Oceania have large excess production over consumption during the medium-term despite Japan's trimming down on capacities, while the other two subregions remain net importers despite their substantial new plant construction programs that may enable them to attain around 81 percent self-sufficiency by 1983-1984.

China and India are the largest consumers and producers of nitrogenous fertilizers, while Japan remains a large producer during the medium term.

Current and estimated ammonia capacities in terms of nutrient are given in Table 2. It shows that the region's share of world ammonia capacity is slightly but steadily reducing from 23.7 percent in 1977-1978 to 22.66 percent in 1983-1984 to 21.13 percent in 1999-2000. This situation contrasts unfavorably with regional trends in consumption. The subregional estimates of ammonia capacity were arrived at by considering the following factors: industrial uses less nitrogenous fertilizers supply from nonfertilizer sources, plant operation rates, conversion losses assumed at 7 percent, and statistical discrepancy taken at 4 percent of consumption. Additionally, in assessing probable new plant construction programs until 1999-2000, other factors were considered: feedstock availability, plant operation learning curve according to size and feedstock mix, hard currency restrictions to finance new plants, and trends in consumption-production balances.

Each subregion was analyzed independently in order to appraise its ammonia production potential. The results of the analysis show the following subregional picture without considering old plant replacements:

Table 1. Nitrogenous fertilizers - Asia and the Pacific region (millions of MT of N)

YEAR	CONSUMPTION				PRODUCTION			
	WORLD	JAPAN AND OCEANIA	FAR EAST AND POLY-NESIA +	ASIA CEN-TRALLY PLANNED	WORLD	JAPAN AND OCEANIA	FAR EAST AND POLY-NESIA +	ASIA CEN-TRALLY PLANNED
1965/66	18.82	0.75	1.13	1.60	20.01	1.53	0.46	0.94
1970/71	31.75	0.84	2.70	3.50	32.97	2.26	1.59	1.63
1977/78	47.77	0.92	5.12	6.64	49.61	1.66	3.62	5.07
	Forecasts				Supply capability			
1978/79	51.76	0.94	5.83	7.07	52.58	1.69	4.28	5.77
1983/84	67.22	1.02	9.27	8.54	67.50	1.61	7.40	7.01
	Projections							
1988/89	84.20	1.13	13.00	10.50				
1999/2000	133.79	1.40	24.17	17.22				

Table 2. World capacity of the main fertilizer intermediates Asia and the Pacific region (millions of MT)

YEAR	AMMONIA				PHOSPHORIC ACID			
	WORLD	JAPAN AND OCEANIA	FAR EAST AND POLY-NESIA +	ASIA CEN-TRALLY PLANNED	WORLD	JAPAN AND OCEANIA	FAR EAST AND POLY-NESIA +	ASIA CEN-TRALLY PLANNED
1973/74	64.57	4.03	3.55	7.13	18.13	1.04	0.47	0.03
1975/76	71.97	4.09	4.54	7.13	24.17	1.07	0.60	0.07
1977/78	78.90	4.17	5.54	8.99	26.82	1.12	1.21	0.07
	Forecasts				Forecasts			
1978/79	84.42	4.17	6.26	9.91	27.76	1.12	1.27	0.07
1983/84	112.18	3.28	10.74	11.40	34.90	0.94	1.54	0.18
	Projections				Projections			
1988/89	135.51	3.46	14.36	13.94	40.67	1.19	1.70	0.37
1999/2000	215.52	4.48	21.54	19.52	71.28	1.41	2.28	1.14

Japan and Oceania will be quite in balance except for some DAP imports by Japan. At average operating rates of 90 percent, this subregion will require five new 1000 MT/D plants between 1983 and 1999. Most of the new capacities will be located in Australia.

Far East and Polynesia will run increasing deficits. At average operating rates of 80 percent, by 1988-1989 the deficit will be 3 million tons, and 85 percent rates, by 1999-2000 the deficit will increase to 8.3 million tons. The new plant construction program will require 14 new 1000 MT/D plants between 1983 and 1988 and an additional 27 plants from 1988 to 1999. Most plants will be located in Indonesia and India.

Asia centrally planned economies will also run growing deficits. At average operating rates of 70 percent, by 1988-1989 the deficit will amount to 2.5 million tons, and at operating rates of 75 percent, by 1999-2000 the deficit will reach six million tons. The new plant construction program will require 10 new 1000 MT/D plants during 1983-1988, and an additional 21 plants during 1988-1999. Most of the new capacities will be located in China. Therefore the region as a whole would need to build 77 new 1000 MT/D plants or about 5 new plants per year from 1983 to 2000. In spite of this, there will still be an estimated deficit of 14 million tons of nitrogen in 1999-2000.

PHOSPHATE FERTILIZERS

Although practically all phosphate fertilizers are derived from phosphate rock, the fertilizer market is supplied by two main sources, both rock-based: higher analysis fertilizers based on phosphoric acid, and lower analysis fertilizers based on nonphosphoric acid sources such as SSP, Thomas slag, nitrophosphates, and ground rock.

Table 3 gives the consumption and production figures for phosphate fertilizers, including both chemical fertilizers and ground rock for direct application, from 1965-1966 to 1999-2000. It shows that the Asia and the Pacific region consumed 19.06 percent of world phosphate demand in 1977-1978 and is estimated to reach 21.57 percent of world demand by 1999-2000. However, its self-sufficiency in production is expected to decline from 85.16 percent in 1977-1978 to 78.82 percent in 1983-1984.

At the subregional level, centrally planned Japan, Oceania and Asia have a better than 90 percent self-sufficiency, although Japan is trimming down capacity while the latter subregion is barely keeping up with its demand growth rates despite the fact that over 95 percent of its fertilizer supply comes from nonphosphoric acid sources.

The Far East and Polynesia region is substantially a net importer since its production self-sufficiency is markedly declining from 64.88 percent in 1977-1978 to 56.46 percent in 1983-1984, despite a 52 percent supply capability increase during the same period. This situation reflects the growing preponderance of phosphoric acid-based sources (69% of the total phosphate fertilizer supply) in this subregion.

China, India, Australia, and Japan are the main consuming and producing countries.

Table 3. Phosphate fertilizers - Asia and the Pacific region (millions of MT of P_2O_5)

YEAR	CONSUMPTION				PRODUCTION			
	WORLD	JAPAN AND OCEANIA	FAR EAST AND + POLY-NESIA	ASIA CEN-TRALLY PLANNED	WORLD	JAPAN AND OCEANIA	FAR EAST AND + POLY-NESIA	ASIA CEN-TRALLY PLANNED
1965/66	16.04	1.85	0.43	0.64	16.75	1.95	0.16	0.56
1970/71	20.98	1.72	0.84	0.97	21.92	1.68	0.49	0.93
1977/78	28.28	1.94	1.68	1.77	30.01	1.86	1.09	1.64
	Forecasts				Supply capability			
1978/79	30.05	2.01	1.92	2.05	35.06	1.91	1.24	1.81
1983/84	38.76	2.22	2.94	2.82	42.94	2.02	1.66	2.61
	Projections							
1988/89	46.48	2.35	3.87	3.75				
1999/2000	72.31	2.70	6.62	6/28				

In order to estimate the long-term production possibilities in the region, the two main sources of fertilizer supply have been analyzed separately. The nonphosphoric acid sources were estimated by aggregate trend extrapolations of the main fertilizer materials. The figures for 1988-1989 and 1999-2000 by subregion are as follows: Japan and Oceania, 1.46 and 1.60 million tons; Far East and Polynesia, 0.7 and 1.09 million tons; Asia centrally planned, 3.23 and 4.85 million tons P_2O_5, respectively.

The phosphoric acid capacities were then estimated and given in Table 2. The table shows that the region's share in world phosphoric acid capacities is steadily reducing from 8.94 percent in 1977-1978 to 7.62 percent in 1988-1989 to 6.72 percent in 1999-2000--the reverse of its consumption trends.

The subregional estimates of phosphoric acid capacities were calculated according to the following factors: fertilizer demand less non-acid supply projections, industrial uses of the acid, average plant operation rates, conversion losses assumed at 6 percent and statistical discrepancy taken at 3 percent of consumption for all subregions. Thereafter, in appraising new plant construction programs to 1999-2000, the following additional factors were considered: phosphate rock availability in quality and quantity, availability, de-bottlenecking of existing plants, capacity increases, plant operation learning curves, hard currency restrictions to financing new plants, and trends in consumption-production balances.

Each subregion was analyzed independently. The results of the analysis give the following subregional situation without considering the replacements for older plants:

Japan and Oceania will be in balance except for DAP imports by Japan. At 90 percent average operating rates, capacity increases to 1988-1989 may be attained mainly through de-bottlenecking, while for 1999-2000 two new 600 MT/day plants are needed, and they will be located in Australia.

Far East and Polynesia will run increasing deficits. At average operating rates of 80 percent, by 1988-1989 the deficit will be 1.90 million tons and at 85 percent rates, by 1999-2000 the deficit increases to 3.76 million tons of P_2O_5. The new plant construction program will require seven new 600 MT/day plants from 1983-1984 to 1999-2000.

Asia centrally planned will also run deficits but less markedly than the Far East due to its greater reliance on non-acid sources. At average operating rates of 70 percent, by 1988-1989 the deficit will amount to 0.28 million tons, and at 80 percent rates, by 1999-2000 the deficit will increase to 0.6 million tons. The new plant construction program will require nine new 600 MT/day plants during 1983 to 1999. Most of the new capacities will be located in China. Consequently the region would need to build 18 new 600 MT/D plants or about one new plant per year from 1983 to 2000 despite an estimated deficit of 4.4 million tons of phosphate by 1999-2000. The main constraint is the local availability of economically exploitable phosphate rock.

POTASH FERTILIZERS

Potash fertilizer production is a combined mining-industrial operation usually carried out at the mine site. Currently, potash production is concentrated in North American and European regions that together account for 98 percent of world ore reserves and 97.5 percent of world production. The Asian and Pacific region has at present only one producer, China, which currently accounts for 1.24 percent of world production. However, there are known but not yet fully quantified deposits in Thailand, and perhaps in Laos, Australia, India and Pakistan as well.

Table 4 gives consumption and production figures for potash fertilizers from 1965-1966 to 1999-2000. It shows that the Asian and Pacific region consumed 10.51 percent of total potash demand in 1977-1978, maintains about even its consumption share until 1983-1984, and thereafter registers a slight decline to 10.32 percent by 1999-2000 despite keeping a healthy 4.15 percent yearly growth rate between 1983 and 1999. However, China's growing output is increasing the region's production self-sufficiency from 13.06 percent in 1977-1978 to 16.27 percent in 1983-1984.

Concerning the region's long-term supply capability, only China's output can be estimated since the other deposits have too many unknowns at the moment to attempt quantification.

Table 4 shows that China's production supplied the Asia centrally planned subregion with 65 percent of its needs in 1965, then dropped to 57.14 percent in 1977, to recover to 64.71 percent in 1983-1984. Taking

Table 4. Potash fertilizers--Asia and the Pacific region (millions of MT of K_2O)

YEAR	WORLD	JAPAN AND OCEANIA	FAR EAST AND + POLY-NESIA	ASIA CEN-TRALLY PLANNED	WORLD	JAPAN AND OCEANIA	FAR EAST AND + POLY-NESIA	ASIA CEN-TRALLY PLANNED
1973/74	12.27	0.76	0.23	0.20	13.96	0	0	0.13
1975/76	16.64	0.83	0.49	0.36	17.83	0	0	0.24
1977/78	23.31	0.94	0.95	0.56	25.76	0	0	0.32
	Forecasts				Supply capability			
1978/79	25.19	0.95	1.05	0.60	27.07	0	0	0.36
1983/84	31.98	1.00	1.53	0.85	33.35	0	0	0.55
	Projections							
1988/89	40.36	1.05	2.09	1.10				
1999/2000	62.79	1.18	3.57	1.73				

into consideration current plans and ore reserves, it is assumed that China could supply about 80 percent of the subregion needs by 1999-2000. The corresponding potash capacity required to meet this production target is 1.89 million tons K_2O--that increases the region's self-sufficiency to 21.36 percent of projected consumption.

CONCLUSIONS

From the above analysis and an appraisal of raw material reserves in the Asian and Pacific region, it can be concluded that there are interesting but somehow limited possibilities to spur fertilizer and fertilizer intermediates flows within the region.

The more likely originating points for fertilizers/intermediates flows are Indonesia for ammonia and urea; Australia for ammonia, phosphoric acid, urea, and DAP; and Japan for sulphur.

Unless there are discoveries of new economically exploitable deposits of fertilizer raw materials, the region is likely to remain a net importer of chemical fertilizers at least until the end of the century.

EMERGING FERTILIZER PRODUCTION CAPACITIES

S.R. PANFIL*

ABSTRACT

This paper presents a review of additions to existing world ammonia, phosphoric acid, and potash capacities for the period 1979-1980 to 1984-1985 by nutrients and regions. Data on capacity developments have been elaborated upon and the relationship between capacity figures and estimates on production, supply capability, and available supplies has been explained to facilitate correct interpretation of the forecasts. The paper draws attention to the difficulties encountered when attempting to compile reliable capacity lists for plants under construction and firmly committed projects. It displays examples of discrepancies between information collected from different sources and focuses on the time-sensitivity of estimates which affects their ad hoc validity and causes misunderstandings. Conclusions have been drawn regarding likely future capacity development trends.

Data presented in this paper are based on recent reviews conducted by the UNIDO/FAO/World Bank Working Group on Fertilizer and on information from other internationally recognized sources.

A detailed review of the development of fertilizer capacities in Japan and China has been included. It highlights emerging relevant changes in the fertilizer supply pattern of the East Asian and Pacific region.

INTRODUCTION

Will there be adequate fertilizer supplies to enable farmers to produce enough food to feed the growing population of the world?

This rhetorical question introduces a chain of issues on which the attention of fertilizer producers and consumers has been focused for many years because of its globally vital importance.

From the point of view of the fertilizer industry, with a few limitations and observations, the answer is a clear "yes." While the real limitations basically concern availability of raw materials, there is a great range of secondary constraints which can be considered more or less subject to human control.

The necessity of accelerating the establishment of new production capacities is one of the elements which causes major concern because of the considerable amount of funds needed to satisfy the ever increasing fertilizer demand. Technology and manpower is available; and curiously enough, financing of economically feasible projects does not pose major problems despite the high cost of equipment and the technical infrastructure required.

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This explains in rough terms why the fertilizer plant investment market has been threatened with overcapacity for the past few years.

However, the economic viability of many projects in favorable locations, defined by the existence of abundant raw materials resources and absorptive domestic markets in a given country, is overshadowed by the financial burden arising from high investment costs which entail high manufacturing costs. Governments of developing countries are increasingly aware of the fact that the manufacture of fertilizer can no longer be considered as a source of profit if food security is at stake. Export orientation of investment in fertilizer industries could in many cases offer a prospective solution, but the world fertilizer market is increasingly dominated by countries which are financially powerful enough to undertake advance investment and dispose of the prerequisite wealth of raw materials.

The industrialized countries, in which the development of fertilizer industries was traditionally to a large extent based on imported raw materials, are gradually losing interest in the expansion of this industry for a number of obvious reasons and trends such as: tough dependence on supplies of raw materials, low return on capital investment, and increasing transportation costs. The manufacture and export of plant equipment offers a higher return, and the flexibility of the internal structures of the developed countries' economies permit them to decrease their involvement in capacity development of the fertilizer industry.

The changing investment environment is reflected in the following pages dealing with estimates of capacity development in the fertilizer manufacturing sector for the immediate future, that is, from 1979-1980 to 1983-1984. Although not specifically supported by statistical data or projections, it appears from this review that producers and consumers of fertilizer all over the world are concerned about the impending inescapable fuel crisis which is likely to have a strong and lasting bearing on the profitability of export-oriented projects in faraway locations and on fertilizer prices which many fear will exceed the purchasing power of large groups of consumers in the developing countries who are dependent on imported fertilizers.

For the next three years, the capacity growth in the fertilizer industry should follow a regular trend. The development trend for the second half of the next decade remains uncertain, despite the large number of projects under consideration or in preparation worldwide. The food crop prices follow a slower trend line than would be desirable to balance out the increasing fertilizer manufacturing and transportation costs. Therefore, the conclusion may be drawn that the investment climate in the fertilizer industries of the developing countries will be influenced by the food prices rather than by techno-economic considerations of plant sizes and their locations.

The following review also considers the development of capacities in Japan and China. These two countries were selected to highlight the specifically different features of the development trends of the previous largest fertilizer exporter and the future largest fertilizer producer/consumer in the East Asian region. As for the other Asian countries, the situation seems clearer because statistical data and information relating to the development of production capacities is amply publicized.

THE DEVELOPMENT OF FERTILIZER MANUFACTURING CAPACITIES

Nitrogen Fertilizer

The development of ammonia capacities is under constant review by the UNIDO/FAO/World Bank Working Group on Fertilizer. Primary ammonia production is the basic source of nitrogen for the manufacture of N-fertilizer and hence development trends of ammonia capacity characterize to a large extent the development of the N-fertilizer industry in a given country or region. Recognition of this basic fact permits us to draw conclusions on the development of this industry as a whole.

The method adopted by the Working Group for screening available information on development is more complex than it may appear at first glance. In practice it is quite difficult to correctly assess on-stream dates, on-stream factors, and effective plant capacities because first-hand information is scarce. In order to arrive at neutral results the Working Group regularly reviews information obtained from many sources. This also increases the degree of probability that the data finally presented will stay valid for at least one year. The capacity list compiled by the Working Group is composed of existing and firmly committed plants only, so that the supply-demand balances prepared by the Working Group reflect the widening or narrowing gap between the expected supply capabilities and the consumption forecasts.

Table 1 displays the growth of ammonia production capacities by region. The regional groupings of countries comply with the official UN/FAO classification, which is disputable as far as its appropriateness for monitoring the fertilizer supply-demand situation is concerned.

Table 2 is an example for the global summary only showing how capacity data is used for the assessment of N-fertilizer supply capabilities and supply-demand balances. The methodology applied takes into account country data, past records of plant capacity utilization, conversion losses, obvious compound discrepancies, and other factors, so that the final supply figures thus obtained can be compared with consumption statistics and forecasts obtained from other sources. For some countries a number of assumptions have to be considered in order to arrive at a quantitatively relevant and coherent picture of the actual use of ammonia which largely influences the sum of losses between the source (primary ammonia production) and the real nutrient availability (marketed ammonia-based fertilizer products inclusive of anhydrous ammonia for direct application).

The data displayed in Table 1 speak for themselves. However, attention should be drawn to the sensitivity of the exercise with regard to ad hoc and long-term validity.

A simple comparison of two approaches made less than three months apart provides evidence that it would be unreasonable to consider the yearly capacity data (for a few years ahead) definite or reliable. In order to avoid large discrepancies, the Working Group does not include in its lists vague indications of planned capacities since these might entail large deductions ex post in case of project cancellations, which are quite frequent because of the governments' and companies' changing investment priorities and programs.

Table 1

Development of production capacities

Present status and forecasts

Ammonia in 1000 mt N

Region	1977	1978	1979	1980	1981	1982	1983	1984	1985
World Total	78898	84417	91692	99150	105141	109986	112184	113147	113351
Developed Market Economies	38557	39468	41077	41321	41735	42081	42335	42936	42936
North America	18576	19199	20080	20210	20210	20210	20210	20210	20210
Western Europe	15010	15260	15988	16033	16341	16649	16903	17504	17504
Oceania	440	440	440	440	478	516	516	516	516
Other Developed Market Economies	4531	4569	4569	4638	4706	4706	4706	4706	4706
Developing Market Economies	10632	12555	14896	17584	19424	21694	23064	23233	23233
Africa	411	411	479	740	1012	1012	1035	1058	1058
Latin America	2652	3547	3971	3984	4476	5363	6004	6004	6004
Near East	2025	2342	3321	4336	4771	5124	5287	5423	5423
Far East	5544	6255	7125	8524	9165	10195	10738	10738	10738
Centrally Planned Economies	29719	32394	35719	40245	43982	46211	46785	46988	47192
Far East	8985	9913	10968	11198	11398	11398	11398	11398	11398
Eastern Europe including USSR	20724	22481	24751	29047	32584	34813	35387	35590	35784

Table 2

Development of supply capabilities

and available supplies

Ammonia in 1000 mt N

World Total	1977	1978	1979	1980	1981	1982	1983	1984	1985
Capacity	78898	84417	91692	99150	105141	109986	112184	113147	113351
Production	61649	64941	70672	79490	84130	88856	91497	92919	93449
N-technical use	8236	8661	9103	9565	10051	10050	11016	11530	12035
Supply capability conversion losses and statistical discrepancies	4346	4582	4979	5599	[illegible]22	6253	6439	6540	6575
Available supplies	49067	51698	56590	64236	68157	72053	74042	74849	74839

Source: UNIDO/FAO/WB Working Group (Tentative list June 1979)

World total yearly capacity increases (ammonia, 1000 mtpy N)

	1979	1980	1981	1982	1983	1984
1. March 1979 (Refer to Table 3)	7221	4594	6575	2191	747	
2. June 1979 (Refer to Table 1)	7458	5991	4845	2198	963	

With reference to Table 3, it may be noted that major fertilizer complexes during the period under review are emerging in the developing countries, and in particular in the centrally planned economies of Europe and Asia. This trend is bound to continue under the assumption that the capacity development plans which have become known so far for the period beyond 1985 (possibly for not more than five years beginning with 1984) will be implemented. The period 1984-1985 is inadequately covered by definite new announcements. However, it would still be possible to bring some new plants on stream before the end of 1985 if firm decisions are taken before the end of 1980.

The yearly additions to ammonia capacities shown in Table 3 are decreasing toward the end of the period reviewed. This should not be

interpreted as a decreasing interest in or need for establishment of new capacities. As delineated in the recent UNIDO Second World-Wide Study on the Fertilizer Industry: 1975:2000 (UNIDO/ICIS. 81, 11 September 1978), capacity development may be inadequate to cover the real future needs.

Table 3

Additions to world fertilizer production capacities

Ammonia plants (Unit: 1000 mtpy N)

Year	1979/80	1980/81	1981/82	1982/83	1983/84	beyond 1984
World total	7221	4594	6575	2191	747	19 617
Developed market economies	145	82	690	244	271	5 402
North America						722
Western Europe	145		614	244	271	4 354
Oceania			76			
Other Developed market economies		82				326
Developing market economies	2405	2092	3459	1577	272	11 744
Africa	601	272	54	46		2 269
Latin America		572	1010	518		4 141
Near East	1141	272	326		272	2 665
Far East	663	776	2069	1013	163	2 669
Centrally planned economies	4671	2220	2426	370	204	2 471
Region Eastern Europe and USSR	4440	2220	2426	370	204	2 471
Far East	231	200				

This, however, is a different aspect which calls for investigation into the causes of likely unfavorable trends in this respect. During the period until the end of 1983, data are relatively reliable, with a few exceptions where delays in project implementation may result in the flattening of the development curve. Beyond that date the uncertainties described above do not permit us to draw valid conclusions other than those implied in the tentative projections which are based on the assumption that capacity development will continue to be congruent with future demand patterns. To what extent the impending increase of shipment costs will change the interregional trade flow is yet to be seen, although there is not much room for maneuver because capacity development will be decreasingly viable in countries where the raw materials are not readily available on the spot. Trade in fertilizer intermediates may increase for a limited period ahead because of existing downstream processing capacities. In the future, when worn out, these plants are unlikely to be replaced and the supply pattern may be expected to shift definitely in favor of the countries possessing raw materials which have a good chance in the long run to become the sole exporters of fertilizer.

Phosphate Fertilizer

This review of emerging phosphate fertilizer capacities concentrates on phosphoric acid production facilities which are representative of the phosphate processing industry as a whole, although in a less consistent way than is the case with the relationship between ammonia and nitrogen fertilizers.

The methodology applied in compiling and evaluating capacity data is the same as that described above for nitrogen fertilizer. The accuracies attained are of similar nature and background.

Table 4 displays trends for phosphoric acid that are similar to those forecast for N-fertilizer capacity developments. Lack of fully reliable data on some of the large producer or consumer countries (USSR, China) makes it difficult to come up with a more consistent or streamlined capacity development trend. Uncertainties regarding the timing of start-completion schedules of the investment projects are more pronounced in this sector of the fertilizer industry worldwide.

On the other hand, what has been noted above concerning the obvious close relationship between raw material availability and viability of projects is equally valid for consideration of the development of phosphate industries. This is particularly so because of the relatively unfavorable transportation cost to rock phosphate price ratio which is bound to deteriorate further with the increasing fuel prices.

Table 5 reflects the method of calculating available phosphate supplies. Attention should be drawn to the relative importance of "other P_2O_5 production" which is composed of ground rock phosphate for direct application. The world totals given in Tables 4 and 5 are slightly different owing to recent updating.

Table 4

Development of production capacities

Present status and forecasts

Phosphoric Acid in 1000 mt P_2O_5

Region	1976/ 1977	1977/ 1978	1978/ 1979	1979/ 1980	1980/ 1981	1981/ 1982	1982/ 1983	1983/ 1984	1984/ 1985
World total	26100	26820	27880	29830	32620	34250	34420	34420	34970
Developed Market Economies	16790	17070	17050	17740	17900	18060	18060	18060	18060
North America	9630	9780	9920	10410	10410	10410	10410	10410	10410
Western Europe	5060	5230	5170	5370	5410	5570	5570	5570	5570
Oceania	200	200	200	200	200	200	200	200	200
Other Developed Market Economies	1900	1860	1760	1760	1880	1880	1880	1880	1880
Developing Market Economies	4280	4400	4610	5130	6600	7740	7910	7910	7960
Africa	1550	1550	1550	1880	2540	2540	2710	2710	2720
Latin America	990	990	990	990	1370	1680	1680	1680	1690
Near East	650	650	800	990	1150	1980	1980	1980	1990
Far East	1090	1210	1270	1270	1540	1540	1540	1540	1540
Centrally Planned Economies	5030	5350	6220	6960	8120	8450	8450	8450	8950
Far East	70	70	70	180	180	180	180	180	180
Eastern Europe including USSR	4960	5280	6150	6780	7940	8270	8270	8270	8770

Table 5

Development of supply capabilities

(total P_2O_5 supplies including other P_2O_5 and ground phosphate rock)

1000 mt P_2O_5

World Total	1976/ 1977	1977/ 1978	1978/ 1979	1979/ 1980	1980/ 1981	1981/ 1982	1982/ 1983	1983/ 1984
Phosphoric acid capacity	26100	26820	27880	29730	32510	34140	34310	34450
Phosphoric acid production	18870	20130	19620	20650	22000	23530	25180	26180
Other P_2O_5 production	11290	12700	14260	14520	14860	15200	15470	15630
Supply capability	30160	32830	33880	35170	36860	38730	40650	41810
Losses and statistical discrepancies	905	985	1020	1060	1110	1160	1220	1250
Available supplies	29255	31855	32860	34110	35750	37570	39430	40560

A comparison of yearly additions to phosphoric acid capacities derived from Tables 4 and 6 displays the uncertainties which largely affect the short-term estimates of capacity development and the supply-demand balances

World total yearly capacity increases (Phos. acid, 1000 mtpy P_2O_5)

	1979	1980	1981	1982	1983	1984
1. March 1979 (Refer to Table 6)	2501	2649	1929	165	435	
2. June 1979 (Refer to Table 4)	1950	2790	1630	170	0	

With reference to Table 6, it may be observed that the developed countries are reluctant under prevailing conditions and prospects to take firm decisions on future investment in this sector. For the period beyond 1984 the capacity development trend seems to revive. However, announcements on future plant construction are composed of replacement

Table 6

Additions to world fertilizer capacities

Phosphoric acid plants (Unit: 1000 mtpy P_2O_5)

	1979/ 1980	1980/ 1981	1981/ 1982	1982/ 1983	1983/ 1984	Beyond 1984 or indefinite
World Total	2501	2649	1929	165	435	5919
Developed market economies	1337	160	165			1041
North America	967					363
Western Europe	370	40	165			666
Oceania						12
Other developed market economies		120				
Developing market economies	550	1404	1134	165	152	3681
Africa	330	660		165		1755
Latin America		373	308			1252
Near East	220	371	826		152	174
Far East		277				500
Centrally planned economies	614	1085	660		283	1197
Eastern Europe and USSR	505	1085	660		283	1197
Far East	109					

and modernization programs for non-fertilizer use of phosphoric acid. The relevance of data in the "Beyond 1984 and indefinite" category is rather vague.

Many developing countries are considering starting or increasing production of SSP based on low-grade indigenously available rock phosphate resources. This trend does not directly affect the trade flow of phosphate fertilizer since the SSP production increases known so far are lower than the consumption growth of phosphate fertilizer in the countries concerned.

No detailed studies were made on the development of MAP, DAP, TSP, and NPK compound fertilizer capacities. Because of the smaller size of capital investment requirements and the shorter implementation period of projects in this field, available data on capacity development could not be expected to be sufficiently accurate to draw conclusions beyond three years in the future.

POTASH

The development of mining and refining capacities of the potash industries is keeping pace with the market trends. Relatively small overcapacities and flexibility in adjusting utilization rates to the actual needs are a natural consequence of the mining techniques and processing methods applied. The short-term forecasts display narrowing margins between available supplies and demands. However, this is an easy-to-explain phenomenon. In this sector of the fertilizer industry, pre-investment considerations and the implementation of expansion plans are less complex than is the case with the nitrogen and phosphate fertilizer industries which are continuously under pressure from worldwide competition. Except for planning of construction of new mines, the mining and processing intensification programs are easier to organize from the technical viewpoint and thus need less lead time before the supply-demand balance is readjusted to match new conditions. The potash consumption growth rate is following a stable trend and is less sensitive to price changes experienced in the commodity and energy market. Moreover, the difference between nominal capacity and supply capability or actual production comprises a certain reserve which allows for almost immediate increase of output if the absorptive capacity of the market is growing faster than expected. For these reasons no emergency shortage situations are likely to occur despite the apparently decreasing difference between production and consumption over the coming four-year period.

There is growing concern that the impending inescapably rapid increase of transportation costs will have an impact on future capacity development trends because of the unfavorable product price to transportation cost ratio. This, however, is a common feature of almost all low-analysis fertilizers. Sales prices of fertilizer raw materials and intermediates will also be affected. In particular, this will be the case where the distances between the location of production facilities and consumption areas are unfavorable from the viewpoint of means and cost of shipment.

In this connection, attention should be drawn to the East Asian market which is steadily growing while exploration for sources of potash supply is relatively slow. Geologically, China seems to be amply endowed

with potash containing salt deposits and may become the future chief supplier for the entire region. But the infrastructure needed to make remarkable progress toward changing the potash supply pattern of East Asia may not permit the attainment of tangible results in the near future, that is, in the next ten years at least. Similar considerations are valid with respect to the Thai/Laotian potash deposits which have been found suitable for undertaking a large development program. In this case, the continuing political constraints pose a barrier to investment initiatives. In the short run, there is little hope that the political, and hence the investment, climate will become adequately conducive to begin at least some technical preparatory work. In this case as well, extensive advance financing is required to solve technical, infrastructural, environmental, and internal transportation problems before an internationally marketable product would become available.

Data on the World Potash Capacity Development as of June 1979 compiled and critically reviewed by the UNIDO/FAO/World Bank Working Group on Fertilizer is shown in Table 7.

New capacities are being established and are under consideration in Canada, Brazil, Jordan, and the USSR, while other increases are due to expansion projects at existing mines.

The narrowing margin between total world supply and demand is evident from the following set of data:

(1000 metric tons K_2O - source UNIDO/FAO/WB June 1978)

	1978-1979	1979-1980	1980-1981	1981-1982	1982-1983	1983-1984
World total capacities	32.540	33.750	35.060	36.480	37.810	N/A
Available supply	27.190	28.250	29.290	30.200	31.150	N/A
Demand forecast	25.430	26.650	27.990	29.290	30.750	N/A
Balance (surplus potential availability)	+ 1.760	+ 1.600	+ 1.300	+ 910	+ 400	-

However, the recently revised assessment of the short-term capacity development (June 1979), if compared to the estimates made in June 1978, reveals that industry reacted correctly, as might have been expected, and seemed to speed up their construction and intensification plans. At the same time the actual consumption decreased slightly and consequently the lower consumption forecasts also contributed to widening the margin.

Table 7

World Potash Capacity Development

(1000 metric tons of K_2O per year)

Regions	1978/ 1979	1979/ 1980	1980/ 1981	1981/ 1982	1982/ 1983	1983/ 1984	Forecast including Uncommitted expansions
World Total	32537	33746	35062	36142	39442	41407	47985
Developed market economies	18047	18336	18632	19112	21042	22167	25285
North America	10477	10587	10867	11197	13017	14112	16610
Western Europe	6820	6999	7015	6965	6925	6955	7335
Oceania	-	-	-	-	-	-	-
Other developed market economies	750	750	750	750	1100	1100	1100
Developing market economies	30	30	30	30	750	990	1350
Africa	-	-	-	-	-	-	-
Latin America	30	30	30	30	270	270	630
Near East	-	-	-	-	720	720	720
Far East	-	-	-	-	-	-	-
Centrally planned economies	14460	15380	16400	17050	17650	18250	21450
Far East	360	380	400	450	500	550	650
East Europe and USSR	14100	15000	16000	16600	17150	17700	20800

(Forecasts as of June 1979)

	1978-1979	1979-1980	1980-1981	1981-1982	1982-1983	1983-1984
World total capacities	32.537	33.746	35.062	36.142	39.442	41.407
Available supply	27.066	28.221	29.379	30.190	31.722	33.499
Demand forecast	25.180	26.420	27.980	28.980	30.460	31.990
Balance (surplus potential availability)	+ 1.886	+ 1.801	+ 1.689	+ 1.210	+ 1.262	+ 1.509

In summary, the world potash capacity is estimated to grow in five years from 32.537.00 (1978-1979) to 41.407.00 mtpy (1983-1984), that is, by 8.870.000 mtpy or 27 percent, with favorable prospects of further unconstrained growth in the years to follow.

The development of capacities in the Asia and Pacific region remains an open issue. Unless the market is under pressure of a supply shortage or the transportation costs become prohibitive, it seems unlikely that the presently prevailing supply pattern is going to change over the next decade.

JAPAN

Japan's Ammonia and Urea Plant Disposal Plan provides evidence of the definitely changing investment environment of the fertilizer industry in the East Asian and Pacific region. For many years this industry has been concerned about its aggravating dependence on external raw materials supplies. It is for this reason that since 1972 only two ammonia plants were constructed in Japan (one replacement plant and one relatively small expansion capacity).

The disposal schedule has been agreed upon among the major fertilizer producers. Substantive government support is being provided in order to alleviate the financial consequences of the capacity reduction program.

Under the plan the following definite capacity reductions were endorsed in 1978:

Ammonia plants (unit: metric tons of product per year)

Existing capacities	Definite shutdown	Remaining capacity
3.898.900	1.158.350 (19.7%)	2.240.550

In 1979 part of the program had already become effective:

Capacity, April 1979	Closures	Reduced capacity, July 1979
3.898.900	836.700	3.062.200

Non-fertilizer ammonia capacity is kept unchanged at the 1979 level, that is, 543.000 in tpy (reduced from 668.500 in tpy).

Urea manufacturing capacities will be reduced accordingly (metric tons of product per year):

Urea Plant Disposal Plan (1978)

Existing capacities	Definite shutdown	Remaining capacity
3.969.800	1.720.350 (43.3%)	2.249.800

Actual situation as of July 1979:

Existing capacities	Effective closures	Reduced capacity
3.969.800	1.352.100	2.617.700

Some of the capacities have already been idle since 1976 or 1977.

The reduction program of phosphate fertilizer capacities follows a similar pattern. While in 1976-1977 the total capacity of phosphoric acid production was 935.000 mtpy and 891.000 in tpy after the first phase of reduction, it is planned to reduce the capacity further to approximately 740.000 mtpy.

The curtailing of ammonia, urea, and phosphoric acid capacities is expected to improve considerably the utilization rate of the remaining capacities.

Million metric tons per year	Ammonia (incl. techn.)	Urea	Phos. acid
present capacity, mtpy	4.56	3.99	0.93
plant operation rate (%)	61.6	49.4	58.1
reduced capacity, mtpy	3.37	2.25	0.74
plant operation rate (%)	88.1	93.6	81.1

As concerns phosphoric acid production, the overcapacities will be gradually reduced to reach the agreed upon operationally and economically justifiable lower level by 1982-1983.

The Japanese nitrogen and phosphate fertilizer industry is considered "structurally depressed" under the relevant government act which advocates definite capacity adjustments in the form of plant scrapping, transfer of plants to developing countries, or permanent closures. The export potential of this industry will thus be extensively reduced and ultimately no capital investments are going to be considered in the near future. Possibly even through the end of the century, no new export-oriented capacities are likely to emerge.

CHINA

Nitrogen Fertilizer

The fertilizer industry of the China is developing at a fairly high rate. As is generally well known, since the early 1960s a large number of small- and medium-size plants have been constructed in China. The establishment of relatively small-scale plants based on indigenous technology is a continuing process. The need for spreading the location of manufacturing facilities all over this immense country is obvious because industry is developing faster than the transportation infrastructure for fertilizer raw materials and products. Some of the recently constructed large-scale plants are facing transportation bottlenecks and so it is understandable that for quite some time ahead investment policies favoring decentralization of production of bulky fertilizer materials will continue as a logical consequence in contrast but not contradictory to economies of scale.

The 13 large-scale ammonia-urea complexes which recently came on stream operate efficiently with a few temporary exceptions. After start up, some of the plants faced serious feedstock supply problems entailing supplementary investment.

In addition to these new most up-to-date capacities four more N-fertilizer complexes are being planned, but reportedly the execution of the projects has been postponed owing to financial constraints. Out of the four complexes, three ammonia plants of 1,000 tpd capacity each are designed to use heavy residue oil as feedstock, while one is supposed to be a coal-based plant. So far only the contracting of the ammonia plants has been made public. Downstream processing of ammonia from these plants may not be envisaged, since substitution of small-scale ammonia plants feeding the commune bicarbonate units may be considered a likely new trend. The establishment of ammonium nitrate plants is under consideration by the government.

In accordance with the internally well coordinated plant construction program which is evidently the result of a high degree of self-reliance in the manufacture of the necessary machines and equipment, the country is in a position to establish every year:

one middle-scale ammonia plant	30.000 mtpy
2 - 3 small-scale plants	7.500 mtpy each
4 - 5 small-scale plants	2.000 mtpy each

A number of "Chinese standard size" complexes were put on stream in recent years, but the typical capacities were different from the above quoted figures. Ammonia plants of 3.300 mtpy (N) capacity equivalent to ca. 4,000 mtpy product and plants of 162.400 mtpy (N) capacity equivalent to ca. 600 mtpd product were up to now the most frequently repeated plant sizes. The former plants work in combination with ammonium bicarbonate plants while the latter are combined with urea plants. The medium-size ammonia and urea complexes are composed of multistream plants.

Monitoring of plant capacity and production development of the Chinese fertilizer industry is a difficult task because of the lack of official data and the exceptional features of Chinese production patterns which make it difficult to assess the yearly output of the large number of seasonally operating ammonium bicarbonate plants. Through comparison of fertilizer consumption assessments and other factors such as estimated capacity utilization rates of the medium- and large-scale plants, fertilizer application rates, application of organic fertilizers, crop yields, and import of fertilizer, attempts have been made by many organizations to assess the actual production of the existing 540 primary ammonia and downstream ammonia processing plants in China.

The following information shows how difficult or even impossible it is to produce valid data which could be used for comparisons between estimates made by various authors. Lack of official statistics is, of course, the crucial obstacle and thus the results arrived at vary with the diversity of assumptions which necessarily have to be made.

Despite the inherent inaccuracies, the following data reflect the capacity development trend as forecast in 1976 in terms of "N fertilizer supplies" and the development of production based on indigenous technology (units: 1,000 mtpy N-fertilizer in terms of nitrogen).

N-fertilizer	1975-1976	1976-1977	1977-1978	1978-1979	1979-1980	1980-1981
Local supplies						
From existing and new indigenous facilities	3,561	3,750	3,849	3,948	4,047	4,146
Production increase over previous year	400	189	99	99	99	99
From 13 planned* large-scale plants	30	747	1,805	2,557	2,880	2,942
Production increase over previous year		717	1,058	752	323	62
Total supplies	3,591	4,497	5,654	6,505	6,927	7,088
Total production increase		506	1,157	851	422	161

* Phasing-in factors 75/80/9,090 for first, second, and third year of operation, respectively.

In 1978 the exercise was repeated by the same group of authors. The set of figures produced two years later are largely different because capacity instead of production data were analyzed. Table 8 shows to what extent the figures vary between the studies prepared by different authors.

Table 8

Development of nitrogen fertilizer and ammonia manufacturing capacities and production in China

Unit: 1000 mtpy N	Existing and forecast N-fertilizer capacities	Supply of N-fertilizers[1]	UNIDO/FAO/WB ammonia capacity data[2]	UNIDO/FAO/WB ammonia production assessment (tentative)[2]	UNIDO/FAO/WB N-fertilizer supply capability estimates (tentative) June 1979[2]	FAO statistics N-fertilizer production[6]
1	2	3	4	5	6	7
1972/73	4598	3239				
1973/74	4693	3835				
1974/75	5278	3816				3090
1975/76	5457	4323				3172
1976/77	6014	4655				3842
1977/78	6842	4973	8042	4930	4577	4600
1978/79	8212	5278	8744	5467	5075	
1979/80	8498	5566	9724	6028	5596	
1980/81	9202	5836	9954[5]	6411	5950	
1981/82	9364	6020	9954	6546[4]	6073	
1982/83	9527	6237	9954	6567	4 5	
1983/84	9689	6346	9954	6555		
1984/85	9852	6510	9954	6510		
1985/85	10014	6655	9954	6470		

Notes:
1. 1978, not published source
2. exclusive of Taiwan
3. total production of ammonica less technical use
4. no increase is expected unless more plants come on stream
5. further growth not estimated for methological reasons
6. Vol.2 April 1979, FAO Monthly Bulletin of Statistics

Moreover, when comparing the capacity increments it becomes evident how sensitive the estimates are to changes in the implementation of investment plans.

Increases over the previous year (1,000 mtpy N):

1976	1975/ 1976	1976/ 1977	1977/ 1978	1978/ 1979	1979/ 1980	1980/ 1981
N-fertilizer supply estimate	906	1,157	851	422	161	
1978						
N-fertilizer capacity (Table 8, col. 2)	557	828	1,370	286	704	
1979						
Ammonia capacity (Table 8, col. 4)	-	-	702	980	230	

The picture would be even more confused if data from other sources were added to the above list.

The foregoing brief review of N-fertilizer capacity estimates illustrates that presently in general all the capacity statistics and forecasts concerning China, which are to a large extent necessarily based on assumptions and anticipations made by numerous organizations, cannot be expected to accurately reflect the actual situation. Obviously, also the terminology used ought to be correctly understood. Frequently misinterpreted or confused terms are: Ammonia (nameplate) capacity, effective ammonia capacity, ammonia production, available ammonia supplies, fertilizer-N-supplies, N-fertilizer supply capability, N-fertilizer production.

Updating exercises and cross-evaluation of estimates show quite clearly the delays occurring during project implementation which consequently adversely affect the production increase rates over a certain period.

The confusion caused by early announcement of planned investment is relatively remarkable in the case of China since large capacities are involved. As an example, the aforementioned four additional plants may be mentioned. Although the plants were said to have been contracted a year ago, it is still not certain when these plants actually will be established. Six more large plants are under consideration by the government, but the precontracting discussions are still far from the point when the respective plant capacities can be listed as "firmly committed" projects.

Despite all the uncertainties and inaccuracies displayed above, there is no doubt that in consistency with past experience medium- and large-scale nitrogen fertilizer plants will continue to be built in China. This statement is based on two facts. As soon as possible the

government plans to attain a high degree of self-sufficiency in fertilizer supplies based on indigenous raw materials. This is an obvious consequence of the country's ever growing food needs. Second, and equally important, is the fact that a capable metallurgical and engineering industry already exists which is developing well on the basis of indigenous resources and ambitions. The local potential for supplying the machines and equipment needed to construct new fertilizer plants in a consistently centrally planned way is increasing because the government allocates the same priorities to the development of agro-related and supporting industries in various sectors of the national economy.

However, it seems unlikely that China will emerge as a major exporter of nitrogen fertilizer before the end of this century despite the growing potentialities in the field of raw materials availability, as well as in engineering, construction, and operating experience.

Phosphate Fertilizer

Accurate information on the development of capacities in the phosphate industry of China is practically outside the reach of international and commercial organizations trying to monitor the fertilizer supply-demand balances worldwide. Figures produced in publications are usually footnoted so that the attention of the reader is drawn to the vagueness of the source of the information. Consequently, there is no ground on which valid conclusions could be based. At this moment, the vague background of data collected and reviewed by UNIDO does not permit a more specific discussion going beyond assumptions and guesswork.

Recent announcements regarding the discovery of huge phosphate deposits in the Chinese desert regions may lead to speculations that before the end of the century the phosphate supply pattern of the East Asian region is likely to change to a large extent. When considering likely effects of the imminent technical and economic development of China over any conceivable time span ahead, superlatives cannot be avoided. Vast unexplored, untouched areas of geologically favorable structures exist in China. Investment in natural resource-based industries is being allocated high priority in all the centrally planned economies. Last but not least, once the mineral wealth is fully explored, the establishment of huge mining and processing capacities is naturally bound to follow. At present, however, despite these signs of probability, premature speculations on the export potential of future phosphate industries in China would only lead to unrealistic conclusions because the time factors governing the development in this field are not known.

FERTILIZER SUPPLY AND DEMAND-TRENDS AND CYCLES TO THE YEAR 2000--THE INDIAN CONTEXT

B. L. NARAYANA*

ABSTRACT

Fertilizer consumption has been growing very rapidly in India over the past three decades. Domestic industry is also growing fast, but not fast enough to catch up with the demand. The gap is met by imports. Since imports of both raw materials and finished products are still sizable, the world supply and demand trends and cycles also have an impact on India. In recent years, the government has been taking some measures to partially insulate domestic prices from the impact of international price trends. This paper deals with the Indian situation from the period 1951-1952 through the year 2000.

DEMAND TRENDS

Fertilizer consumption in India started in the 1920s when ammonium sulphate was used mainly in plantation crops. In the initial stages, the rate of consumption was very low. During the period 1951-1952, total fertilizer consumption in India was only 66,000 tons of nutrients. It gradually increased to 3.4 million tons by 1976-1977, to 4.3 million tons by 1977-1978, and to 5.11 million tons by 1978-1979. The increase was 77 times over a period of 27 years. These figures show that India has made spectacular achievements in the area of fertilizer consumption over the last three decades. Even then, in terms of per hectare consumption of nutrients, it remains at a very low level compared to several other countries.

From 1960-1961 onward and up to 1971-1972, fertilizer consumption in the country was doubling almost every five years. It also increased during the next two years (1972-1973 and 1973-1974), but the growth rate declined sharply (4.3 percent and 2.6 percent, respectively). From the point of view of fertilizer consumption, the year 1974-1975 was the worst time, since fertilizer consumption slumped by 9.4 percent compared to the previous year's level. This, however, was not typical of India alone, but was more or less a global phenomenon that followed the oil crisis and the consequent steep rise in fertilizer prices. In India, in addition to the increase in fertilizer prices, other factors such as aberrant weather, physical controls on fertilizer distribution, inadequate availability of credit, and irregular supplies also contributed to this sharp and unprecedented decline in fertilizer consumption. It caused a great deal of concern to all the agencies involved in the process of agricultural development. To check this declining trend and to give a boost to fertilizer consumption, several remedial measures were taken,

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including the withdrawal of physical controls, reduction of fertilizer prices, and arranging for adequate supplies of fertilizers. These measures yielded positive results and the year 1975-1976 witnessed an upturn with 12.5 percent increase in consumption over the 1974-1975 level. The subsequent three years (1976-1977, 1977-1978, and 1978-1979) showed an increase of 17.9 percent, 25.6 percent, and 19.3 percent, respectively.

Fertilizer consumption data for the last 27 years (from 1951-1952 to 1978-1979) are presented in Appendix I. The yearly variation percentages are shown in Appendix II. A graph showing the fertilizer consumption trend of all nutrients from 1951-1952 to 1978-1979 and projections up to the year 2000 is given in Appendix III.

Compound growth rates for different periods which correspond to the Indian Five-Year Plans are shown in Table 1.

TABLE 1-- GROWTH RATES IN NPK CONSUMPTION IN INDIA, 1951-1952 TO 1978-1979

PLAN PERIOD	COMPOUND GROWTH RATE (%)			
	NITROGEN	PHOSPHATE	POTASH	TOTAL
First Five-Year Plan (1951-1952 to 1955-1956)	16.3	11.1	45.1	18.6
Second Five-Year Plan (1956-1957 to 1960-1961)	14.0	40.0	21.0	19.0
Third Five-Year Plan (1961-1962 to 1965-1966)	22.3	13.5	22.5	20.5
Annual Plans (1966-1967 to 1968-1969)	28.0	42.5	30.2	31.7
Fourth Five-Year Plan (1969-1970 to 1973-1974)	8.3	4.3	14.7	8.1
Fifth Plan (1974-1975 to 1977-1978)	12.3	7.4	8.9	10.9
Sixth Plan (First Year) (1978-1979)	17.1	27.1	18.2	19.3
For the entire period (1951-1952 to 1978-1979)	16.2	20.7	22.2	17.5

The growth rate of fertilizer consumption remained between 19 to 21 percent during the First, Second, and Third Five-Year Plans. It increased to 32 percent during the three annual plans (1966-1967 to 1968-1969). The growth rate declined sharply to 8 percent during the Fourth Plan period. It increased to 11 percent during the Fifth Plan period and further to 19 percent in the first year of the Sixth Plan.

If we take long period trends (1951-1952 to 1978-1979), the cumulative growth rate (in percent) for nitrogen, phosphate, and potash was 16.2, 20.7, and 22.2, respectively. The growth rate of all three nutrients was 17.5 percent.

DEMAND ESTIMATES

Fertilizer consumption is affected by a large number of factors. As such, the estimation of fertilizer consumption for future years is a difficult task. From time to time, several agencies have come out with their estimates based on various methods, such as straight line fit, quadratic fit, population nutrition method, crop area, and recommended dose approach. Experience has shown that more often than not the estimates do not conform to actual consumption figures. This is mainly due to the fact that the assumption of "normal" conditions does not hold good because of abnormal weather conditions, physical controls, inadequate supply, unprecedented price hikes, and adverse input-output ratios. Even so, efforts to obtain reasonably good predictions are made by several organizations such as the Planning Commission, Ministry of Agriculture and Irrigation, Ministry of Petroleum and Chemicals, the Fertilizer Association of India (FAI), the National Commission on Agriculture, and IFFCO. These estimates are for different periods of time. They are presented in Appendix IV.

After taking into account the high and low estimates made by different agencies, the most likely ones are presented in Table 2.

TABLE 2-- PROJECTED NPK CONSUMPTION AND GROWTH RATES, 1978 TO 2000

	CONSUMPTION MILL. TONS				COMPOUND GROWTH (%)			
	N	P_2O_5	K_2O	TOTAL	N	P_2O_5	K_2O	TOTAL
1978-1979	3.4	1.1	0.6	5.1	-	-	-	-
1982-1983	5.2	1.5	1.0	7.7	11.3	8.1	13.6	10.9
1987-1988	8.0	2.2	1.4	11.6	9.0	7.9	6.9	8.6
2000	13.5	4.0	2.0	19.5	4.0	4.7	2.8	4.0

SUPPLY TRENDS

Nitrogen

The fertilizer industry in India is of comparatively recent origin. Although the year 1906 marked the beginning of the production of synthetic fertilizers with the installation of the first superphosphate plant at Ranipet (Tamil Nadu), very little progress was made in setting up fertilizer capacities during the first half of this century.

Indigenous production of fertilizers received an impetus in the early fifties when the era of planned development started in the country with the launching of Five-Year Plans. The capacity of N built up from 1951-1952 to 1978-1979 and the production levels achieved during the same period are shown in Table 3.

TABLE 3-- N PRODUCTION CAPACITIES AND ACTUAL PRODUCTION, 1951-1952 TO 1978-1979

PLAN PERIOD	CAPACITY ('000 TONS)	PRODUCTION	
		'000 TONS	COMPOUND GROWTH (%)
1951-1952 (Beginning of First Five-Year Plan)	88.7	28.9	
1955-1956 (Last year of First Plan)	88.7	76.9	27.7
1960-1961 (last year of Second Plan)	162.2	112.0	7.7
1965-1966 (Last year of Third Plan)	324.0	237.9	16.2
1968-1969 (End of Third Annual Plan)	904.5	531.3	30.7
1973-1974 (Last year of Fourth Plan)	1,933.5	1,049.9	14.7
1977-1978 (Fourth year of Fifth Plan)	3,189.0	2,000.0	17.5
1978-1979 (First year of Sixth Plan)	3,264.0	2,169.0	8.4
For the entire period (1951-1952 to 1978-1979)	-	-	17.3

It can be seen that the growth rate in domestic production of nitrogen was uneven during different plan periods, the best being the annual plan period from 1966-1967 to 1968-1969. The overall compound growth for the 27 years of planned development was 17.3 percent.

Phosphates

Until the end of 1960 the entire supply of phosphatic fertilizers in the country was only through single superphosphate. It was during 1961-1971 that the production started of complex fertilizers such as ammonium phosphate sulphate, nitro-phosphate, di-ammonium phosphate, urea ammonium phosphate, and NPK of different grades.

The capacity of P_2O_5 built up from 1951-1952 to 1978-1979 and the production levels achieved during the same period are given in Table 4.

TABLE 4-- P_2O_5 PRODUCTION CAPACITIES AND ACTUAL PRODUCTION, 1951-1952 TO 1978-1979

PLAN PERIOD	CAPACITY ('000 TONS)	PRODUCTION	
		'000 TONS	ANNUAL GROWTH RATE (%)
1951-1952 (Beginning of First Five-Year Plan)	27.7	9.8	C.g.r.
1955-1956 (Last year of First Plan)	43.2	12.4	6.0
1960-1961 (Last year of Second Plan)	95.6	53.7	34.1
1965-1966 (Last year of Third Plan)	187.5	118.8	17.1
1968-1969 (End of Third Annual Plan)	431.2	213.2	21.5
1973-1974 (Last year of Fourth Plan)	534.2	324.5	8.6
1977-1978 (Fourth year of Fifth Plan)	1,026.0	671.0	19.9
1978-1979 (First year of Sixth Plan)	1,103.0	776.0	15.6
For the entire period (1951-1952 to 1978-1979)	-	-	17.6

It can be seen that the growth rates of domestic phosphate production were also uneven. The growth rates in the First and Fourth Plan periods were low and the growth rates for the nine-year period from 1960-1961 to 1968-1969 covering the Second and Third Five-Year Plans and the three Annual Plans period were good. The overall compound growth rate for the entire 27-year period from 1951-1952 to 1978-1979 was 17.6 percent, almost equal to that of nitrogen.

Imports

Even though the domestic fertilizer industry is growing quite rapidly, fertilizer consumption is, in fact, growing faster, always leaving a gap to be bridged through imports. Since there are no known sources of potash, the entire requirement is met through imports. The extent of imports of nitrogen and phosphate varies from year to year. A statement showing the importation of N, P_2O_5, and K_2O from the year 1951-1952 to 1978-1979 is shown in Appendix V. The proportion of domestic consumption of nitrogen and phosphate met through imports is shown in Appendix VI and VII.

The supply gaps in nitrogen met through imports varied from period to period. During the period from 1960-1961 to 1963-1964, the gaps were of the order of 40 to 45 percent. From 1964-1965 to 1968-1969 the gaps increased to a range of 55 to 60 percent. During the period 1969-1970 to 1973-1974 the gaps decreased to around 45 percent. During the last five years from 1974-1975 to 1978-1979, the supply gaps met through imports further decreased from 24 to 36 percent.

In the case of phosphates, since the demand was low up to the year 1961-1962 domestic production was adequate to meet it.

Regular imports started from the year 1962-1963 onward. For the first three years (1963-1964 to 1965-1966), the imports were very meager and formed only 7 to 12 percent of the total demand. From 1966-1967 onward, for the eight years up to 1973-1974, imports ranged from 41 percent to 57 percent. During the last five years from 1974-1975 to 1978-1979, the phosphate supply gap met through imports fell from 22 to 29 percent.

Production Estimates up to 2000

Only nitrogenous and phosphatic fertilizers are domestically produced. The entire requirement of potassic fertilizers is met through imports. Production estimates of both N and P_2O_5 made by different agencies are presented in Appendix VIII. All of these agencies have made systematic estimates only up to the period 1987-1988. The estimates beyond that time are on the basis of assumed growth rates. Based on the high and low estimates, the most likely ones are presented in Table 5.

Supply Gap

The anticipated gaps in supply for different periods are indicated in Table 6.

TABLE 5-- PROJECTED N AND P_2O_5 PRODUCTION ESTIMATES UP TO THE YEAR 2000

	PRODUCTION (Million tons)		GROWTH RATE %	
	N	P_2O_5	N	P_2O_5
1978-1979	2.17	0.78	-	-
1982-1983	4.26	1.11	18.5	9.3
1987-1988	6.00	1.68	7.1	8.6
2000	12.80	2.98	6.0	4.5

(In the absence of any domestic production, estimates for K_2O are not indicated.)

TABLE 6-- ANTICIPATED SHORTFALL BETWEEN PROJECTED NPK DEMAND AND INDIGENOUS PRODUCTION

(Million tons)

	NITROGEN (N)			PHOSPHATE (P_2O_5)			POTASH	TOTAL
Year	Consumption	Prodn.	Gap	Consumption	Prodn.	Gap	(Gap)	(Gap)
1978-1979	3.4	2.17	1.23	1.1	0.78	0.32	0.6	2.15
1982-1983	5.2	4.26	0.94	1.5	1.11	0.39	1.0	2.33
1987-1988	8.0	6.00	2.00	2.2	1.68	0.52	1.4	3.92
2000	13.5	12.80	0.70	4.0	2.98	1.02	2.0	3.72

Two graphs showing consumption, domestic production, and gap in respect to N and P_2O_5 are shown in Appendix IX and Appendix X.

FERTILIZER PRICES

In India the prices of nitrogenous fertilizer have always been controlled by the government. Until March 16, 1976 the prices of phosphatic fertilizers were not subject to government control. Since March 16, 1976 they have been brought under informal price control. Since February 2, 1979 the prices of complex fertilizers and TSP have been under formal price control. The prices of single superphosphate have been under informal control since 1966. The Fertilizer Association of India (FAI) fixes their prices from time to time in accordance with Tariff Commission formula.

Despite a substantial increase in domestic fertilizer production, imports constitute a sizable portion of the total supply. To a large extent the nitrogenous fertilizer industry in India is based on indigenous feed stock. In respect to phosphates, even the indigenous production is based on imported rock and sulphur or imported phosphoric acid. As previously mentioned, all potash is imported.

In view of the substantial dependence on imported fertilizers or fertilizer raw materials, domestic prices in India are exposed to the price fluctuations of world markets. However, to a small extent the Central Fertilizer Pool operated by the Government of India tries to insulate domestic prices from severe international fluctuations.

For example, when the domestic cost of production of urea was lower in June 1974, the government of India levied a Fertilizer Pool Equalization Charge (FPEC) of Rs.610/-* per ton on domestic production and subsidized the imported fertilizer with the fund so created. During subsequent years when international prices started falling, this FPEC was also reduced gradually and the domestic price of urea was brought down.

Similarly, when the prices of phosphatic fertilizers and raw materials were very high in the international markets, the government of India reduced the import duty on phosphoric acid from 30 percent to 15 percent and brought down the domestic cost of production. To bring about a further reduction in the price of phosphatic fertilizers, the government introduced a subsidy of Rs.1250/- per ton of P_2O_5 for all domestic manufacturers in March 1976.

A statement showing the variations in domestic fertilizer prices of urea and DAP, the main nitrogenous and phosphatic fertilizers in the country, is given in Appendix XI and a graph showing the price trends is in Appendix XII.

It may be noticed that the domestic price of urea which was Rs.680 per ton in February 1966 increased to Rs.840/- in April 1967, an increase of 23.5 percent which was mainly due to devaluation of Indian currency.

During the subsequent seven years from April 1967 to June 1974, the price of urea gradually increased from Rs.840/- to Rs.1050/-, an increase of 25.0 percent over the entire seven-year period.

However, in June 1974 the price of urea shot up from Rs.1050/- per ton to Rs.2000/-, an increase of 90.5 percent. It remained high for one year. Again from 1975 onward there was a systematic reduction each year by about Rs.100/-. Over a period of five years (1974 to 1979) the price of urea was brought down from its peak level of Rs.2000/- to the current level of Rs.1450/-, marking a reduction of 27.5 percent over the five-year period. This reduction is partly due to the reduction in international prices and partly due to the initiative of the government in reducing pool equalization charges and excise levies.

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* $1= Rs.8.00 (approximately).

Similarly, the price of DAP which was Rs.833/- per ton in April 1966 increased to Rs.1095/- per ton in April 1967, marking an increase of 31.3 percent due to devaluation. The rise in domestic price of DAP was very moderate during the period from March 1969 to June 1974. During this five-year period the price has gone up from Rs.1217/- per ton to Rs.1335/- per ton, marking an increase of only 9.7 percent.

In June 1974 the price jumped from Rs.1335/- to Rs.3005/-, an increase of 224.7 percent. This high price lasted one year. In July 1975 the domestic price was reduced from Rs.3005/- to Rs.2805/- due to a moderate fall in the international price. In December 1975 it was further brought down to Rs.2600/- per ton by reduction of import duty on phosphoric acid.

During the years 1974-1975 and 1975-1976 phosphate consumption dropped due to high prices. To remedy the situation the government introduced a subsidy of Rs.1250/- per ton of P_2O_5, which brought down the price of DAP to Rs.2210/- per ton. During March 1979 the price was further adjusted downward to Rs.2200/- per ton. Thus during the five-year period from June 1974 to March 1979 the price of DAP was brought down from its peak of Rs.3005/- to Rs.2200/- per ton, marking a reduction of 26.8 percent.

Outlook

Nitrogen in air is a renewable resource even though production of nitrogenous fertilizer requires a lot of energy. Depending upon the various energy sources such as naphtha, natural gas, coal, lignite, or electricity available, each country can develop its nitrogenous fertilizer industry. Fortunately for India the recent discovery of large reserves of oil and natural gas in the sea off Bombay has given new hope for rapid development of nitrogenous capacity in the country. The gas available from Bombay high and Bassein offshore structures is estimated to be around 14 million cubic meters. It can support at least six large-sized ammonia/urea units, each capable of producing about 700,000 tons of urea, that is, a total of 4,200,000 tons of additional urea. The work on four such units has already begun and these are expected to be in production by 1985. With the commissioning of these units, the dependence on imports will be curtailed.

Some deposits of phosphate rock have been discovered in the country and efforts are being made to step up mining. Even after developing these mines, the indigenous availability of rock will be very meager compared to the large requirements. Total reserves of phosphate/lapatite of all categories and grades is estimated at 100 million tons. Only one-sixth of them are concentrated enough as feed material for phosphoric acid or superphosphate. Therefore, dependence on other countries either for phosphate rock or phosphoric acid, or complex fertilizers will continue.

Since there are no known substitutes for phosphate rock and the known world resources are limited, the export surpluses may not keep pace with the requirements of P_2O_5 for agriculture by the end of this century. Since phosphate rock is a nonrenewable resource, some countries

may start conserving their resources by reducing the rate of mining and export. Therefore, India may experience a shortage of P_2O_5 and may have to pay high prices by the end of this century.

Since there are no known resources of potash in the country, all requirements must be met through imports. However, Indian soils are still high or medium in their potash status and thus the potash requirement may not pose a serious problem even by the end of this century.

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Appendix I

CONSUMPTION OF FERTILIZER IN TERMS OF NUTRIENTS IN INDIA
(1951-52 TO 1978-79)

Unit: 1,000 tons

Year	N	P	K	Total
1951-52*	58.7	6.9	-	65.6
1952-53	57.8	4.6	3.3	65.7
1953-54	89.3	8.3	7.5	105.1
1954-55	94.8	15.0	11.1	120.9
1955-56	107.5	13.0	10.3	130.8
1956-57	123.1	15.9	14.8	153.8
1957-58	149.0	21.9	12.8	183.7
1958-59	172.0	29.5	22.4	223.9
1959-60	229.3	53.9	21.3	304.5
1960-61**	210.0	70.0	28.0	308.0
1961-62	250.0	61.0	23.0	334.0
1962-63	333.0	83.0	36.0	452.0
1963-64	377.0	116.0	51.0	544.0
1964-65	555.0	149.0	69.0	773.0
1965-66	575.0	132.0	77.0	784.0
1966-67	738.0	249.0	114.0	1101.0
1967-68	1035.0	335.0	170.0	1540.0
1968-69	1208.0	382.0	170.0	1760.0
1969-70	1356.0	416.0	210.0	1982.0
1970-71	1479.0	541.0	236.0	2256.0
1971-72	1798.0	558.0	300.0	2256.0
1972-73	1840.0	581.0	348.0	2769.0
1973-74	1829.0	650.0	360.0	2839.0
1974-75***	1765.7	471.5	336.1	2573.3
1975-76	2148.1	466.8	278.3	2893.1
1976-77	2457.1	635.3	318.6	3411.0
1977-78	2913.0	866.6	506.2	4285.8
1978-79	3412.0	1101.7	598.4	5112.1

NOTE: Figures from 1951-52 to 1959-60, distribution figures are treated as consumption.

Source: * Fertiliser Statistics: 1976-77 (p.1-182 & 103).
** Indian Agriculture in brief: 15th Edition (p.207 & 214).
*** Fertiliser News: July 1979.

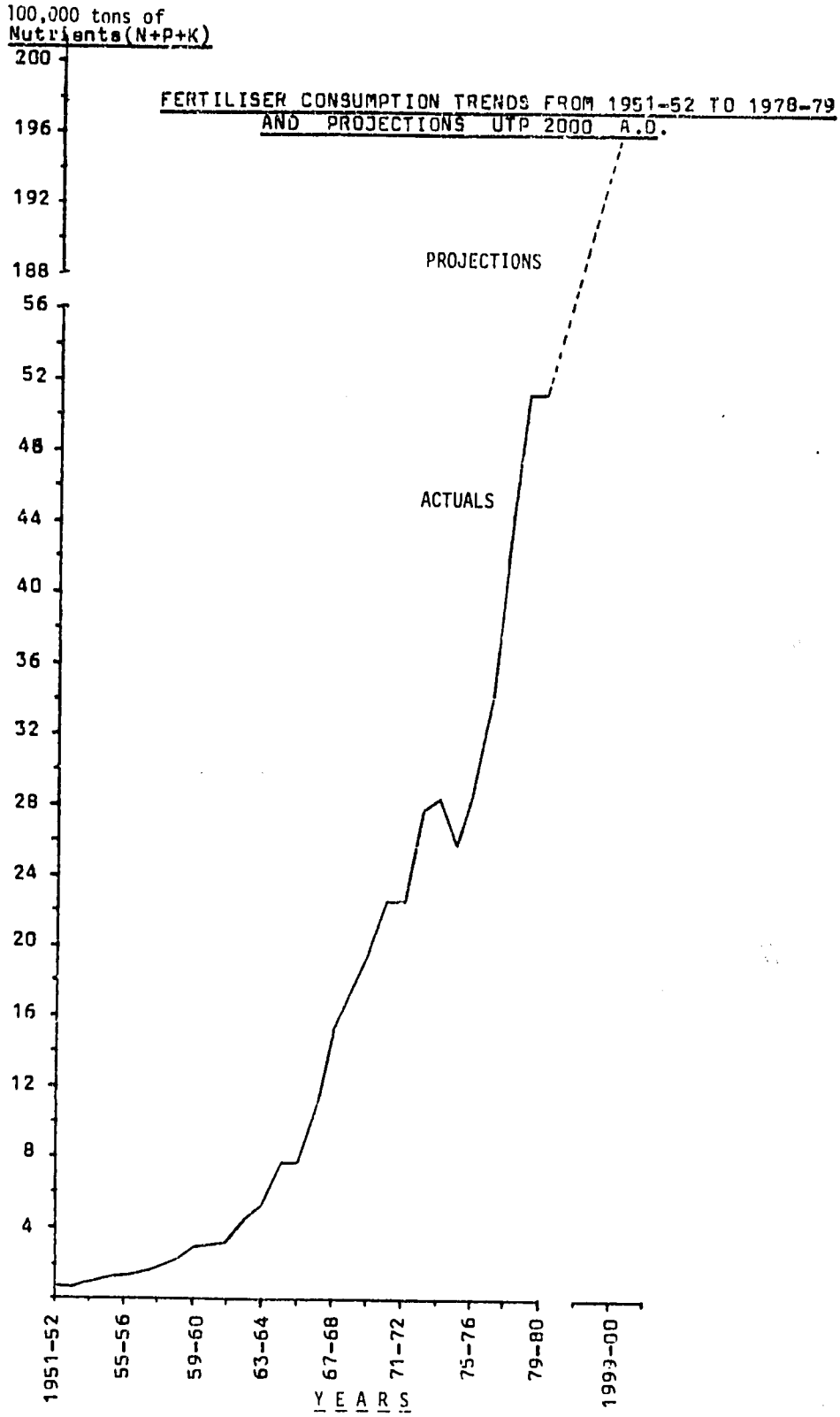
Appendix II

VARIATION IN CONSUMPTION OF FERTILIZERS IN TERMS OF (N, P_2O_5 AND K_2O IN INDIA (1951-52 TO 1978-79)

Unit of Quantity: 1,000 tons

Year	VARIATION OVER PREVIOUS YEAR							
	N		P_2O_5		K_2O		TOTAL	
	Qty.	Per-centage	Qty.	Per-centage	Qty.	Per-centage	Qty.	Per-centage
1951-52	-	-	-	-	-	-	-	-
1952-53	-0.9	-1.5	-2.3	-33.3	3.3	100.0	0.1	0.2
1953-54	31.5	54.5	3.7	80.4	4.2	127.3	39.4	60.0
1954-55	5.5	6.2	6.7	80.7	3.6	48.0	15.8	15.0
1955-56	12.7	13.4	-2.0	-13.3	-0.8	-7.2	9.9	8.2
1956-57	15.6	14.5	2.9	22.3	4.5	43.7	23.0	17.6
1957-58	25.9	21.0	6.0	37.7	-2.0	-13.5	29.9	19.4
1958-59	23.0	15.4	7.6	34.7	9.6	75.0	40.2	21.9
1959-60	57.3	33.3	24.4	82.7	-1.1	-4.9	80.6	36.0
1960-61	-19.3	-8.4	16.1	29.9	6.7	31.5	3.5	1.1
1961-62	40.0	19.0	-9.0	-12.9	-5.0	-17.9	26.0	8.4
1962-63	83.0	33.2	22.0	36.1	13.0	56.5	118.0	35.3
1963-64	44.0	13.2	33.0	39.8	15.0	41.7	92.0	20.4
1964-65	178.0	47.2	33.0	28.4	18.8	35.3	229.0	42.1
1965-66	20.0	3.6	-17.0	-11.4	8.0	11.6	11.0	1.4
1966-67	163.0	28.3	117.0	88.6	37.0	48.0	317.0	40.4
1967-68	297.0	40.2	86.0	34.5	56.0	49.1	439.0	39.9
1968-69	173.0	16.7	47.0	14.0	NIL	NIL	220.0	14.3
1969-70	148.0	12.3	34.0	8.9	40.0	23.5	222.0	12.6
1970-71	123.0	9.0	125.0	30.0	26.0	12.4	274.0	13.8
1971-72	319.0	21.6	17.0	3.1	64.0	27.1	400.0	17.7
1972-73	42.0	2.3	23.0	4.1	48.0	16.0	113.0	4.3
1973-74	-11.0	-0.6	69.0	11.9	12.0	3.4	70.0	2.5
1974-75	-63.3	-3.5	-178.5	-27.5	-23.9	-6.6	-265.7	-9.4
1975-76	382.9	21.7	-4.7	-1.0	-57.8	-17.2	321.1	12.5
1976-77	308.5	14.4	168.5	36.1	40.3	14.5	517.3	17.9
1977-78	455.9	18.6	231.3	36.4	187.6	58.9	874.8	25.6
1978-79	499.0	17.1	235.1	27.1	92.2	18.2	826.3	19.3

Source: Worked out by Marketing Services Department, IFFCO


100,000 tons of
Nutrients(N+P+K)
FERTILISER CONSUMPTION TRENDS FROM 1951-52 TO 1978-79
AND PROJECTIONS UTP 2000 A.D.
PROJECTIONS
ACTUALS
200
196
192
188
56
52
48
44
40
36
32
28
24
20
16
12
8
4
1951-52
55-56
59-60
63-64
67-68
71-72
75-76
79-80
1999-00
YEARS

DEMAND ESTIMATES FOR N, P_2O_5 & K_2O BY DIFFERENT AGENCIES

Unit: 1,000 tons

Agency	Nutrient	1979-80	1980-81	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88
1. Planning Commission	N				5.3					7.0
	P_2O_5				1.6					2.5
	K_2O				1.1					N.A.
	TOTAL				8.0					9.5
2. Ministry of Agri. and Irrigation	N	3.9	4.3	4.7	5.2					7.5
	P_2O_5	1.1	1.3	1.5	1.7					2.5
	K_2O	0.6	0.7	0.8	0.9					1.6
	TOTAL	5.6	6.3	7.0	7.8					11.6
3. Ministry of Petroleum & Chemicals	N	3.7	4.2	4.7	5.3	5.6	5.9	6.2	6.6	7.0
	P_2O_5	1.1	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.5
	TOTAL	4.8	5.4	6.1	6.	7.3	7.8	8.3	8.9	9.5
4. Fertilizer Association of India (FAI)	N	3.8	4.2	4.8	5.3	5.9	6.5	7.1	7.8	8.5
	P_2O_5	1.0	1.2	1.3	1.4	1.6	1.7	1.8	2.0	2.1
	K_2O	0.6	0.7	0.7	0.9	0.9	1.0	1.1	1.2	1.3
	TOTAL	5.4	6.1	6.8	7.6	8.4	9.2	10.0	11.0	11.9
5. National Commission of Agriculture	N		3.4				3.6			
	P_2O_5		1.3				1.3			
	K_2O		1.0				1.1			
	TOTAL		5.7				6.0(8.8)			
6. IFFCO	N	3.7	4.2	4.6	5.2	5.7	6.3	6.9	7.5	8.1
	P_2O_5	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
	K_2O	0.6	0.7	0.8	0.9	1.0	1.2	1.2	1.3	1.5
	TOTAL	5.5	6.2	6.8	7.6	8.3	9.2	9.9	10.7	11.6

( ) :- High estimate of fertilizer consumption in 1984-85 by National Commission on Agriculture

Source: 1. Fertiliser Statistics (FAI), 1977-78 (p.p.-I-191).

2. Report of the "Sub Working Group on Fertiliser" for the period (1978-83), 1978, Government of India, Ministry of Agriculture, New Delhi (Annexure-IV).

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4. Fertiliser News (FAI), Dec. 1978 (p.p. 63).

5. Report of National Commission Agriculture (Part-X), 1976 (p.p. 73).

Appendix V

IMPORTS OF N, P_2O5 & K_2O FERTILIZERS

1951-52 to 1978-79 (April-March)

Unit: 1,000 tons

Year	N	P_2O_5	K_2O	TOTAL (N+P+K)
1951-52	28.8	15.5	7.7	52.0
1952-53	44.0	-	3.0	47.0
1953-54	19.0	-	7.0	26.0
1954-55	20.0	-	11.0	31.0
1955-56	53.0	-	10.0	63.0
1956-57	57.0	-	15.0	72.0
1957-58	110.0	-	13.0	123.0
1958-59	97.0	-	22.0	119.0
1959-60	142.0	4.0	33.0	179.0
1960-61	399.0	-	20.0	419.0
1961-62	307.0	-	75.0	382.0
1962-63	244.0	10.0	41.0	295.0
1963-64	228.0	13.0	40.0	281.0
1964-65	232.0	12.0	57.0	301.0
1965-66	326.0	14.0	73.0	413.0
1966-67	632.0	148.0	118.0	898.0
1967-68	867.0	349.0	270.0	1486.0
1968-69	844.0	138.0	213.0	1195.0
1969-70	667.0	94.0	120.0	881.0
1970-71	477.0	32.0	120.0	629.0
1971-72	481.0	248.0	268.0	997.0
1972-73	665.0	204.0	325.0	1194.0
1973-74	659.0	213.0	370.0	1242.0
1974-75	884.0	286.0	437.0	1607.0
1975-76	996.0	361.0	278.0	1635.0
1976-77	750.1	22.8	277.8	1050.7
1977-78	758.1	163.9	598.9	1520.9
1978-79	1233.0	243.0	517.0	1993.0

Source: 1) Fertiliser Statistics (FAI), 1977-78 (p.p.-I-178 and 179).

2) Fertiliser Marketing News, May, 1979 (p.p. 18).

Appendix VI

PRODUCTION AND CONSUMPTION OF NITROGENOUS FERTILIZERS IN INDIA DURING THE FIVE YEAR PLANS (1951-52 TO 1978-79)

Unit: 1,000 tons

Year	Plan	Consumption	Production	Gap (Deficit/ Surplus)	Gap as % of consumption
1951-52	First Plan	58.7	28.9	-29.8	-50.8
1952-53		57.8	53.1	- 4.7	- 8.1
1953-54		89.3	52.9	-36.7	-40.8
1954-55		94.8	68.5	-26.3	-27.7
1955-56		107.5	76.9	-30.6	-28.5
1956-57	Second Plan	123.1	78.8	-44.3	-36.0
1957-58		149.0	81.1	-67.9	-45.6
1958-59		172.0	80.8	-91.2	-53.0
1959-60		229.3	83.7	-145.6	-63.5
1960-61		210.0	112.0	-98.0	46.7
1961-62	Third Plan	250.0	154.3	-95.7	-38.3
1962-63		333.0	194.2	-138.8	-41.7
1963-64		377.0	219.1	-157.9	-41.9
1964-65		555.0	243.2	-311.8	-56.2
1965-66		575.0	237.9	-337.1	-58.6
1966-67	Annual Plans	738.0	309.0	-429.0	-58.1
1967-68		1,035.0	402.6	-632.4	-61.1
1968-69		1,208.0	531.3	-676.7	-56.0
1969-70	Fourth Plan	1,356.0	730.6	-625.4	-46.1
1970-71		1,479.0	832.5	-646.5	-43.7
1971-72		1,798.0	949.2	-848.8	-47.2
1972-73		1,840.0	1,054.5	-785.5	-42.7
1973-74		1,829.0	1,049.9	-779.1	-42.6
1974-75	Fifth Plan	1,765.7	1,186.6	-615.4	-34.2
1975-76		2,148.6	1,508.0	-640.6	-29.8
1976-77		2,457.1	1,862.0	-595.1	-24.2
1977-78		2,913.0	2,000.0	-913.0	-31.3
1978-79	Sixth Plan	3,412.0	2,169.0	-1,243.0	-36.4

Source: 1) Fertiliser Statistics (FAI), 1977 (p.p.-I-178 and 179)

2) Fertiliser News, July, 1979 (p.p. 3 of Annual Review of Fertiliser Consumption and Production 1978-79).

Appendix VII

PRODUCTIONS & CONSUMPTION OF PHOSPHATIC FERTILIZERS IN INDIA DURING FIVE YEAR PLANS (1951-52 to 1978-79)

Unit: 1,000 tons

Year	Plan	Consumption	Production	Gap (Deficit/ Surplus)	Gap as % of consumption
1951-52	First Plan	6.9	9.8	2.9	42.0
1952-53		4.6	7.4	2.8	60.9
1953-54		8.3	13.8	5.5	66.3
1954-55		15.0	14.3	-0.7	-4.7
1955-56		13.0	12.4	-0.6	-4.6
1956-57	Second Plan	15.9	17.6	1.7	10.7
1957-58		21.9	25.8	3.9	17.8
1958-59		29.5	31.0	1.5	5.8
1959-60		53.9	51.4	-2.5	-4.6
1960-61		70.0	53.7	-16.3	-23.3
1961-62	Third Plan	61.0	65.4	4.4	7.2
1962-63		83.0	88.3	5.3	6.4
1963-64		116.0	107.8	-8.2	-7.1
1964-65		149.0	131.0	-18.0	-12.1
1965-66		132.0	118.8	-13.2	-10.0
1966-67	Annual	249.0	145.7	-103.3	-41.5
1967-68		335.0	207.1	-127.9	-38.2
1968-69		382.0	213.2	-168.8	-44.2
1969-70	Fourth Plan	416.0	223.7	-192.3	-46.2
1970-71		541.0	228.1	-312.9	-57.8
1971-72		558.0	290.3	-267.7	-48.0
1972-73		581.0	330.3	-250.7	-43.1
1973-74		650.0	324.5	-325.5	-50.1
1974-75	Fifth Plan	471.5	331.2	-140.3	-29.8
1975-76		466.8	319.7	-147.1	-31.5
1976-77		635.3	478.3	-157.0	-24.7
1977-78		866.6	671.0	-195.6	-22.6
1978-79	Sixth Plan	1,101.7	776.0	-325.7	-29.6

Source: 1) Fertiliser Statistics (FAI), 1977 (p.p.-I-178 and 179)

2) Fertiliser News, July, 1979 (p.p. 3 of Annual Review of Fertiliser Consumption and Production 1978-79).

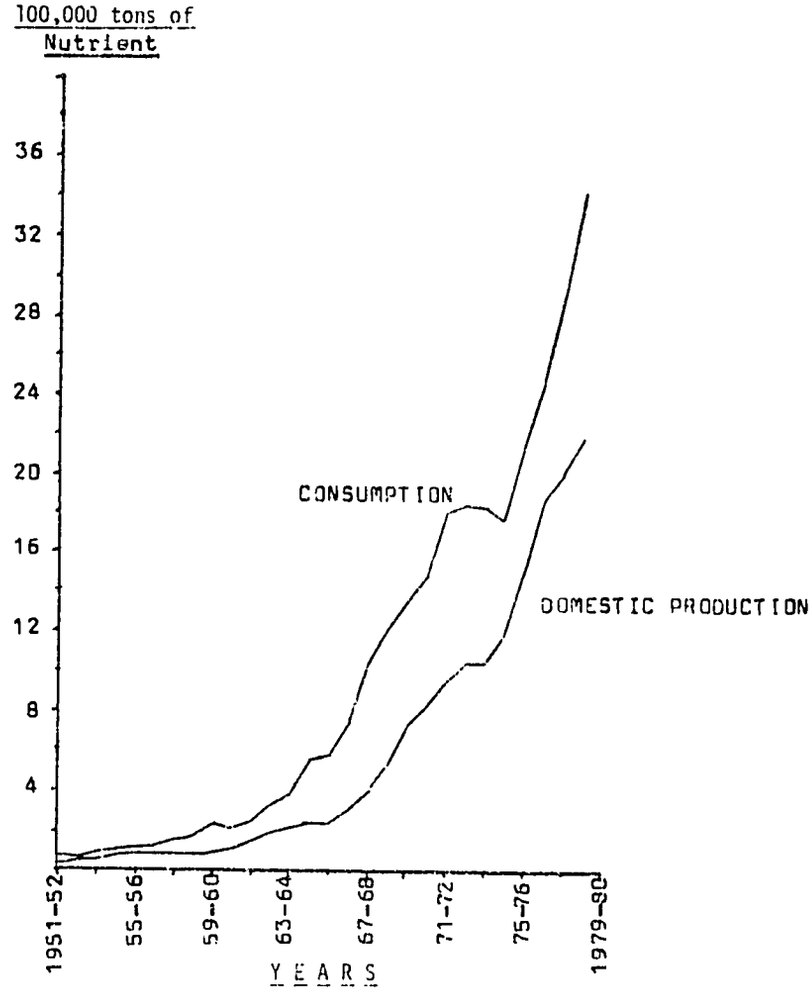
ESTIMATES OF CAPACITY AND PRODUCTION OF N, P_2O_5 BY DIFFERENT AGENCIES

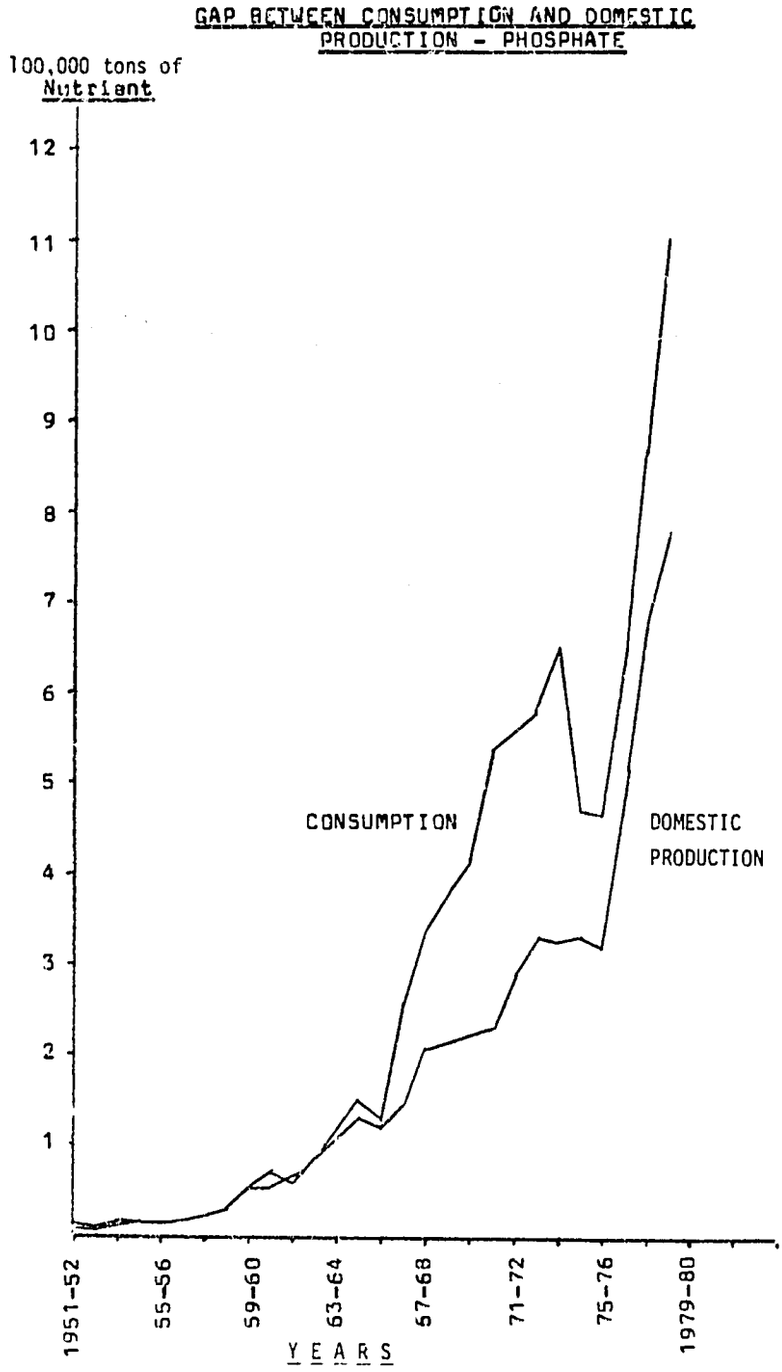
Unit: 1,000 tons

Agency/Nutrient		1979-80		1982-83		1987-88	
		Capacity	Production	Capacity	Production	Capacity	Production
1. Planning Commission	N			6111	4100		6370
	P_2O_5			1426	1125		2250
2. Ministry of Petroleum Chemicals & Fertilizers	N	4690	2840	6369	4370	7422	5640
	P_2O_5	1301	875	1631	1205	2686	2000
3. Fertiliser Association of India	N	4782	2980	6623	4427	7500	5983
	P_2O_5	1451	835	1533	1014	1608	1059
4. IFFCO	N	4699	3126	6618	4408	7226	6275
	P_2O_5	1334	886	1467	1120	1467	1120

Source:
1. Fertiliser Statistics (FAI), 1977-78 (p.p.-I,191)
2. Report of the "Sub Working Group on Fertilisers" for the period (1978-83), 1978, Government of India, Ministry of Petroleum, Chemicals and Fertilisers, New Delhi.
3. Fertiliser News, (FAI), Dec. 1978 (p.p.71).

GAP BETWEEN CONSUMPTION AND DOMESTIC PRODUCTION - NITROGEN




GAP BETWEEN CONSUMPTION AND DOMESTIC PRODUCTION - PHOSPHATE
100,000 tons of Nutrient
12
11
10
9
8
7
6
5
4
3
2
1
CONSUMPTION
DOMESTIC PRODUCTION
1951-52
55-56
59-60
63-64
67-68
71-72
75-76
1979-80
YEARS

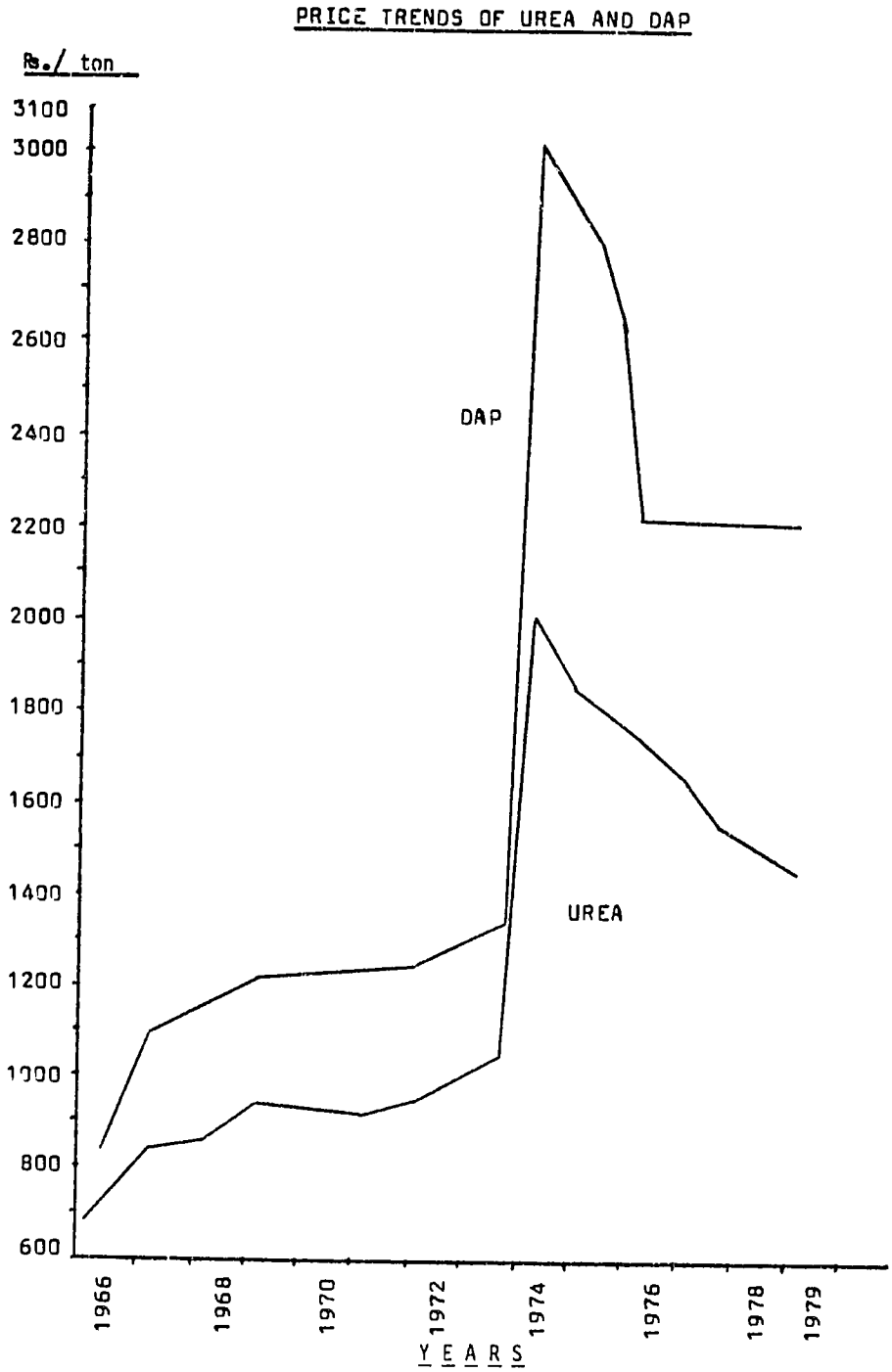
Appendix XI

CHRONOLOGICAL HISTORY OF FERTILIZER PRICE CHANGES

Fertilizer	Price (Rs./ton)	Effective from	Reason for price Revision
Urea	680	1st Feb. 1966	
	840	1st April 1967	Devaluation of Indian currency w.e.f. 6.6.1966.
	860	1st April 1968	Increase in the price of raw materials like Naphtha and Fuel Oil.
	943	17th April 1969	Imposition of 10% excise/ countervailing duty on fertilizers.
	923	9th March 1971	Reduction in indigenous production cost and consequential reduction by Government of India.
	959	17th March 1972	Increase in excise/countervailing duty from 10 to 15%.
	1050	10th Oct. 1973	Due to steep rise in the price of Naphtha twice resulting in the increase cost of indigenous production.
	2000	1st June 1974	Rise in the import cost as well as indigenous production cost of fertilizers. A sum of Rs.610/per ton was imposed by Govt. of India as Pool Equalization charges.
	1850	18th July 1975	Moderate fall in the import prices. Pool Equalization charges reduced to Rs.335/- per ton.
	1750	16th March 1976	Pool Equalization charges further reduced to Rs.165/- per ton.
	1650	8th Feb. 1977	Pool Equalization charges further reduced to Rs.65/- per ton.

Fertilizer	Price (Rs./ton)	Effective from	Reasons for Price Revision
	1550	12th Oct. 1977	Government accepted Fertilizer Prices Committee report and fixed consumer price at new level.
	1450	10th March 1979	Reduction in excise duty from 15 to 7.5 per cent advalorem.
DAP	833	April 1966	
	1095	1st April 1967	Devaluation of India Currency
	1217	1st March 1969	Incidence of 10% excise duty on fertilizers.
	1246	17th March 1972	Increase of excise duty from 10 to 15%.
	1335	11th Oct. 1973	To cover the increased cost of indigenous production.
	3005	1st June 1974	Rise in the import price as well as indigenous cost of production because of global oil crisis.
	2805	18th July 1975	Moderate fall in the import price.
	2600	1st Dec. 1975	Reduction in Import Duty on phosphoric acid from 30 to 15 per cent.
	2210	20th April 1976	Government of India announced subsidy of Rs.1250/- per ton on indigenous P_2O_5 w.e.f. 16.3.76 but DAP price was lowered w.e.f. 20th April 1976.
	2000	10th March 1979	Rationalization of prices of complex fertilizers.

Source: Prepared by Marketing Services, IFFCO, New Delhi.


PRICE TRENDS OF UREA AND DAP
Rs./ ton
3100
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
DAP
UREA
1966
1968
1970
1972
1974
1976
1978
1979
YEARS

FERTILIZER TRADE PATTERNS AND TRENDS, WITH SPECIAL REFERENCE TO ASIA AND THE WEST PACIFIC

DONALD W. FRYER*

ABSTRACT

Both world fertilizer production and world trade in fertilizers have increased rapidly since World War II, but this development has mainly involved, and has principally benefited, countries at a high level of economic development. Fertilizer production has long been an energy intensive industry, whose location patterns in the past, and at the present, closely reflect the availability of low-cost energy supplies. The production of nitrogenous fertilizers has become more widely disseminated around the world in response to changing energy supplies, but that of non-nitrogenous fertilizers still broadly conforms to the older location pattern of the nineteenth century. World trade in fertilizer reflects these changes, but Europe remains the leading producer and exporter, while the increased importance of Japan and the USSR conforms to their greater status in the world economy. The Third World produces and consumes little fertilizers, and much of its demand originates in export-oriented cash crop industries. Rapidly rising costs pose great problems for the further dissemination of fertilizer production, and underline the need for international cooperation.

THE WORLD FERTILIZER

The manufacture of fertilizers is a processing industry closely affiliated with both the chemical and mining industries, and particularly with fuel minerals. These industries are among the most capital intensive of all, typically demonstrating a high capital investment, energy consumption, and floor space per worker. Employment in such industries is largely confined to a limited number of scientific workers and skilled technicians; and their capacity to generate new job opportunities is low, a fact which has not, however, reduced their desirability in the national development plans of Third World countries. Typically also, they tend to be dominated by giant multinational corporations, which in conformity with the general practice of such organizations show no great belief in the virtues of competition, and much prefer to cooperate amicably with their fellows, either in informal pricing and marketing agreements, or sometimes in formal cartels of which OPEC is only the latest and by far the most successful.

World production and consumption patterns, the location of production, and world trade in fertilizers, closely reflect these basic facts. Since World War II both production and consumption have increased in a dramatic and unforeseen manner under the stimulus of an ebullient world economy with growth rates, until 1973-1974 at least, unmatched at any

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time in the past. By the mid-1970s the world fertilizer production (in terms of plant nutrients) of some 90 million tons was more than ten times that of the late 1930s, admittedly a time of general depression; but both production and exports were five times the levels of those of the mid-1950s.

THE LOCATION OF FERTILIZER PRODUCTION

Far reaching changes in the location of fertilizer production, which reflect similar changes in the location of the chemical and fuel mineral industries, have accompanied this rapid growth. From their first appearance in the second quarter of the nineteenth century until the first decade of this century, fertilizer production was a raw materials-oriented industry whose location pattern was determined by the existence of suitably high-grade mineral deposits. The large bulk, high proportion of waste in processing and relatively low unit value of such deposits compelled that they be processed very close to their geographic location, a choice largely determined by the costs of obtaining energy and fuel supplies.

Such considerations still broadly govern the location of phosphatic and potash fertilizer production, but profound changes have occurred in the location of nitrogenous fertilizer production. Natural nitrates now account for only a trifling proportion of world total nitrogenous fertilizer output. Chile, which at the turn of this century still enjoyed an almost complete monopoly, by 1975 supplied only 0.25 percent of world output of this important class of fertilizers. Over this period so-called synthetic nitrogen fertilizers have come to dominate the world market, and their production is essentially a fossil fuel-oriented industry, whose location pattern continues to change as new sources of low-cost fuels become available.

Early efforts in this century toward the fixation of atmospheric nitrogen which employed the arc process were located in those parts of Europe with cheap hydroelectricity; but for the whole of the interwar period the production of synthetic nitrogen fertilizers was an adjunct of the coal chemical industries, in which Germany has long been a world leader. By-product ammonium sulphate derived from ammonia produced in the coke-ovens of the iron and steel industry, the direct combination of hydrogen and nitrogen in the Haber-Bosch process, a triumph of Germany's IG Farbenindustrie, and the production of calcium cynamide, all essentially depend on the availability of cheap coal and on a well developed heavy chemicals industry which in turn largely grew up in association with the expanding European textile industries located on coal fields, particularly those in close proximity to salt deposits. By the outbreak of World War II some 90 percent of world total synthetic ammonia apacity was coal based.

Since 1950, however, there has been a progressive shift away from coal-based production of synthetic nitrogen, as the real costs of coal extraction have steadily increased, toward petroleum and natural gas based production, particularly in the form of urea. And from a marked concentration on or near the coal fields of the Western world, nitro-

genous fertilizer production has become more widely disseminated with the expansion and geographic dissemination of the petroleum industry. Both technological changes in refining, which have made possible the creation of large refining complexes in all major oil importing countries, and the growth through nationalist pressures of refining industries in Third World "host" countries have made nitrogenous fertilizer production profitable in many coal-deficient countries. And in host countries petrochemical and fertilizer plants can also make use of "associated" natural gas previously flared for want of a market. Since all national development plans in the Third World involve a large investment in enhanced energy production, which together with petrochemicals and fertilizers and enhanced agricultural output can be assembled in a package attractive to aid donors, a progressively wider geographical distribution of nitrogenous fertilizer production appears assured.

In contrast, the production of phosphate and potash fertilizers has shown no comparable tendency toward a wider geographic dissemination. Phosphate rock deposits occur widely, but the requirement that with present technologies such deposits need a P_2O_5 content of 30 percent or more to permit economic exploitation restricts production to four principal areas; the United States, the USSR, North Africa, and certain Pacific islands. Moreover, the conversion of rock phosphate to more valuable superphosphates requires substantial energy and the products of the heavy chemical industries; thus while North Africa and the Pacific islands export this output largely in unprocessed form, most long-established centers of heavy chemicals are involved in superphosphate production. Moreover, certain European countries, notably France and Germany, whose iron and steel industries long depended on low-grade domestic phosphoric ores, have long had an important by-product phosphate fertilizer industry in the form of basic slag, the group up linings of converters, and open-hearth furnaces.

Production and exports of potash fertilizers are even more restricted geographically. Imperial Germany dominated the potash industry in the early part of this century with its famous deposits in Saxony and Alsace, and an undivided Germany would in fact still constitute the world's second largest producer after the USSR. That position, however, is held by Canada, where production from newly discovered deposits in the Prairie Provinces has increased dramatically over the past two decades, a development which has made the country the world's largest potash exporter. The other major producers include the United States, France, and Israel, the latter being the only significant Asian producer, although China almost certainly has the potential for a large increase in production.

WORLD TRADE IN FERTILIZERS

Fertilizer production and consumption are heavily concentrated in countries at a high level of development, since these alone possess the prerequisites for economic manufacture and a capital intensive agriculture constituting a large market. Such countries enjoy the economies of scale in production; and because political exigencies compel that

virtually every branch of agriculture is subsidized by the state in one way or another, fertilizer prices to farmers in real terms are relatively low. In the great majority of Third World countries on the other hand, developmental policy maintains low internal food prices in the interests of the urban-industrial sector; the price of fertilizers to farmers is thus very high in real terms, and both manufacture and use are discouraged. Even those energy rich Third World countries with new fertilizer industries have to import other inputs from the developed world, and rising energy prices will compound the obstacles to fertilizer manufacture in energy-deficient Third World countries, the so-called "Nopecs."

In the mid-1970s world fertilizer exports amounted to some 25 million tons annually, almost 30 percent of world consumption; nitrogenous fertilizers accounted for about 30 percent, phosphates for a little less than 20 percent, and potash for around 50 percent of total exports (Table 1). In conformity with the general pattern of world trade in manufactured products, trade in fertilizers is largely conducted among countries at a high level of development, which in the mid-1970s accounted for nearly two-thirds of total exports and almost one-half of total imports. Western Europe has traditionally been a large net exporter of all three classes of fertilizers and still accounts for nearly 40 percent of world exports of nitrogenous fertilizers; but as an exporter of phosphate and potash fertilizers, it has had over the past decade to cede first place to North America. In consequence of its burgeoning chemical industries and ebullient economy, Japan has become the world's largest natural exporter of nitrogenous fertilizers, but in other fertilizers it is a substantial net importer, the deficit in potash fertilizers being especially heavy. The rise of North America as a major fertilizer exporter was in large part a consequence of World War II; but the increasing importance of the USSR as an exporter, particularly of potash fertilizers, is also noteworthy. In keeping with the general pattern of USSR trade, however, Soviet fertilizer exports are largely directed to its satellites and to countries in its highly selective aid program. Table 2 demonstrates that while countries at a high level of development are large importers of phosphates, they dominate the import trade in potash.

TABLE 1-- WORLD FERTILIZER PRODUCTION AND EXPORTS, (AVERAGE 1974-1976)
(million tons, plant nutrients)

	PRODUCTION	EXPORTS
Nitrogen	43.1	7.5
Phosphate	25.3	3.8
Potash	23.6	12.4
Total	92.1	23.7

Source: FAO. Annual Fertilizer Review, 1976.

TABLE 2-- PERCENTAGE SHARE OF WORLD FERTILIZER IMPORTS, AVERAGE 1974-1976

	N	P	K
Highly developed countries	28	40	59
Developing countries	51	21	16
Centrally planned economies	21	10	25

Source: Calculated from FAO. Annual Fertilizer Review, 1976.

Africa, Asia, and Latin America are in large deficit and collectively rely on imports for about 70 percent of total fertilizer consumption. But for most countries of the Third World, the degree of dependence on imports is even more extreme, since fertilizer production is heavily concentrated in a few countries, notably India, Korea, Taiwan, and in oil-rich countries of the Middle East, so that the contribution from the numerous national fertilizer industries is pitifully small. Nitrogenous fertilizers are the most important class of fertilizer imports to developing countries; but the distribution of N, P, and K imports between the various component regions of the Third World is very significant (Table 3).

TABLE 3-- PERCENTAGE SHARE OF THIRD WORLD FERTILIZER IMPORTS BY REGIONS, 1975

	N	P	K
Far East*	42	45	35
Near East	20	5	--
Latin America	28	41	52
Africa**	8	9	11

* Excludes China, Taiwan, Japan
**Excludes Libya, Egypt, and the Sudan (allocated to the Near East) and South Africa

Source: Calculated from FAO. Annual Fertilizer Review, 1976.

That the Far East and Latin America absorb some 70 percent of all Third World nitrogenous imports is scarcely surprising in view of their combined share of total Third World population, but they account for over 85 percent of phosphate and for nearly 90 percent of potash imports. These disparities reflect the great concentration of export-oriented cash crop production in the Third World within these two regions, an activity in which Western enterprise still plays an important, if declining, role. Though precise figures are lacking, it is clear that a

large proportion of total fertilizer consumption in these two major regions is absorbed in the cultivation of sugar cane, coffee, vegetable oils, cotton, cocoa, and rubber. It is clear that most of Africa's food crops receive little or no fertilizer. Lightly populated Zimbabwe-Rhodesia consumes three times as much fertilizer annually as Africa's population and petroleum giant Nigeria and is by far the most important fertilizer market in Sub-Saharan Africa after South Africa itself, which accounts for about one-third of total fertilizer consumption in continental, or geographic Africa. The Near East of Table 3, that is, Southwest Asia plus Egypt, Libya, and Sudan, clearly has a very different fertilizer import pattern; its only major agricultural export is cotton from the Nile Valley, whose cultivation accounts for a large proportion of the region's total nitrogenous fertilizer consumption.

FERTILIZER TRADE OF ASIA AND WESTERN PACIFIC

The fertilizer trade of the respective countries that make up this vast and diverse area reflects their general trade patterns. The great majority are integrated in the world economy largely through the export of a very limited range of crops or industrial raw materials; and their economies are for the most part competitive rather than complementary, so that in trade terms they turn their backs on one another. Japan, the new giant of the world economy, is a striking exception. It has become the principal trading partner of almost every country within the region (New Zealand is the only important exception). It is a leading world fertilizer manufacturer and exporter, but as with Japanese manufacturing in general, its fertilizer industries are overwhelmingly dependent on imported raw materials. It is the principal supplier of nitrogenous fertilizers to many countries in the region; but in other fertilizers it is a net importer and its large potash requirements have to be met by imports from outside the Asia-Pacific region. Japan is also outstanding among Asian countries in its very high fertilizer consumption and even balance of N, P, and K per hectare of cropland, a consequence of the very low price of fertilizers in real terms to its farmers, who are among the most pampered on earth. This fertilizer pattern is also discernable in Japan's former possessions, Taiwan and Korea.

India is a large fertilizer producer, but is nevertheless in heavy deficit. Its fertilizer imports, as with virtually all of India's food and material imports, have been largely supplied on concessional terms under various foreign aid programs. Of the new fertilizer producers of the Middle East, virtually the entire output of Kuwait, Saudi Arabia, and Qatar, whose agricultural possibilities are very restricted, is available for export; but that of Iran and Iraq appears largely destined for domestic consumption for some time to come.

Australia and New Zealand constitute a fourth concentration of fertilizer production, but are also net importers. These two countries consume virtually the entire output of the phosphate originating islands (Ocean, Nauru, and Christmas Islands), exploited by the British Phosphate Commission and have a unique fertilizer consumption pattern in which phosphate and potash outrank nitrogen by ratios of approximately five to

one and one to 25 respectively. This situation arises from the distinctive character of their agricultures, in which crop production is anomalous (despite Australia's large wheat and sugar exports) and is largely dependent on livestock production based on improved pastures established and maintained through "sub and super" (subterranean clover and superphosphate) grassland techniques in which these countries are world leaders.

Throughout the rest of non-Communist Asia, fertilizer consumption and trade in fertilizers are closely related to agricultural patterns and to the realism or otherwise of national development plans and the degree of success in implementing them. Throughout Southeast Asia and in the humid portions of South Asia, where padi is by far the most important crop, traditional varieties showed no response to fertilizer and received none, nor indeed were organic manures much used in rice production. But the "Green Revolution" has greatly increased fertilizer demand in those countries where adoption of the new techniques, often under the stimulus of foreign aid programs, has been rapid. Thus the Philippines has both a much larger fertilizer production and import trade than has Thailand, whose rice output is much the greater, but which for various reasons has rejected widespread adoption of the new high-yielding seeds. The Philippines, moreover, has important cash crop export industries which consume large quantities of fertilizers.

Indonesia, the large rice producer of Southeast Asia, would undoubtedly consume more fertilizers if it could afford to do so, but imports have fluctuated in capricious fashion reflecting Indonesia's "boom or bust" economic fortunes in recent years and are still largely dependent on foreign aid. Its small domestic fertilizer industry has the potential for great expansion, as do those of Malaysia and Brunei which are also significant petroleum producers; but it was the grandiose development plans assigned to, or perhaps appropriated by Pertamina, Indonesia's national oil entity, and prominent among which was a technically ambitious floating fertilizer plant based on offshore natural gas production that precipitated the country's present severe economic crisis. The resuscitation of Indonesia's long neglected and mismanaged export crop industries would create an enlarged demand for non-nitrogenous fertilizers, and competition for available fertilizer supplies between food and non-food crops would be increased.

Malaysia, Sri Lanka, Mauritius, and Fiji all possess an agriculture in which export crop industries are very important in the agricultural sector, and supremely so in the first named. Malaysia is not only a far larger fertilizer importer than its population or cultivated area would appear to merit, but also its efficient tree-crop industries generate a fertilizer consumption pattern with a large component of non-nitrogenous fertilizers. Rubber, Malaysia's most important crop, is not normally treated with fertilizer, but its application to immature rubber at certain stages of growth is mandatory in the country's massive replanting and new planting programs, and fertilizers are also necessary for oil palm, now a close rival to rubber. But Malaysia also stands with Japan in being one of the very few Asian countries to pay its farmers relatively high prices for rice; moreover, rice farmers, who are overwhelmingly Malay,

also receive subsidized fertilizers under rural development programs, facts which also help explain the country's abnormally high per capita fertilizer consumption for an Asian country.

On the other hand India, Indonesia, Thailand, Burma, and all Communist countries strongly depress the investment of fertilizers and of other inputs in agriculture through pricing and procurement policies which keep food prices low for the privileged urban population.

PROSPECT

That world fertilizer output will continue to grow is certain, yet it is already clear that the high growth rates of the recent past cannot be maintained. The escalation of energy costs with the Yom Kippur war resulted in a marked levelling off of output in the early seventies, and it is certain that such costs will continue to climb, perhaps rapidly, at least until alternatives to gaseous and liquid hydrocarbons can be developed. Except for the states of the Persian Gulf, Australia, Indonesia, Malaysia, and Brunei, all the countries of the region are dependent on imported energy. And neither Australia nor Indonesia, given current rates of increase in domestic demand on the one hand and of new discoveries on the other, appear likely to be self-sufficient in petroleum by the end of the century.

Some of the more grandiose new fertilizer and petrochemical projects already begun in the region now appear unlikely to be completed as planned; cutbacks have been recently announced in such undertakings in both South and Southeast Asia and even in the energy rich Middle East itself, and the future of those planned as joint ventures with Japanese interests are particularly uncertain. But Japan's export of noxious industries, whose further expansion in Japan itself is increasingly unacceptable to the Japanese themselves, has become a matter for apprehension in many Asian countries, whose major urban and industrial areas already have a severe problem of atmospheric pollution.

An unfortunate consequence of the Green Revolution has been to commit those countries adopting it to increasingly costly imported inputs, but the scope for a reduction in such costs through expanded domestic production can easily be overstated. A large new industrial complex in the Third World can seldom attain planned productivity, since social and political pressures force the employment of a far larger labor force than is necessary or desirable, and none of the new fertilizer plants in the Middle East are as yet working at capacity. Cooperation to develop new sources of supply and to promote fertilizer flows within the region, perhaps under the aegis of a regional association, can confidently be expected, and ASEAN has shown the way with its program for other industrial projects. But what has been agreed upon is only a shadow of what was hoped and at one time appeared feasible, although Indonesia has undertaken to help meet the petroleum needs of its fellow members in the organization.

Much fertilizer will probably continue to flow in the region under aid programs, and better surveillance might ensure that a larger proportion of such supplies reaches the fields of the poorer farmers. Indeed, the institutional obstacles to more effective utilization of available fertilizer supplies in many Asian countries pose more intractable problems than increasing such supplies, since such obstacles form part of the apparatus by which the ruling elite maintains itself in power.

COMPARATIVE ANALYSIS OF FERTILIZER MARKETING SYSTEMS IN SOUTH ASIA: WORKSHOP REPORT

TIKIRI SUBASINGHE*

A socio-economic study recently conducted under the INPUTS project has shown that although most governments have the goal of providing the necessary organization, structure, and incentive to make fertilizer available at a place and time convenient to the farmer, in a form and grade that are suitable for his crops and at a price that he can afford, the actual situation was far from this--particularly in developing countries. The general ineffectiveness of the fertilizer marketing systems prevalent in these countries appears to be a factor contributing to this situation (Ahsan et al, 1978).

This aspect of fertilizer usage was discussed at the Second Review Meeting of the INPUTS project held in May 1978, and it was recommended that a study of the fertilizer marketing systems prevailing in some countries be undertaken (Ahmed & Gynasena, 1978). Following upon this recommendation, the Resource Systems Institute of the EWC initiated a study on Comparative Analysis of Fertilizer Marketing Systems in South Asia. In view of their rather similar socio-economic conditions and cultural backgrounds, Bangladesh, India, Nepal, Pakistan and Sri Lanka were selected for the study.

The study has the following objectives:

1. To identify operation modes of various fertilizer marketing systems currently operating in South Asia.

2. To identify the merits of these systems relative to their objectives.

3. To develop and make available detailed methodologies at micro level for evaluating operating marketing efficiencies.

4. To analyze constraints and disincentives to efficient fertilizer distribution at the village level and to optimum fertilizer use by the farmer, that may prevail in various countries/areas.

5. To develop recommendations for policy considerations for improving fertilizer marketing and use to meet future demands, so as to enhance food production in various countries.

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Ten public and private organizations in the five South Asian countries surveyed agreed to cooperate with East-West Center and participate in the implementation of the study. These are listed in Table 1. A preliminary meeting of the participating organizations was held in Islamabad/Lahore (Pakistan) in September 1978 to develop the study schedules, programmes and questionnaires. At this meeting it was also decided that the study should be conducted in two phases, Phase 1 being devoted to study the marketing systems at macro level and Phase 2, to study the marketing systems at micro level.

TABLE 1--ORGANIZATIONS PARTICIPATING IN THE IMPLEMENTATION OF THE FERTILIZER MARKETING STUDY

I. BANGLADESH

1. Bangladesh Agricultural Development Corporation, Dacca
2. Bangladesh Agricultural Research Council, Dacca

II. INDIA

3. Fertilizer Corporation of India, Delhi
4. Indian Farmers' Fertilizer Cooperative Ltd., Delhi
5. Madras Fertilizers Ltd., Madras

III. NEPAL

6. Agriculture Inputs Corporation, Kathmandu

IV. PAKISTAN

7. Exxon Chemicals Pakistan Ltd., Karachi
8. National Fertilizer Marketing Ltd., Lahore

V. SRI LANKA

9. Agrarian Research and Training Institute, Colombo
10. University of Sri Lanka, Peradeniya

In Phase 1, fertilizer manufacturers, importers, distributors, marketers, bankers, government policy-makers and transport agents were interviewed.

Last week, preliminary results of Phase 1 were reviewed at the Workshop on Fertilizer Marketing.

Based in this review, the general situation of fertilizer marketing at national level in the five countries surveyed may be broadly described as follows:

A. Marketing Structure and Management

1. The concept of marketing of chemical fertilizers has been of recent origin in all five countries. All of them have either already floated commercial enterprises for handling fertilizers, or are in the process of doing so. The strength and spread of marketing organizations depend largely on the marketing system employed. It is observed that fewer staff are located at the grass root level. The type of vehicles used by front line sales officers vary widely, and include public buses, bicycles, motorcycles and motor cars.

2. Private trade has started playing an increasingly important role in fertilizer marketing.

3. A multi-channel distribution system is the pattern prevalent in the surveyed countries.

4. No exclusive territorial rights for operation are given to private trade in any country. However, in India, where there are a large number of fertilizer marketing organizations, there is a tendency for organizations to concentrate their efforts in some areas.

5. In all 5 countries, import of fertilizer is channeled through a government agency, but marketing is through all available channels. Cooperatives play an important role in marketing, particularly of imported products, in some countries.

6. Competition among marketers is more prominent in India and Pakistan than in other countries.

7. Promotion of fertilizer use is the overall responsibility of the governments' extension services in these countries. However, in India and Pakistan, certain amount of brand promotion is undertaken by manufacturers and marketers. In India, manufacturers/marketers also undertake long term agricultural development programs as part of their extension services.

8. Levels of marketing margins offered to dealers by distributors vary widely from country to country, and are influenced by government policies.

9. The field staff of each marketing organization is the main source of information feed-back to the organization. This information is used to monitor marketing/distribution programs, product mix, and promotion mix.

10. Blended or mixed as well as straight fertilizers are supplied in different proportions. In Sri Lanka, a major portion of fertilizer is supplied in the form of physical mixtures, whereas in India and Pakistan, supplies mainly consist of complex NP and NPK products.

11. Regulations governing product quality, movements and prices of fertilizer exist in these countries. However, envorcement of these regulations is a problem in most of them.

B. Supplies and Sales

1. All countries are dependent on imported fertilizers to meet their requirements, partly or fully. Sri Lanka and Nepal import all of their requirements, whereas India, Pakistan and Bangladesh import part of their nitrogenous and phosphatic fertilizers to supplement local production. There is no production of potash in any country.

2. During the recent past, fertilizer supplies have suffered to a great extent in all countries due to balance of payments difficulties, international market prices, and world shortages.

3. Demand for fertilizer has increased in all countries during the recent past. This is about 62% in Bangladesh, 45% in Nepal, 52% in India, 28% in Pakistan, and 44% in Sri Lanka.

4. In all countries, present fertilizer use is below recommended rates based on agronomic grounds. Product non-availability is one of the major factors contributing to this low use.

5. Fertilizer sales patterns in all countries indicate seasonality in demand in different localities. In India, however, when the sales pattern for the entire country is taken into consideration, there is a significant volume of sales throughout the year for one product or the other.

C. Pricing, Subsidy, Taxation and Credit

1. In all countries fertilizer prices to farmers are fixed by the government. In Bangladesh, Nepal, Sri Lanka and Pakistan, price is the same all over the country; in India, however, there is a slight difference from place to place depending on local taxes.

2. There is a significant variation in fertilizer prices in different countries. The current price of urea, for example, is US $127/per MT in Bangladesh, 181 in India, 203 in Nepal, 126 in Pakistan and 133 in Sri Lanka. This difference is mainly due to variations in procurement prices and differences in the rate of subsidy. In Nepal cost of transport is an important component in farmers' price.

3. In terms of current prices, urea/paddy price ratio appears to be favorable in Bangladesh, Pakistan and Sri Lanka, but not so in India and Nepal.

4. There is a large variation in marketing and other incidental costs in the five countries. It varies from $15/ton (or 11% of factory cost) in India, to $92/ton (38% of import price) in Nepal.

5. All countries have a subsidy on fertilizer, but the percentage varies from country to country.

6. Transport costs are borne by the marketing organizations up to a limit in all countries. In Nepal, an additional subsidy is given for transport in mountainous regions.

7. There is no taxation on fertilizer in Sri Lanka, Pakistan, Bangladesh and Nepal. In India, however, fertilizer is taxed at several points by the central government, state governments and local government authorities.

8. Marketers offer credit to their dealers in all cases. The period of credit varies from 30-45 days. In the case of farmers, credit is provided by fertilizer dealers, banks of cooperatives. Bank or cooperative credit usually covers all inputs.

D. Transportation and Warehousing

1. Both rail and road transport are used for primary transportation of fertilizer in India, Bangladesh, Nepal and Pakistan in varying degrees. Bangladesh, in addition, uses waterways. In Sri Lanka, primary transportation is entirely by road.

2. Inadequacy of railway rolling stock and trucks for transport is a major problem in all countries.

3. In India and Pakistan, manufacturing plants and sea ports are situated away from major agricultural areas. Therefore, fertilizer has to be transported long distances to make it available to farmers.

4. Road transport is provided primarily by private transport contractors in all countries.

5. The maximum carrying capacity of trucks in Pakistan and India is 10 tons, while in Nepal and Bangladesh, it is 7 tons, and in Sri Lanka, six tons.

6. The time taken for moving fertilizer to a distance of 200km by railway is two to seven days in India, Sri Lanka and Pakistan, and ten days in Bangladesh. In case of trucks, the time taken for the same distance is less than a day, except in hilly regions of Nepal, where it can be considerably longer.

7. The most commonly used bag size is 50kg in all countries. In Bangladesh, 25kg bags are also used to some extent.

8. Imports to Bangladesh and Nepal are all in bagged form. Other countries import some fertilizer in bulk form also.

9. Warehouses are generally available at producing as well as import points. Average period of warehousing varies from country to country. The quality of warehouses available also varies from location to location.

10. Losses in warehousing is highest in Nepal and lowest in India.

E. Sales Support

1. Marketing of branded products in a common practice in all countries surveyed except Bangladesh. In India, imported products and products marketed under products exchange arrangements are also sold under brand names.

2. Newspaper is the most commonly used mass communication medium in all countries. Cinema and radio are other forms of media used to the extent of their availability. In India and Pakistan, TV is also used to some limited extent.

3. Literature (crop booklets, brochures, posters) and giveaways are also extensively used for sales promotion, particularly in India and Pakistan. Some organizations in India also use billboards and wall paintings for brand promotion.

4. Majority of manufacturers and marketers advertise their products on their own rather than on joint basis with their retailers.

Future Plans

In the course of the discussions certain missing links and gaps in the macro-level study were identified. Neccessary data will be collected by various cooperation institutions and mailed to the East-West Center.

Phase 2 of the study, focussing on farmers and fertilizer retailers at the village-level, will now be carried out in the five concerned countries based on research methodology and questionnaires developed last week. It is envisaged that this phase will be completed by mid 1980.

It is suggested that administrators, policy makers, bankers and chief executives of various fertilizer manufacturing and marketing organizations be invited to the final meeting of this study, where results obtained will be discussed and relevant recommendations for policy considerations, developed.

FERTILIZER MARKETING IN ASIAN COUNTRIES

- WITH EMPHASIS ON VILLAGE LEVEL OPERATIONS -

CHONG YEONG LEE*

INTRODUCTION

Although various efforts are being made by governments in Asia, the level of fertilizer use by Asian farmers, especially by the small farmers, is still very low (except for a few countries in which the level of fertilizer is much higher than the rest of the Asian countries.) The wide gap in fertilizer use in the Asian countries, which ranges from 10 kg to over 300 kgs per ha. per year, is one of the important reasons for the wide gap in crop yield, which ranges from less than 2 tons to over 6 tons of paddy per acre.

Realizing the importance of promotion of efficient fertilizer marketing systems in increasing fertilizer use, ESCAP (United Nations Economic and Social Commission for Asia and the Pacific) started the Agricultural Requisites Scheme for Asia and Pacific (ARSAP) in 1976 and country reports on fertilizer marketing, distribution and use were prepared covering 10 Asian countries. Some of the country reports have been revised to bring them up to date.

This paper attempts to provide a comparative overview of the situation regarding fertilizer marketing and use, especially at the village level, in 10 developing countries in Asia (Bangladesh, India, Indonesia, Korea, Malaysia, Nepal, Pakistan, Philippines, Sri Lanka and Thailand). Due to socio-economic and cultural differences at the village level and also due to the fact that the village-level studies were carried out by the local officers with various educational backgrounds, it was difficult to make a rigorous comparison of the data collected.

Despite the limitations and difficulties in the comparison, a careful analysis of the data revealed many interesting factors which need to be considered in improving fertilizer marketing and use, especially at the village level in the developing Asian countries. The objective of this paper is to present a comparative highlight of fertilizer marketing systems in the developing Asian countries, which will hopefully lead to the identification of policy directions.

INSTITUTIONAL SET-UP RELATED TO FERTILIZER DISTRIBUTION

In addition to the agencies which are directly responsible for fertilizer import and/or distribution, agricultural credit agencies are

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usually directly related with fertilizer distribution. Similarly, government food procurement agencies are often related to fertilizer distribution, with repayment in kind of farmers' production loans.

In many countries, policy matters are decided by the Ministry of Agriculture, mainly in the field of demand estimates. Ministries of Trade, Finance, and Planning also play an important role in fertilizer policies. In the case of the Philippines, the power is concentrated in the Fertilizer and Pesticide Authority (formerly the Fertilizer Industry Authority), and in India, a Fertilizer Policy Coordination Committee has been recently established for coordination purposes. A similar body has been established in Pakistan.

For fertilizer distribution, government or public agencies (including cooperatives) play a dominant role in all the countries, except the Philippines where a corporation has the major share. The importation of the commodity is monopolized by the government or public agency, except for the Philippines, Thailand and Malaysia where private sector participation is allowed.

The role of institutional credit is critical in making fertilizers available to the small farmers. In terms of overall rural credit requirements, the public or government credit institutions still hold less of a share than private sources in most of the countries, yet for short-term production loan to small farmers (which includes loans for fertilizers), public institutional credit is vital. The credit is provided by various forms of government-financed agricultural banks and cooperatives, which are separate from the fertilizer distribution agencies, excluding Korea where National Agricultural Cooperative Federation monopolizes both fertilizer distribution and institutional credit.

It is commonly understood that a linkage between fertilizer distribution and institutional credit with marketing of produce is desirable to insure coordination and integration of fertilizer distribution, credit, and produce marketing activities. The closest link can be seen in Korea where only one agency (National Agricultural Cooperative Federation) is responsible for the fertilizer and pesticide distribution, agricultural credit disbursement, and marketing of agricultural produce. In Thailand, the link is being established under the Marketing Organization for Farmers and Agricultural Cooperative Federation of Thailand. In the Philippines, the integration is being carried out on a pilot project basis. In India, the Food Corporation of India also handles imported fertilizers. In all other countries, paddy procurement bodies have no direct relationship to either fertilizer distribution or to agricultural credit. This situation makes the integration or coordination of the three interrelated activities difficult.

MARKETING CHANNELS

There are two models of marketing channels at the wholesale level. In general, the ASEAN countries (Indonesia, Malaysia, Philippines and

Thailand) let private sector (or commercial sector) play a more important role in fertilizer distribution, while government agencies (or cooperative sector) dominate the wholesale marketing channel in the rest of the countries.

Although the ideal situation may be that farmers' organizations, such as agricultural cooperatives, handle fertilizer distribution all the way down to the village-level, the non-existence or inefficiency of village-level agricultural cooperatives makes it difficult for many of the Asian countries to make use of farmers organizations as a major fertilizer marketing channel. In addition, there is pressure on the private sector to be utilized as fertilizer retail outlets at the village-level so that the farmers can have easy access to the fertilizer. Because of this situation, the private sector plays a relatively important role in fertilizer retailing at the village-level in most of the countries, except for Korea and Nepal.

There are two criteria in evaluating the efficiency of fertilizer retail outlets in serving small farmers at the village-level, regardless of whether they are cooperative retailers or private traders. First, there should be an adequate number of retail points, which means that the covering area per retailer should be small enough to provide adequate service to the farmer customers. Secondly, they should be in or near the farming area so that villagers will have to travel a shorter distance to obtain fertilizers. On the other hand, sales per retailer should be large enough to allow investment on storage and other capital facilities and also to increase their managerial efficiency.

In India, (a large country with various terrain conditions), the average coverage area per retail sales points varies widely, from 338 ha in the State of Pondichery to 9,400 ha in the State of Nagaland. This is far away from the national average of 1,760 ha per retail sales point.

In Malaysia, about 80% of the private and cooperative retailers are concentrated along the west coast of Peninsular Malaysia. The three east coast states of Peninsular Malaysia (Kelantan, Trengganu, Pahang), as well as Sabah and Sarawak are served by only 20% of the retailers although these areas cover two-thirds of the total land area and contain close to 40% of the cropped area.

Another measurement of the efficiency of retail outlets is the amount of fertilizer handled per year. If the total quantity sold by a retail is too small, it would neither provide the incentive, nor the ability to improve the distribution and physical handling efficiency. The annual turnover per retailer ranges from 25 tons in Bangladesh to nearly 900 tons in Korea.

In order to introduce management efficiency of retailers, the annual sales volume should be large enough to meet the overhead costs. To increase the sales volume, fertilizer consumption per ha should increase together with a larger coverage area. This means that the transport situation should be adequate to cover a larger area efficiently. The

retailers in Malaysia and Korea approximately meet these requirements, while the retailers in Bangladesh and Nepal are far below the standard.

MARKETING COSTS AND MARGINS

Squeezed in between the rising import of ex-factory costs and the need to sell at a cheaper price to the farmers, reduction of marketing costs and margins become critical.

Various complicated factors make international comparisons of marketing costs and margin very difficult, but it can be said that the marketing costs and margin roughly constitute about 25-35% of the retail price.

On marketing margin, the retail dealer's margin directly affects the incentive and promotional efforts of retailers (whether public, cooperative or private) and their willingness to reach farmers. As fertilizer marketing is a non-competitive, primarily government controlled business, the retail margin is fixed by the government in most of the Asian countries The retail margins range from $2.94/ton in India to $11.50/ton in Nepal, in most cases it is around $7/ton.

In order to encourage movement of fertilizer to remote areas away from wholesale warehouses, additional margins are often allowed to compensate the additional transport costs. In Bangladesh, the retailers who are in more than 3 miles away from the Thana wholesale warehouse are given an additional $13/ton for every 3 miles--up to 9 miles, to subsidize the transport costs. As this is an additional discount given to the retailers, the retail price should remain the same throughout the country. In Sri Lanka, the retailers are given, in addition to the basic discount of $3/ton (Rs. 45), US¢ 4.7-6.7 (Rs. 0.70-1.00) per ton per mile as the transport subsidy. In India, the total dealers' margin for the distribution process from the wholesale (state cooperative supply and marketing federation) down to the retail sales point is fixed at $14.35 (Rs. 115) per ton on top of the purchase price by the wholesale distributor. This is divided among the wholesaler, retailer, and retail sales point, of which the retailer gets the largest share.

In addition to the officially allowed retail margin, empty fertilizer bag is another source of fairly substantial income. In India, an empty bag is sold at Rs. 5 per piece of 50 kg bag, or Rs. 100 ($12.50) per 20 1 ton capacity bags. In fact the sales revenue from the bag is much more than the officially allowed dealer margin.

In order to improve retail dealers' efficiency in serving the farmers' need, the total income from the fertilizer business should be large enough to allow incentive for improvement. Because of the small volume of fertilizer business, the retailers' annual income in Bangladesh and India is just about $200 per year making it difficult to introduce innovation.

PHYSICAL DISTRIBUTION

1. Storage

Storage used by retailers vary from the use of a rented facility to the ownership of a storage of over 100 ton. During the peak season, necessary storage facilities are rented from private or public agencies. The storage rental charge at village-level (retail level) varies from US$0.1/ton/month in Sri Lanka to 80¢/ton/month in Malaysia, but in most cases the rent is around 30¢ to 50¢/ton/month.

The storage rent tends to be higher in larger city areas than in rural areas. One of the key questions, however, in comparing storage rental cost is the quality of the storage facility. Many of the storages available in village areas in the "low storage charge" countries are sub-standard wooden structure or mud-bricks with rusted tin roofs. Quality and quantity losses during the storage period, especially during rainy season, tend to be high. In Korea, Malaysia, Thailand and Philippines, the storage quality is better than in the rest of the countries, although the charge is subsequently higher.

As to one of the most favorable subjects at discussion, i.e., storage losses, it is difficult to estimate average figures, and a very careful study is necessary to make a meaningful estimate--although the losses were estimated to be about 2-3% in Sri Lanka, about 3% in Indonesia, and similar figures in Bangladesh. One way of looking at the loss is to compare the storage and handling loss officially allowed by the fertilizer distribution agency or the government. In Korea, the National Agricultural Cooperative Federation, the sole distributor of fertilizers in the country, is allowed to claim up to 0.22% as physical losses. Their actual claim, however, which needs to be endorsed by accounting evidence, is only 0.01%, meaning that only 14 bags out of 10,000 bags are counted as loss.

One of the main problems with the physical loss from the village farmers point of view is that the so called "recognized loss" is imputed into the cost calculation and dealers margins. Due to accounting and management difficulty however, the loss is usually passed to the village-level retailers and then on to the farmers. Bags are delivered to the retail shop by trucks or bullock cart, including broken bags which are counted as full bags. The retailer has only two choices; either bear the loss, or pass it on to farmers. When fertilizer is in short supply or sold through credit coupons, the loss is often passed on to the farmers, otherwise he absorbs the loss or tries to pass it back to the wholesaler. By introducing a simple stock control system and delivery certificate, the party who should be accountable for such breakage or loss can be made clear, and such system will force the concerned parties to make efforts in minimizing damages.

2. Transport

For long-distance transport, railway is used as it is cheaper, while trucks are utilized for relatively shorter distance. In Korea, Bangladesh, and India, railway transport plays the major role, while in the Philippines the boat transport is very important.

Apart from the overall macro-figures as above, the immediate concern for the small farmer is the distance between his village and the nearest fertilizer sales point from which he can pick up fertilizer. Not only the distance but the available means of transport and time required to travel affect the availability of fertilizer to the farmers. In Pakistan, a systematic survey was carried out in which the distance to the nearest fertilizer retail points was also included. Although the 9 villages studied in each of the 9 Asian countries under the FAO/ESCAP Programme in 1976-77 may not represent the typical situation, the distance from farmers villages to the nearest fertilizer dealers vary from 0-25 km.

Another important factor is that the mean figures may not mean much as there are many remote areas in many Asian countries, except Korea, where the situation is more or less the same in most of the villages covered by the 1,500 retail outlets.

One way of improving the transport efficiency is to establish many retail outlets close to villages--a difficult situation when economy of scale is taken into consideration. Another way is for the village farmers to get together and organize group transport. In Korea, each fertilizer retail outlet (Primary level agricultural cooperatives) covers about 10-15 natural villages (cluster of houses) of 50-150 households. In most cases, the farmers in a natural village grouped together to hire a truck to transport fertilizers from the cooperative society. In all other countries, no such group action was seen.

It is often the case that cooperative retail stores from which farmers can buy fertilizer on credit are located much further away than private retailers from whom farmers often buy fertilizers in cash.

3. Seasonal Fluctuation

Asian small farmers have neither separate storage facilities for fertilizer nor financial capability to stock fertilizer in advance. Farmers therefore buy fertilizer about one week before use which creates a demand rush during a particular time of year.

The seasonally skewed demand for fertilizer (usually twice a year, for two months each) causes stock and physical management problems on the part of the fertilizer distributors and puts pressure on storage space. This situation eventually leads to non-availability of fertilizer at the village level. To help solve this problem, the Agricultural Input Corporation of Nepal offers a special off-season premium commission of 3.5% above the normal 6% dealer commission to the District Cooperative Union. These unions are sub-wholesale agents who supply primary-level cooperative societies (Sajha) for retailing if the DCU lifts the fertilizer from AIC warehouse in the slack season, i.e., the period up to 3 months prior to the time of fertilizer application. This would mean that fertilizer could be lifted in the pre-monsoon season when the weather is good and transportation easy. It would also reduce the storage burden on AIC and the resultant interest payments and losses in storage, as well as ensure availability of fertilizers at DCU level when demanded by Sajha cooperative societies. Such off-season premium commission, if properly administered, will hold the seasonal demand rush on fertilizers.

CREDIT FOR FERTILIZER PROCUREMENT

1. Institutional Credit

Credit for fertilizer procurement is critical in promoting greater use of fertilizers, especially for the small farmers, as village money lenders and fertilizer private retailers offer little with respect to loans for fertilizer procurement. Various schemes and programs are in operation in most other Asian countries in which credit for fertilizer purchase by the small farmer is included; such as the Masagana 99 Programme in the Philippines, BIMAS Programme in Indonesia, 100-Crore Taka Special Agricultural Credit Programme in Bangladesh, New Agricultural Credit Schemes and Comprehensive Agricultural Credit Schemes in Sri Lanka, etc. The quantity of fertilizer sold through credit ranges from 16% in Sri Lanka to 80% in Malaysia.

If we assume that the institutional credit for fertilizer provided by the governments is linked with various schemes and programs intended for small farming development in each country, the small farmer's share of the credit sale of fertilizer must be larger than the overall figures given. Yet due to many problems and difficulties of the institutional credit system, the above hypothesis is not always true.

Availability of institutional credit is the critical factor for the small farmer to use fertilizer, as he will not buy fertilizer by borrowing money from a private money lender at the interest rate of 60% or 100% per year. He buys fertilizer either in cash or in credit provided by public credit institution. Usually an Asian farmer can buy on credit about 200 kg of urea per ha, and the interest rate is around 12% per annum.

As it is a short-term credit for production purpose, often the credit is provided in a package, including production expenses other than fertilizer.

In theory, credit for fertilizer purchase is available for small farmers in all countries in Asia, often without mortgage. In Indonesia, over 60% of the fertilizer is consumed on credit in the areas covered by BIMAS (Mass Guidance Programme) and INMAS (Mass Intensification Programme), provided through village bank network of Bank Rakyat Indonesia at the interest rate of 1% per month. In the Philippines, the major source of production credit includes 800 rural banks and 102 branches of the Philippines National Bank. The credit is provided to farmers through an informal farmer group called "selda," which is a credit guarantee group. The government guarantees 85% of the bad debt. In Thailand, about 30% of the rice farmers receive institutional credit from the Bank for Agriculture and Agriculture Cooperative at the monthly interest rate of 1%, by forming "bank client group" or through cooperatives.

Purchasing fertilizers from a private trader, either in cash or on credit, is simple; a farmer goes to the dealer and picks up fertilizer. Procedures for buying fertilizer on credit from institutional sources is not as easy. There are varieties but every country roughly follows the following procedures:

1) a farmer prepares a farm plan with the help of a government field extension agent,

2) the approved farm plan is submitted to appropriate credit agency for loan approval,

3) a purchase authorization is issued to the farmer,

4) the farmers bring the purchase authorization (or coupon) to an appropriate fertilizer dealer who sells the prescribed fertilizer against the coupon, and the fertilizer is sold.

5) the fertilizer dealer submits the purchase authorization to the credit agency for refunding, and

6) the farmer pays back to the credit agency after the harvest.

In Korea, a farmer submits his short term production credit requirement once a year (in March) to the primary agricultural cooperative, through his Farming Group Leader, who liaises between the primary agricultural cooperatives and its members. The primary agricultural cooperative, having the request cleared by the County Cooperatives, notifies the farmer of the amount approved through the Farming Group Leader. (In 1979 the limit was $1,000 per farmer from the government fund, and an additional $1,000 from the mutual financing fund). The farmer can then use a portion of it to buy fertilizer on credit. He may apply for fertilizer purchase from the primary agricultural cooperative, and pick up the fertilizer from the cooperative warehouse. However, he has to pay 65% of the value in cash and 35% of the value on credit.

In Indonesia, a farmer has to apply to the village head for recommendation for his loan application. The endorsed loan application is then submitted to Bank Rakyat Village Unit for a credit voucher covering the cost of the fertilizers. Fertilizer is sold at village "kiosks" operated by retailers, or by village unit cooperatives (BUUD/KUD).

In the Philippines, a farmer in the Masagana 99 Programme, must join a "selda" (informal credit group) of Samahang Nayon (pre-cooperative group). He prepares his farm plan, with the help of a Farm Technician, and submits it to a rural bank. When the loan is approved, the farmer signs a Loan Agreement, a Promissory Note, and a Marketing Agreement to sell his paddy to Area Marketing Cooperatives. The rural bank provides the farmer with a coupon with which he can buy his farming inputs only in package. Of the total loan granted, 5% is collected (later reduced to 3%) for the Samahang Nayon Barrio Savings Fund, which is used to purchase shares of cooperative bank and Area Marketing Cooperative.

In Nepal, a farmer approaches a junior technical assistant (a field-level agricultural extension worker) to prepare a farm plan. The farm plans are then grouped together by Village Agricultural Cooperatives to be submitted to the District Agricultural Development Officer (DADO). He checks the collected forms and sends the file to the district level branch of the Agricultural Development Bank, with a security signed by the Village Committee chairman. When the loan is approved, the village agricultural cooperatives take the coupons to the nearest Agricultural Input Corporation's sales office to receive the supply. Then the fertilizer is transported to the village for distribution to farmers who have applied for the loan.

In Haryana State, India, under the crop loan scheme introduced by the State Government in 1975, the State Cooperative Bank in consultation with the State Agriculture Department calculates the cost of cultivation and required inputs per acre of Kharif and Rabi crops. Based on the cost estimated, the maximum credit limit (MCL) of a cooperative member farmer is fixed by multiplying the figures with acreage owned by the farmer. In order to verify the state of member farmers about their land acreage, the Primary Agricultural Cooperative Society (Mini Bank) gets the details confirmed by Patwari (Village Accountant) of the area. The confirmed MCL is divided into two portions, "A" component (cash) and "B" component (in kind). The MCL is fixed for three years. At the time of drawing by the farmer from his MCL, he is required to contribute 20% of the MCL to the share capital of the society (10% in the first year and 5% each in the second and third year). When the loan is sanctioned, a farmer can draw up to 50% of the cash component, and he can draw additional cash portion provided he has drawn the kind portion equal to the amount of the cash portion.

2. Availability of Credit

Although institutional credit is available in principle in every country, especially for small farmers in practice at the village level, many difficulties in the credit systems discourage increased use of fertilizer by small farmers. The village level case studies revealed that in many countries, only 30-50% of the farmers surveyed purchased fertilizers on credit from institutional credit sources.

a) Security: Two types of securities are required, group guarantee and land mortgage. Guarantee by group of farmers (5-15 men) is considered to be the ideal way. Often these groups are formed and hastily instructed from "above" just to deliver institutional credit, therefore the farmer members lack group solidarity and group cohesiveness. Because of the group responsibility, all the members cannot benefit from institutional credit if a member of the group becomes delinquent. Rather than trying to pressure the delinquent farmer to pay back, the remaining members chose not to pay back making the group ineligible for another loan. Because of this problem, the minimum number of members of "selda" in the Philippines was reduced from 5 men to 2 men. Mere existence of the village-level cooperative society does not mean that institutional credit is available to the farmers.

In Nepal and also in Bangladesh, land has to be mortgaged to receive institutional loan. Because of incomplete land records, land owned by farmers is mostly inherited and co-owned. In such a situation all the co-owners must make a joint application--to which not all of the co-owners always agree. In this case the applicant farmer has to get the land record mutated from the land office and apply for credit in his own name. But mutation of record is a lengthy and costly procedure, and when land cannot be mortgaged, he cannot receive institutional credit.

Standing crop also can be hypothecated, as is often practiced in the Philippines and India. For cash crops which need to be further processed, such as sugar cane and tobacco, the crop hypothecation

is effective. But for crops such as paddy and vegetable, which can be sold to anyone, the crop hypothecation is not an effective security for credit.

b) Delay: Because of rather complicated loan application processing procedures and inefficiency on the part of the credit institution, credit release is often delayed, and the farmer misses the season for which the applied fertilizers are required. The period ranges from 2 weeks to 6 months.

The delay in credit sanctioning causes two problems, 1) a farmer has to borrow from a non-institutional source and pay it back when the institutional loan is sanctioned, or 2) he does not use fertilizer for his crops, and when the loan is sanctioned he uses the loan for immediate consumption purpose.

c) Loan Repayment: All the governments in Asia have special programs and schemes to provide more credit to the farmers, especially small farmers, so that food production as well as the farmer's income can be increased. Special agricultural credit institutions are in operation, drawing funds from the central bank. Recently in the Philippines and Thailand, commercial banks are required to contribute 10% (Thailand) to 25% (Philippines) of their loanable fund to the agricultural sector, either directly or through the government-designated agricultural banks. In India, it is required that 30% of the loan from the cooperative banks should be given to the marginal farmers (1 ha or less) and the small farmers (1-2 ha).

As a result, greater funds are available particularly for short term production loan with which fertilizers can be purchased. Despite such efforts, the credit institutions cannot provide enough credit to the small farmers, as "credit-worthy farmers" are "running short," which means there are not enough farmers who are eligible for continuous loans, in accordance with the established criteria. For example, the Masagana 99 Programme of the Philippines (which has the most publicized credit scheme in Asia), started with good credit repayment rate of 93% during the first year (1973) but the repayment rate alarmingly dropped to 41% in 1976, along with the decline in the number of farmers served (from 407,000 in 1973 to 316,000 in 1976) and the area financed (641,000 ha in 1973 to 528,000 in 1976).

The repayment performance of BIMAS Programme of Indonesia, another widely publicized credit program, also shows very similar trends.

In Sri Lanka, the repayment performance of the two priority programs, (New Agricultural Credit Scheme and Comprehensive Rural Credit Scheme) has deteriorated to such an extent that the Government recently has withdrawn credit guarantee which used to guarantee up to 75% of the uncollected loans. As a result the banks will have to use their own criteria to screen the loan application.

There are many reasons for such low repayment performance, but one of the most important reasons which is directly related with fertilizer marketing is crop failure. When the harvest is damaged by natural calamity, farmers cannot pay back the loan. Typhoons in the Philippines, and floods in Bangladesh often make it difficult for farmers to pay back the production loan. The crop insurance scheme is in operation only in Sri Lanka

(besides Japan), but the coverage is only 1% of the paddy land and often the compensation (indemnity) is used to offset unpaid premium dues accumulated during the last several years. During the national seminars in 9 Asian countries in 1977 to discuss the findings of the village-level case studies, necessity for introduction of effective crop insurance scheme was mentioned in many instances.*

Another reason is failure or low market price of cash crops. Although fertilizer loan was given for paddy, the paddy area of small farmers is so small that not enough marketable supply is available to pay back the loan. Therefore, the paddy loan is often paid from the income of cash crop, such as sugar cane or jute, or by working as farm labor. When the income from such sources is reduced, it affects repayment of the paddy production loan. This was one of the reasons for the low repayment performance of the Masagana 99 loan in the Philippines in 1976.

Another important reason is the difficulty of selling the produce to get cash to pay back the loan. This problem was expressed in most of the village-level case studies. The farmers would find it much easier and the repayment performance would improve if the credit institution receives the loan repayment in kind. The integration of agricultural credit with output marketing is precisely what all the village-level money lenders have been practicing. In order to make use of the personal contacts and entrepreneurship of local rice millers, the Philippine government, with support from FAO, introduced a fertilizer credit and distribution scheme in Mindanao. Under this scheme fertilizer was distributed through local rice millers to the participating farmers on credit and the farmers paid back in paddy to the rice millers. The project has been successful and an increasing amount of fertilizer is being distributed and spread into other parts of the Philippines.

3. Food Fertilizer Exchange Program

In order to link fertilizer distribution credit with marketing of output, the Food-Fertilizer Exchange Program was introduced in Korea in 1953 and lasted until 1976. Under this program, a farmer receives fertilizer on credit, under the condition that he will pay back in kind, such as paddy or barley, after harvest. The ratio of such exchange is announced by the government before the planting season starts so that he will already know how much paddy or barley he will have to give in exchange for fertilizer purchase on credit. Under the Food-Fertilizer Exchange Act, six commodities, i.e., paddy, barley, wheat, soy bean, millet, and sorghum, are exchangeable commodities, and the exchange ratios are fixed with each of these commodities with each of three major fertilizers, i.e., urea, superphosphate and potassium chloride. For example, the government announced in April 1975 (just before the rice planting season) that a

*Since then the Philippines has made necessary preparation to introduce crop insurance scheme nationwide, a pilot scheme in 200 districts started in 1978 in India, and another pilot scheme by Integrated Rural Development Programme of Bangladesh.

farmer who will receive 1 kg of urea on credit will have to pay back within two months after the harvest 0.26 kg of milled rice to settle the debt.

As the fixation of the exchange ratio has a substantial impact on the government price policy, the ratio should be agreed upon by various agencies. For this purpose, in Korea, a 15-member Food-Fertilizer Exchange Programme Advisory Committee, (chaired by the Minister of Agriculture and composed of vice-ministers of various ministries and farmers representatives) which was established by law in 1965, advises the exchange ratio to the National Assembly for approval. The Food Fertilizer Exchange Act was promulgated in 1965 to give legal foundation to the program.

Under this program, the farmer was free from price and demand risks and he did not have to worry about the price fluctuation after the harvest, as the exchange ratio was set in quantity, not in value. He could also make his production plan in advance as the exchange ratio was known before the planting season. The loan repayment was easy as he did not have to sell paddy to obtain cash to pay back for the fertilizer loan. This factor certainly contributed in higher repayment rate. The program also contributed in the government food procurement program.

Under the program, about 200,000-400,000 tons of fertilizers were distributed annually on credit, and a corresponding quantity of foodgrains were collected. In 1963 about 60% of the food procured by the government was procured through this program. The quantity increased when the government paddy procurement price was considered low. However, since the introduction of the parity rice price policy, which resulted in a high paddy price policy, the necessity for such fertilizer exchange was reduced gradually and in 1976 the program was discontinued.*

USE OF FERTILIZERS

1. Overview

Fertilizer consumption in the 10 Asian countries is around 20-40 kg (in nutrients) per ha. of arable land, with two extremes, i.e., 287 kg/ha in Korea and 7.3 kg/ha in Nepal. Of the total fertilizer consumption in these countries the share of use for paddy ranges from 12% in Pakistan to 86% in Bangladesh. Consumption of fertilizers for paddy also shows a very similar situation, i.e., 20-50 kg/ha in most countries with Korea and Nepal as the two extremes, 228 kg/ha and 4.8 kg/ha respectively.

The amount of the fertilizer used for paddy is very closely correlated with paddy yield, which ranges from 6.9 tons/ha in Korea to 1.8 tons/ha in Nepal. Fertilizer use and paddy yield are also closely related with irrigation.

For details, see Chong Yeong Lee "Food-Fertilizer Exchange Programme - An Integration of Marketing and Credit with Price Policy" in Proceedings of FAO/FIAC Regional Seminar on Fertilizer Pricing Policies and Subsidies, 13-17 February 1978, FAO, Rome, 1979, pp. 240-245.

The most popular product is urea and then ammonium sulphate, which, combined together, shares 60-70% of total fertilizer consumption of most of the Asian countries. (This excludes Malaysia, where muriat of potash and natural phosphate are more popular because c the special crop situation.)

The average use of fertilizers for paddy is still far from the dosages recommended by the respective governments. The gap shows that efforts need to be made. In general, the average fertilizer use on paddy field is around 30% of the recommended dose, with exceptions in the extreme cases. (The average use in Nepal is only 3% of what is recommended, and the figure was 8% in Bangladesh.)

2. Farm Level Fertilizer Use

The field level case studies show that often the average figures on fertilizer use do not represent true picture of actual use. The village level case studies have been conducted in the area where fertilizer is in use and therefore the fertilizer use in those areas tended to be much higher than the national average.

In order for the average figures to represent the farmers fertilizer use in the country, the fertilizer use by the majority of the farmers should be close to the average. The gap between the actual farm level use and the national average is wider in the countries where the average use is low.

There are three types of gaps. Many farmers interviewed have not had much faith in the fertilizer dosage recommended by the government, as the government would not be responsible for any crop failure or economic loss. These farmers strongly believed in their own experiences, rather than the recommended dosage of the government. The same tendency is shown even in Korea where farmers tend to use far more fertilizer than recommended by the government because they say it pays off.

Another problem is uneven distribution of fertilizer use within the country. Of the total cultivated land, the fertilized land area portion is smaller in most of the countries surveyed,(except Korea) and ranges from 25% to 50%. India, for example, being a big country, has a wide gap in agricultural development among the states and therefore shows a big variation in the fertilizer consumption.

There are similar concentrations of fertilizer use in only certain parts of the countries, such as Bangladesh (Dacca-Comila-Chitagon belt), Indonesia (about 65% in Java), India (Punjab), Malaysia (about 80% in west coast of West Malaysia), Nepal (about 60% in Kathmandu Valley), Pakistan (about 70% in Punjab), Philippines (Luzon), and Thailand (Central Zone), except Korea where fertilizer use is rather evenly distributed throughout the country (excluding the hilly areas along the eastern coast).

Another discrepancy comes from seasonal conditions. During the wet season, farmers would not apply much fertilizer for fear of flood or excessive water, or because the land remains under water.

However in most cases, fertilizer use is concentrated during the dry season only in those areas where irrigation facility is available. For

example in Thailand, about 476,000 ha of land was planted under paddy in 1978 (about 5% of the total paddy area) and 97% of the irrigated paddy land was fertilized. The average use during the 1978 dry season was about 100 kg/ha in nutrient, while the national average was about 13 kg/ha.

Even distribution of fertilizer use, throughout the country and throughout the season is desirable for overall increase in fertilizer use and agricultural production.

PRICES AND ECONOMICS OF FERTILIZER USE

1. Price

Although chemical fertilizers are rather standard products, the retail prices set by each government varies widely among the Asian countries, depending upon the government pricing policies and subsidy schemes. Urea which is the most popular product, is the most expensive in Korea and the cheapest in Bangladesh. In Nepal, the price of ammonium sulphate is high because of the government pricing policy to discourage overuse of the product. Details are shown in Table 1.

Table 1: Retail Price of Major Fertilizers, 1976 (US $/ton)

Country	Urea	Ammo. Sulph.	T.S.P.	Potassium Chloride	16:20:0
Korea	252	141	150	104	-
Malaysia 1/	208	104	-	138	-
Philippines 2/	205	75	259	140	178
Nepal	195	150	305	126	-
India	182	111	189	96	202
Indonesia 3/	169	-	169	-	-
Thailand 4/	160	65	-	-	140
Sri Lanka	159	91	181	-	-
Pakistan	136	62	92	-	78
Bangladesh	109	-	87	73	-

Note: 1/ Private retailers price
2/ Average ex-warehouse price in Luzon. No fixed retail price.
3/ Retail price for BIMAS/INMAS Scheme
4/ Wholesale price to private retailers.
All others are retail prices announced by the respective governments.

Although Table 1 shows the prices announced by the government, the actual price paid by the farmers at retail shop is often different from the price quoted by the governments. In most cases, the farmers pay more (5-10%) than what the government said the fertilizer price was.

2. Paddy/Urea Ratio

Usually in each country there is a political pressure to lower fertilizer price so that farmers may find it beneficial to use more fertilizer which in turn will increase food production. But low fertilizer price does not guarantee higher fertilizer use by the farmers, nor does it always lead to increase in food production. Therefore, fertilizer price should be evaluated by comparing it with the price of agricultural produce. In comparing fertilizer prices and price of the most significant agricultural produce for which the major portion of fertilizer is used (such as paddy), the prices announced by the governments do not mean much. The farm gate price, actually paid or received by the farmer is important. Table 2 shows the differences among the countries under study.

Table 2: Paddy-Urea Ratio, 1976 (US cents/kg)

Country	Urea Price (1)	Paddy Price (2)	Paddy/Urea Ratio (2÷1)
Korea	25	43.0	1.72
Sri Lanka	20	23.4	1.17
Malaysia	17	19.5	1.15
Indonesia	17	16.3	0.96
Bangladesh	10	8.5	0.85
Philippines	23	17.4	0.76
Thailand	20	11.7	0.59
Pakistan	14	7.2	0.51
India	20	9.5	0.50
Nepal	20	9.8	0.50

Above table shows, for example, that with 1 kg of paddy, a Korean farmer could buy 1.72 kg of urea in 1976, while a Nepalese farmer could buy only 0.5 kg of urea. Although the Korean farmer's fertilizer price was the highest among the 10 countries, the paddy price in Korea was relatively much higher so that the Korean farmer's terms of trade were much better off than that of the Nepalese farmer. The urea price paid by the Bangladesh farmer was the lowest, i.e., only 40% of what the Korean farmer paid, but the price of paddy he received was also relatively much lower, i.e., only 20% of what the Korean farmer received. Therefore his profitability was only less than a half of his counterpart in Korea.

In general it seems that the paddy/urea ratio which shows the farmers' terms of trade is closely correlated with fertilizer use and yield as shown in Table 3.

Table 3: Relationships of Paddy/Urea Ratio, Fertilizer Use for Paddy and Paddy Yield, 1976

Country	Paddy/Urea Ratio		Fertilizer Use		Paddy Yield	
	Ratio	Ranking	kg/ha	Ranking	kg/ha	Ranking
Korea	1.72	(1)	228.0	(1)	6,870	(1)
Sri Lanka	1.17	(2)	51.8	(3)	2,269	(5)
Malaysia, W.	1.15	(3)	56.3	(2)	3,057	(2)
Indonesia	0.95	(4)	43.8	(5)	2,763	(3)
Bangladesh	0.85	(5)	20.9	(8)	1,939	(7)
Philippines	0.76	(6)	43.4	(6)	1,959	(6)
Thailand	0.59	(7)	13.3	(9)	1,813	(9)
Pakistan	0.51	(8)	45.0	(4)	2,400	(4)
India	0.50	(9)	29.0	(7)	1,813	(9)
Nepal	0.50	(10)	4.3	(10)	1,806	(10)

Note: Coefficients of rank correlations of above three sets of data are:

0.8364 between paddy/urea ratio and fertilizer use,
0.7879 between paddy/urea ratio and paddy yield, and
0.9515 between fertilizer use and paddy yield,
using Spearman's formula for rank correlation

$$r = 1 - \frac{6 \Sigma D^2}{N(N^2 - 1)}$$

where r = coefficient of rank correlation
D = differences between ranks of corresponding values of the pair of data
N = number of pairs of values in the data, i.e., 10.

Above analysis shows that in order to encourage greater use of fertilizers, the price of fertilizers should be adjusted vis-à-vis the price of agricultural produce. A lower fertilizer price through subsidy does not guarantee increase in fertilizer use.

3. Value/Cost Ratio

The value/cost ratio is the most commonly used indicator of assessing the economics of fertilizer use. The VCR is a function of management of farming practices, soil, and an adequate supply of other agricultural production inputs in addition the price of fertilizer and agricultural produce. A nationwide average VCR is not available in all the countries, and most of the data available are fertilizer trials and demonstration on some selected farmers land as shown in Table 4.

Table 4: Value/Cost Ratio of Fertilizer Use for Paddy, 1976

Country	V/C Ratio	Remarks
Bangladesh	5.36	Boro HYV, FAO/FIAC Fertilizer Price Policy Seminar Proceedings, Bangkok, Fe. 1978
India	3.25	HYV, FAO/FIAC Seminar
Indonesia	5.40	Irrigated Paddy, FAO Fertilizer Programme
Korea	4.50	HYV, a case study in Osan myon, Iksan-gun Chunpook, FAO/ESCAP Workshop case study Korea
Malaysia	2.00	Trial results in MUDA Project area
Nepal	1.53	Local variety, in 7 locations, by Ag Dept, GON
Pakistan	3.20	IRRI 6, Punjab Province, FAO/FIAC Seminar
Philippines	3.98	1,326 trials under FAO Fert. Programme
Sri Lanka	5.50	Annurdhapura Dict., ARSAT Country report
Thailand	3.12	RD-1, Gov't fertilizer trials, ARSAP country report

If we accept the common understanding that VCR should be at least 2 or more to provide sufficient incentive for a farmer to use more fertilizers, above figures indicate that the minimum economic condition for increased fertilizer use are prevailing in most of the countries if high yielding varieties of seeds are used, and if there are no natural disasters.

PROMOTION OF FERTILIZER USE

1. Agricultural Extension Service

Agricultural extension service is a critical factor in promoting greater, as well as scientific use of fertilizers. In all of the Asian countries, the extension is available at least in principle. Usual extension methods are: fertilizer trial, demonstration, farmers field day, fertilizer festival, leaflet, pamphlets, radio, use of key farmers (model farmers), etc. It is difficult to compare the intensity of the extension service available to the farmers. A popular measure is physical coverage of the field level extension workers and the number of farm householdings to be covered by an extension worker. Assuming that they work in the field as they are supposed to do, the number of field workers (excluding those who work in the office), and covering area and covering farmers give some indication.

The area to be covered by a field extension worker is around 2,000 ha per extension worker, ranging from 380 ha (Korea) to 6,000 ha (Thailand). Certainly this is too large an area to be covered adequately by one field extension worker. Between 1,300-2,000 farm households have to be served by a field extension worker who usually has no transport, except Malaysia, Korea, Philippines and Sri Lanka. These extension workers have many other

duties such as collection of field statistics, community development, family planning, and occasionally political election campaign. This is one of the reasons why many farmers interviewed said that they have never seen extensio workers in the last one or two years.

Another measurement of the intensity of the extension service is its financial intensity. According to available information on limited number of countries, the agricultural extension budget is around $1,300 per extension worker and only $2-3 per farm household, except for Korea and Japan.

2. Use of Fertilizer Dealers

In many countries, farmers complained that the services of field extension workers were not enough, or were not available. But all the farmers interviewed knew that "fertilizer is something" useful to crops, like a medicine to human body, although very few farmers in most of the countries except Korea, knew correct dosage. Therefore a farmer buys only the amount of fertilizers that he can afford. In order to buy fertilizer he has to contact a fertilizer retailer. Therefore fertilizer dealers, whether cooperative societies or private retailers, can be used as very effective extension agents to promote and instruct the use of fertilizers.

The fertilizer retailers, cooperatives and private, surveyed had very little knowledge on the product and proper usage of fertilizers. They were then not in a position to give proper answers to the questions by farmers about fertilizers.

Only Planters' Product, Inc. (PPI), which shares about 70% of the total fertilizer distribution in the Philippines has a thorough and systematic program to make full use of its retail dealers for the promotional activities, under its "farm demonstration program," which is a cooperative effort between PPI and its dealers to convince more farmers to use more fertilizers correctly. Under this program, all of the 1,000 dealers in 900 municipalities are required to set up a minimum of one demonstration farm 1 ha planted to rice or corn per cropping season through a volunteer farmer-cooperator. The dealers advance all the farm inputs, payable at cost after harvest. On the other hand, the company provides all the advisory, management and technical services in the entire process of the demonstration and disseminates the results to farmers. In order to carry out this program, the dealers should have proper knowledge on fertilizer use. Therefore all the dealers have to go through dealer training process and, in recruiting its dealers, the company applies its "Dealer Criteria and Requirements."

It seems that the effectiveness of fertilizer retailers, whom the farmers make contact to buy fertilizers, would be very useful and could be the practical augmentation to the official extension workers' limited time available for each farmer.

Promotional activities by fertilizer manufacturers or distributors are commonly practiced in India, Malaysia, Thailand, in addition to the Philippines, where commercial fertilizer manufacturers or distributors are involved in fertilizer distribution. Some of the innovative programs in India are summarized in Table 5.

Table 5: Innovative Fertilizer Promotion Programs in India

Program	Started	Major Features of the Program	Result
Village adoption program	1960s	Intensive promotional work on a selected village "adopted" by a manufacturer	50% increase in production 58% increase in fertilizer use
Technical extension program	1960s	One unit of TEP consists of 5-10 villages, with 1 ha demonstration plot in a central village as a living classroom	On 3 crops of rice, one farmer harvest 22 tons of paddy a year
Fertilizer Festivals	1960s	Training and demonstration for farmers by using music and other traditional festival features	Very effective promotional means
Marginal farmer development	1970s	A compact block of 8 marginal farmers (1 acre) in a village, was recommended intensive cultivation by providing inputs, with IARI and ENSP supports	Wheat yield increased from 1.5 ton/ha to 4.2 ton/ha and improved cultivation practices
Block Demonstration	1973	Demonstration in block of 2-100 ha of contiguous land, by fertilizer manufacturers and with government support	Significant increase in yield and adoption of improvement management
Integrated nutrient supply system	1975	To teach efficient use of fertilizers and organic manures, to monitor crop nutrient change and to improve general soil fertility, in 53 village by ICAR	Fertilizer utilization and plant nutrients improved considerably

Source: Summarized from H.L.S. Tandon "Fertilizer Promotion - A Review in Fertilizer News," Fertilizer Association of India, July 1978.

In many countries, the problem with such innovative programs was that the programs were rather limited in scope and coverage, lacked continuity, and were concentrated on certain aspects of agriculture only. Therefore the programs could not be developed into a national program and they did not contribute in the overall increase of fertilizer use.

COMMON CONSTRAINTS AND APPROACHES FOR THE IMPROVEMENT OF FERTILIZER MARKETING

Excluding Korea and in some cases, Malaysia, the problems and constraints related with fertilizer marketing especially at the village level are more or less similar in all the developing Asian countries, although there are some differences in terms of urgency and emphasis. Detailed measures to improve the situation should be different by countries, but many of the problems are common and similar approaches may be contemplated.

1. Pricing and Economics

The best incentive for farmers to use more fertilizer is not cheaper fertilizer price but favorable crop price vis-à-vis fertilizer price. The improvement of the crop/fertilizer price relationship in favor of farmers is essential. Many countries levy tax on fertilizer trade (import duty, excise duty, sales tax, etc.) and the fertilizer price may be lowered by removing the taxes or subsidizing the price through government budget. But higher crop price, rather than lower fertilizer price, is more effective in increasing farmers' net returns and therefore in increasing fertilizer use, as was shown in Korea and also experienced in the Philippines.

There is a very strong positive co-relationship between the crop/fertilizer price relation, fertilizer use and crop yield.

The increase of crop price is politically more difficult than lowering fertilizer price. A strong political commitment in favor of farmers, especially small farmers, is essential in improving the situation.

2. Institutional Arrangements on Marketing and Credit

One of the problems most often cited in the village-level case studies, and also during the national workshops in the nine Asian countries, was an insufficient number of fertilizer retail points close to the village. The farmers have to travel up to 25 km to buy fertilizers, and the road linkage is poor.

The solution has many implications. To have a retail point near or in every village so that farmers' travel time and transport costs may be reduced, the area and the number of farmers to be served by each retailer would be small so that the retailer may be able to offer more intensive service. On the other hand, it will reduce its volume of trade which has an immediate impact on its managerial efficiency. India's plan is to have one fertilizer retail point within 5 km of every village. The closeness of the retailer to the village and his operational efficiency has to be considered simultaneously.

The approaches would be from both sides, reach-down and reach-up. The number of retail points should be increased, especially in the South Asian countries, and at the same time efforts should be made to place them in villages not concentrated in market areas only. Parallel with this effort, the village farmers should be encouraged to organize group purchase and

group transport from retail point to the village. The group transport on a voluntary basis is a common practice in Korea.

Inefficient credit system is another very important constraint. At the village level, the availability of short-term production credit in which fertilizer credit is included is linked more with application procedures and repayment than with availability of funds on the part of the credit institutions. The goal of institutional credit is to make the loan procedures as simple as the loan from private money lenders. The complication of the loan application procedures is directly connected with precaution for the loan collection, i.e., collateral. Therefore the basic issue boils down to the loan repayment rate. Strict discipline and direct pressure to pay back are keys for increasing the loan repayment rate. Assuming these basic conditions are met, the most commonly suggested measures are programs to safeguard unexpected crop failure and measures to facilitate the loan repayment. Introduction of crop insurance program was suggested in 7 of the 9 national workshops, and all the national workshops suggested measures to link fertilizer credit with marketing of produce. Based on the experience on crop insurance, (Japan and Sri Lanka), there is scope that crop insurance can be successfully introduced in other Asian countries, and several countries are making preparation for the introduction. For integration of fertilizer credit with crop marketing, a close link with institutions dealing with fertilizer distribution, credit and procurement of agricultural produce should be established. On national scale the program was successful in Korea, and on experimental basis or in some limited scale the program has been carried out in several Asian countries on ad-hoc basis. It is necessary to expand the program and make it an institutional feature.

3. Physical Distribution Management

Basically there are four areas in the physical distribution of fertilizers, i.e., storage, handling and transport packaging and quality control.

The real felt need in all the village level case studies and the national workshops, except for Korea, was good storage facilities for fertilizer retailers. In India, out of 141,000 village cooperatives, only 25,000 or 20% have storage facilities. The village level storage is required for fertilizer quality control and for maintenance of minimum requirement, until replenishment of stock so that fertilizer may be available all the time. In order to solve the problem of the seasonal rush in demand, off-season discount to the retailer (like Nepal) would be useful to disperse the stock down to retailer level during the off-season. This measure was recommended in most of the national workshops. But for this, retailers need storage. Financial support is necessary for this purpose.

In order to reduce the handling costs, the physical handling should be minimized as far as possible. In some countries, fertilizer bags are loaded and unloaded 14 times before it reaches the farmers, causing losses, deterioration of quality, delay and higher marketing costs. The approach should be to separate the physical flow of fertilizer from the flow of the documents. Fertilizer should move from the factory or the

main depot directly to the retailers or as close as possible to them, whereas the documents related with the fertilizer shipment and payment may move through separate channels.

Bulk handling is being practiced in limited scale in Indonesia, Pakistan and the Philippines, but was discontinued in Thailand and Sri Lanka, despite the fact that it would be economical. For the bulk handling to be economical, the entire distribution process and other infrastructure should also be ready for bulk handling. Otherwise, experiences in some Asian countries showed that bulk handling without proper systems organized caused more losses, uneconomical and deterioration of quality.

The most popularly used bag size is 50 kg bag, polythene or jute with polythene liners. For the convenience of handling during loading and unloading and during retail sale to meet the demand for less than one bag, and also to protect fertilizer from quality deterioration, the need for the reduction of the bag size (25 kg) was expressed often by farmers and the national workshop.

Reduction of physical losses during the fertilizer distribution is a critical factor. The losses are often estimated to be 2-3% at least and run up to more than 5%. An approach here would be the introduction of a system whereby the origin and responsibility for the losses may be easily traced and accounted for. Under the present set up, in most cases the losses, both quantity and quality losses, are often passed on to the farmers.

4. Promotion of Fertilizer Use

The economic factors mentioned above are the most critical in promoting more use of fertilizers. But aside from such economic factors, several technical factors affect the fertilizer use.

Throughout the village level case studies, water was the most commonly cited factor which affects use of fertilizer. Fertilizer use for wet season crops is limited because of fear of flood and excessive water. Also fertilizers cannot be properly used during the dry season. Most of the fertilizers used for paddy is used for the dry season under irrigated condition. Therefore development of irrigation facility is an essential precondition for increased use of fertilizers.

Another frequently mentioned problem was the need for proper soil testing which will affect the fertilizer recommendation. In most village-level case studies including the Korean cases, the farmers did not pay much attention to the recommended dosage, but used fertilizers based on their own "experiments," saying that "my soil is different." Under the present set up which does not guarantee the promised yield if the farmer follows the recommended fertilizer dosage, leaving the farmer to take risk, he has no choice but to trust himself only. Establishment of the farmers' confidence on the fertilizer recommendation supported by intensive extension is important.

Extension service is often available on paper but actual contact with farmers is not enough. In order to supplement the extension service, progressive farmers (key farmers, model farmers, contact farmers, etc.) are

used in most of the countries, yet their efficiency also depends upon the efficiency of the formal extension service. Fertilizer dealers can be good augmentation of the formal extension service. Fertilizer retailers (both cooperative and private) can be trained on basic knowledge of agronomy, fertilizers, and fertilizer application, in addition to training on storage management. The dealer training has been mentioned as a very useful program but in most of the countries surveyed, especially in those countries where government and public sector plays dominant role in fertilizer distribution, systematic and intensive dealer training program have not been carried out.

CONCLUSION

The 10 developing countries which have been analyzed in this report may be divided into three groups, with respect to fertilizer marketing systems: South Asia Group (Pakistan, India, Nepal, Bangladesh and Sri Lanka), South-East Asia Group (Thailand, Malaysia, Indonesia and the Philippines), and Far East Asia Group (Korea).

In the South Asian Group, the government dominated fertilizer marketing and related activities because of inherent distrust of private traders. Because of this, bureaucractic situation tends to develop at upper level. But the government intentions reflected in the fertilizer marketing rules and regulations tend to be diluted as the activities move further down toward the village. When it reaches the farm level, the government intention is often not felt by the farmers, and the village-level situation is not the same as the policy planners planned. In order to stimulate efficiency of the government or cooperative marketing channel, perhaps more active utilization of the private sector resources would be useful, especially for village-level fertilizer credit and distribution. Since 1976, Sri Lanka has started to remove restriction of the private sector participation on fertilizer import and marketing. In Bangladesh, there is a strong school of thought that private traders should be more actively used for the village-level fertilizer distribution as the village-level cooperatives are not working properly.

In the South-East Asian Group, in general the tendency is reverse. Here, the government plays a smaller role than in the South Asian countries, and private sector is allowed to play an important role. This tendency is especially true in Malaysia Thailand and the Philippines. In all matters related to trade and mark ting, the governments in the countries of this group seem to try to intervene less and let the private sector play a more important role. The governments in these countries should be more active, and direct the influence of fertilizer marketing and credit systems. The tendency has been seen in the Philippines when Fertilizer Industry Authority (now Fertilizer and Pestic Authority) came into operation. In Thailand, Marketing Organization for Farmers (MOF) started its operation in 1975 and started to intervene in both fertilizer marketing and food procurement. In Malaysia, one of the most strongly supported recommendations during the national workshop on fertilizer marketing (Feb. 1977) was the idea of establishing the Fertilizer Industry Authority to exercise more government control.

In the Far East Group (Korea only for this study), the entire fertilizer marketing system is controlled by the cooperatives under the strong policy guidance of the government. As the major functions which are related with fertilizer marketing, i.e., fertilizer distribution, provision of production credit and providing a market outlet for the farmers' produce, are carried out by one agency and the problem of coordination of these three functions have been solved. Under this system, the government intention does reach the farm level more efficiently than the case of the countries in the South Asian Group or South East Asian Group. Although there is a strong government influence at the policy level, the cooperative sector at village/farm level is under pressure to improve its efficiency, because the cooperative has to compete against private sector, especially in the produce marketing.

RECOMMENDATIONS OF THE FERTILIZER FLOWS CONFERENCE

Summarized by:

RICHARD SHELDON AND SALEEM AHMED*

The recommendations emerging from the Fertilizer Flows Preparatory Conference, made at the conclusion of the two-week fertilizer-related meetings, are summarized below:

A. Fertilizer Resources and Raw Materials

1. A system for the international exchange of data needs to be developed. This system would include fertilizer resource data using standard classification and uniform resource assessment methodology. The exchange could best be accomplished by workshops in countries of the region.

2. Geologic research on origin of fertilizer minerals should be strengthened, and should particularly focus on models of deposition based on chemical sedimentology, paleoclimatology, paleo-oceanography, and plate tectonics.

3. Areal geological and geophysical mapping should be undertaken in countries of the region at scales appropriate to resource assessment and exploration, and should include studies of seismic stratigraphy and basin analysis.

4. Resources in countries of the region need to be assessed, based on evaluation of present geologic data using uniform methodology by applying models of deposition in regions geologically mapped.

5. Exploration of mineral resources should be strengthened utilizing available techniques. This exploration should include the tools of remote sensing and geochemical exploration. New techniques suited to the needs of the region should be developed.

6. Mine designs appropriate to local geologic conditions need to be developed. Improved flow of information on beneficiation technology is also needed in order to utilize local fertilizer raw material ores. Environmental impacts of mining and beneficiation also need to be analyzed.

7. Alternate methods for supplying fertilizers to small farms need to be explored. The utility of the Electric Arc nitrogen and Phosphorus Generator, a potential tool for

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*Richard Sheldon and Saleem Ahmed were co-coordinators of the conference.

small farms using alternative energy sources, should be investigated further. Ways to utilize low grade rock phosphate deposits in conjunction with the generator should also be examined.

B. Fertilizer Needs/Agronomy

1. Studies with urea super granules (USG), to confirm results of previous INPUTS agronomic studies, need to be strengthened. Also marketing, socio-economic and other parameters likely to impact and be impacted by USG use need examination.

2. An examination of the spatial needs and arrangements of the component crops should be included in future work on inter-cropping cereals with legumes. Investigation of residual effect of legumes should be continued.

3. Research to improve biogas utilization, as well as utilization of organic materials as fertilizer should be strengthened.

4. Techniques for more accurately assessing arable lands and for monitoring changes in land use are needed. Although use of Landsat imagery offers a potential tool here, more research is needed to develop correlations between ground observations and Landsat spectral signatures, particularly under small farm systems.

5. Research on water and pest management concepts should be integrated with fertilizer management research in an effort to improve the crop yield: fertilizer-use ratio.

C. Fertilizer Commerce and Marketing

1. Constraints and disincentives to efficient fertilizer marketing and use should be identified, both at the macro and policy-levels, as well as micro and village-levels, in order to increase fertilizer use and enhance food production.

2. Government policies regarding fertilizer pricing, subsidy and taxation, and their effect on fertilizer use need to be evaluated.

3. Studies on farmer decision-making regarding fertilizer use should be continued. Steps to bring about a more balanced use of fertilizers should particularly be explored.

APPENDIX:

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