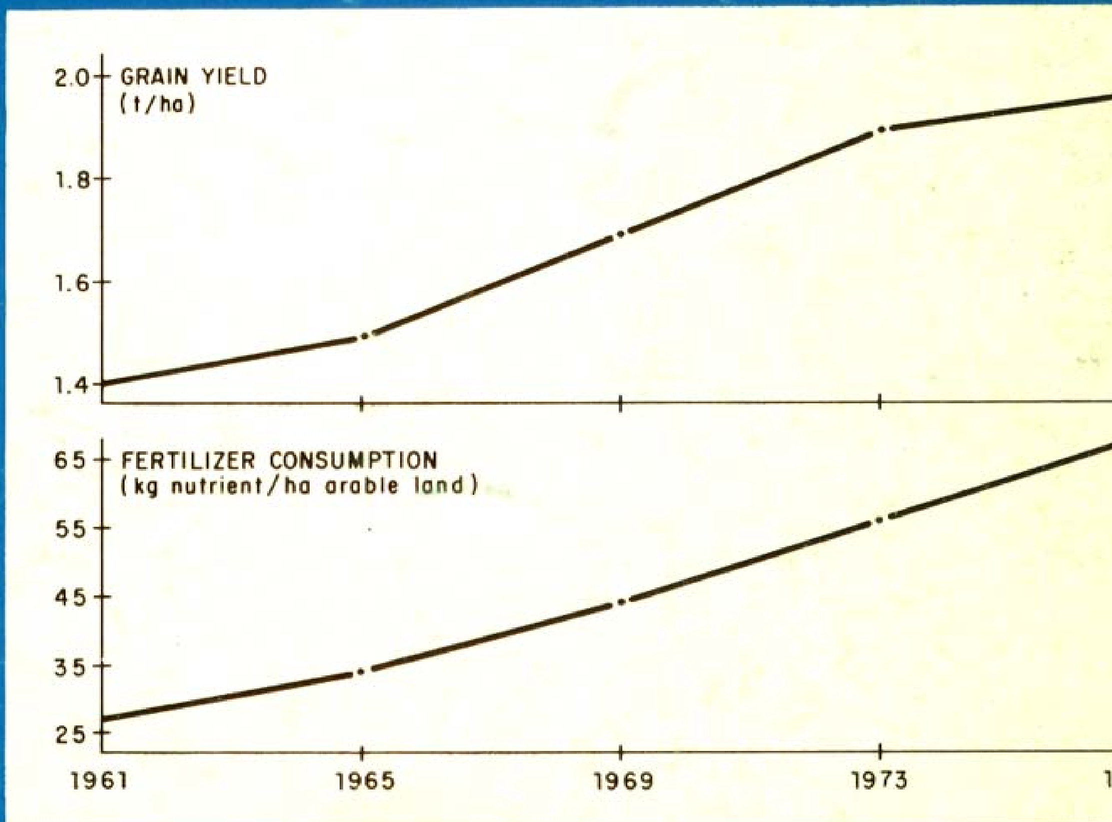
crop production levels and fertilizer use



FOOD AND AGRICULTURE ORGANIZATION
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FAO FERTILIZER AND PLANT NUTRITION BULLETIN 2

crop production levels and fertilizer use

fertilizer and plant nutrition service
land and water development division

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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1. INTRODUCTION

The first edition of Crop Production Levels and Fertilizer Use, by M.S. Williams and J.W. Couston, appeared in 1962, the first publication of the FAO Freedom from Hunger Campaign, Fertilizer Programme. The main topics presented were the relationship between fertilizer use and crop yield at the national level, the role of fertilizer in agriculture and how to get farmers to use fertilizers. Much of the discussions were devoted to the first two issues, which at that time was understandable, considering that the FAO Fertilizer Programme had just started. Among other things, the publication showed that increased use of fertilizer is a pre-requisite to increased agricultural production. This was supported by data on fertilizer use from different countries.

Since 1962, considerable information has become available, particularly on crop response to fertilizer in developing countries. With the advent of high-yielding varieties of crops, most of the response data used in the 1962 edition needed revision and updating. Fertilizer supply and prices have now also become more important issues in the development of fertilizer use, at both the national and farm level.

It was in this context that the FAO/FIAC *ad hoc* Working Party on the Economics of Fertilizer Use in its report of the Seventh Session in March 1977 agreed to undertake the updating and revision of this publication with more attention to the economic aspects.

2. FERTILIZERS IN CROP PRODUCTION

Up to the 19th century world population increased slowly, so food production did not need to increase much either. Where local population numbers increased, food production was increased mainly by enlarging the cultivated area, not by increasing yields per unit of area. In the 20th century, however, the population almost tripled between 1900 and 1980 to over 4 300 million and is expected to reach at least 6 000 million before the end of the century. The solution to the problem of providing enough food for the entire population depends on what extent productivity of existing land could be increased.

2.1 ROLE OF FERTILIZER IN INCREASING PRODUCTIVITY

Increased agricultural productivity usually comes as a result of the effective adoption of improved technologies. Wortman and Cummings, Jr. (1978) recognized four requisites which should be met to enable farmers, regardless of size of holding, to increase productivity. These are (a) An improved farming system: a combination of materials and practices that is clearly more productive and profitable, with an acceptable low level of risk, than the one he currently uses must be available to the farmer; (b) Instruction of farmers: the farmer must be shown, on his own farm or nearby, how to put the practices into use, and he should understand why they are better; (c) Supply of inputs: the inputs required, including fertilizer, and, if necessary, credit to finance their purchase, must be available to the farmer when and where he needs them, and at reasonable cost; (d) Availability of markets: the farmer must have access to a nearby market that can absorb increased supplies without excessive price drops.

The third requisite, supply of inputs, to which fertilizer belongs is indeed one of the most important factors for increased yield. It is assumed that a combination of all the production factors and conditions in a given farm situation results in a given yield, so that, if all factors are optimum - fertilizer type and rate, variety, soil condition, water, pest control, etc. - yield will be maximized. However, the absence of any of these factors would mean that yield is low or nil. If any factor is less than optimum, yield will be reduced correspondingly. For example, the presence of the optimum amount of all factors does not necessarily mean getting optimum yield if fertilizer is absent or applied at a low rate. In fact, the contribution of fertilizer to increased yield is perhaps the greatest among the purchased inputs (Couston and Aspiras, 1979). Fertilizer, when used in combination with the other inputs such as high-yielding varieties and irrigation water, results in positive interaction thereby increasing further its contribution to yield increases.

2.2 FOOD PRODUCTION AND FERTILIZER USE

World food production can be increased by (a) intensifying food crop production on land already under cultivation and (b) expanding the area planted to food crops, e.g. through more continuous use of the very large areas of generally poor soils which are now usually employed only for "shifting cultivation". The success of both methods will depend on judicious use of fertilizers.

Not much more than 25% of the total land area can be considered as suitable for continuous food crop production, of which less than half is presently used. In the world as a whole, 43.5% of the potential crop area is now under continuous crop production but the percentage varies considerably between regions. In Asia, for instance, where it amounts to more than 82%, increased food production must be sought primarily from higher yields per hectare on the existing crop area. In Africa and South America, on the other hand, with about 21% and 11% respectively of the potential crop areas currently being used for sustained food crop production, there are still tremendous possibilities for expansion. One must take into account, however, that most of the reserve soils consist of poor Oxisols and Ultisols. These strongly weathered, highly leached soils of low base status, which cover just over one-half the tropical agricultural areas of South America and Africa, and relatively smaller areas of the high country of South-east Asia, are generally deficient in nitrogen, phosphorus and potash, while micronutrient and sulphur problems are common, and alluminium toxicity problems may occur. Correcting these nutritional problems usually involves substantial investments in fertilizers and other inputs.

In 1972, Asia which had 57% of the world's population, had a potential per capita crop land of about 0.29 hectare, compared with 2.0 and 2.27 hectares respectively for Africa and Latin America. This situation implies that unless a substantial increase in land productivity is achieved, food shortages would be most critical in the Asian region. Food requirement of the developing countries is expected to grow at an annual rate of 3.7% up to the year 2000, while food production would grow at a rate of only 2.7%, leaving a huge food deficit by the year 2000. This shows the urgency of improving the past trend of food production if worldwide hunger is to be avoided.

2.3 THE ADVENT OF HIGH-YIELDING VARIETIES

The technological breakthrough in production per unit of area, known as the Green Revolution, provides the means for a considerable increase in production from existing crop areas. The Green Revolution is based on the development, through breeding and selection, of new crop varieties with high yield potentials. Whether these high yield potentials are realized, however, depends on the fulfilment of a series of factors including proper use of fertilizers and a good, well-controlled water supply, in conjunction with improved cultural practices.

The traditional tropical rice varieties show vigorous growth, tall stature, weak stems and leaves, and low grain : straw ratios. They respond to nitrogenous fertilizer applications by an increase in vegetative development, which may cause lodging and subsequent yield losses at higher nitrogen rates. With high solar radiation, the optimum responses to nitrogen are obtained at 30-50 kg N/ha, with yields in the order of 2.3 tons/ha. Under conditions of low solar radiation during the wet monsoon, even low nitrogen rates may result in decreased yields. Such negative responses of traditional rice varieties to nitrogen are largely the result of lodging.

The introduction of a new rice plant type by the International Rice Research Institute at Los Baños, Philippines has completely changed nitrogen management practices. The new varieties have the ability to convert more nitrogen and photosynthates into grain, using a smaller straw base, than do the tall traditional *indica* varieties.

The development of high-yielding, disease and lodging-resistant, semi-dwarf varieties of wheat, begun by the Rockfellar Foundation in Mexico in 1943, has been one of the most spectacular successes of the Green Revolution, particularly in Mexico and India, where wheat is extensively grown under conditions of well-controlled irrigation. The new varieties have made it possible to utilize more fully the inputs of water, fertilizer and pesticide.

Short-statured, fertilizer-responsive varieties with a high production potential have also been developed for sorghum (*Sorghum bicolor*) and millets (particularly pearl or bulrush millet, *Pennisetum typhoides*) but in developing countries these are mainly grown in semi-arid areas, where lack of moisture may be a limiting factor. Even so, significantly higher yields have been achieved in many semi-arid areas by combining the use of high yielding varieties with proper soil, moisture and crop management systems, including a well-balanced fertilizer programme with moderate amounts of nitrogen and phosphate, often supplemented with some zinc.

Because water must be considered as a basic input in more intensive farming, the use of the new high-yielding varieties will tend to be concentrated in areas under controlled irrigation or with assured rainfall but not subjected to damaging floods. The importance of irrigation, particularly in the densely populated, land-scarce areas of Asia and the Middle East, and the importance of water as one of the basic inputs in the technological breakthrough in production per unit of area must be made quite clear. On the other hand, because irrigation projects are costly enterprises, it is essential to give full attention to all aspects of making the most profitable use of the irrigation water by means of high-yielding varieties, fertilizer, plant protection measures, and so on.

If adequate irrigation facilities are available in tropical areas, where temperature is not a production-limiting factor, there are possibilities for double or multiple cropping. Within the framework of the Green Revolution, new short-duration varieties have been developed which are much better adapted to multiple cropping rotation schemes, permitting three or even four different crop yields per year. Short-duration varieties with reasonably high production levels have been developed, for example, for rice, wheat, maize, sorghum, millet, potatoes, rapeseed and grain legumes.

2.4 FERTILIZER USE AND IMPROVED AGRICULTURAL TECHNOLOGY

2.4.1 Shifting Cultivation to Modern Agriculture

The development of fertilizer use had an influence on the practice of shifting cultivation and triggered the start of permanent cropping in some countries where agriculture is relatively well developed. However, shifting cultivation occurs in almost half the tropical world in both forested and savanna areas. These are usually the least developed areas, where peasants cut and burn a small area, plant several crops in the same field, and abandon the fields when yields decrease under the influence of declining soil fertility, increasing weed infestation or other factors.

With shifting cultivation, soils of naturally low fertility are utilized in a sequence of short periods of crop production and longer periods of fallowing. During the fallow period there is a build-up of soil fertility and an accumulation of plant nutrients in the natural vegetation and in the top layer of the soil, which are used by the crops during the cultivation period. Different amounts of nutrients are stored in different plant associations. The amount stored generally declines from tropical rainforest, through monsoon forest and secondary forest, to woodland and grass savannas. Peasant farmers make use of the nutritional accumulation of several years of fallowing, concentrated in biomass and organic matter, for the short-term growing of food crops. Burning, used to clear the land, causes a rapid release of the organically-bound nutrients. In the process of burning however, much of the nitrogen and sulphur, is lost by volatilization.

Although shifting cultivation is also widely used in the Amazon Basin of South America, Central America and the hill country of Southeast Asia and the Pacific, it is practised most extensively in Africa, where it is part of the social and economic life of many millions of people and is closely associated with subsistence farming. With a low population density and with still enough land available for cropping, shifting the crop area to newly cleared land, although very labour-intensive, is the least expensive method in capital investment for maintaining a certain, relatively low level of production, particularly when all the labour needed is provided by the family.

Under the impact of increasing population pressures, the system of shifting cultivation, which is only possible in thinly populated areas, is now breaking down fairly rapidly in many parts of Africa and elsewhere. As population density increases, the fallow periods left for the restoration of soil fertility become shorter and shorter and the accumulated nutrient reserves less and less. In consequence, the only reasonable solution to the resultant problem of nutrient deficiencies is the rational use of fertilizers. Without the use of fertilizers, crop yields drop to uneconomic levels after a couple of years of continuous cropping.

It is quite clear, therefore, that any significant extension of the cropping period must be accompanied by appropriate use of fertilizers if yields are to be maintained and that, in the gradual transformation of shifting cultivation into more permanent cultivation, the use of fertilizers is the main spearhead. In most cases the use of fertilizers has proved to be economic, provided the types and quantities have been adjusted to the prevailing conditions.

Apart from increasing population pressure, another reason for the necessary transformation of shifting cultivation into permanent cropping systems is the change from a subsistence to a market economy. The objective of subsistence farming is to produce for the current demand of the farmer and his family. In modern society, however, agricultural activity has a much wider and more complicated three-fold task. Firstly, it must provide for the requirements not only of a rapidly increasing rural population but also an even more rapidly growing urban population. Therefore a considerably higher and steadily increasing surplus will be necessary to maintain self-sufficiency in food production. Secondly, agriculture has to provide several of the raw materials, e.g. fibre and oil crops, required for developing local industries, while thirdly, for most developing countries, it is the agricultural sector which has to earn badly needed foreign exchange by remunerative production of export crops. Thus, in the predominantly agrarian communities of developing countries, a highly productive agriculture is of the utmost importance. Such a highly productive agriculture is inconceivable without judicious use of fertilizers.

The use of fertilizer appears to be one of what may be called the "lead" practices. It is one of the practices which tend to be adopted fairly early by farmers as they move from traditional system farming to more improved and productive systems. Research studies indicate that farmers tend to change from traditional patterns by first accepting one or two fairly simple new ideas and putting them into practice. However, once the process of change starts, it tends to accelerate. Experience in other countries indicates that this tendency is widespread.

Teaching farmers the proper use of fertilizer can be a strong factor in motivating them to accept other modern methods to increase crop production. The response from fertilizer is usually strikingly visible - the differences in growth, colour of the plant, and size of the crop or fruit are evident to the eye of even the untrained observer. Secondly, fertilizer is something tangible. The farmer can see it, handle it, and know when he has applied it. Another advantage is that the farmer gets relatively quick returns from the use of fertilizer, especially on annual crops.

2.5 BASIC TECHNIQUES AND METHODS TO MOTIVATE FARMERS TO USE FERTILIZERS

One of the most difficult problems in moving from a traditional to a modern agricultural economy is the well-known resistance to change by the individual cultivator. While experience in one country cannot be transferred exactly to another country, the techniques and methods used can provide guides for developing programmes and activities elsewhere. Therefore, the methods used in some of the more developed countries may be helpful in securing the adoption of new practices in the developing countries.

The present conditions in most developing countries dictate that simple and practical methods must be used in securing the acceptance of fertilizer use by farmers. The following suggestions are based on what have been proved by experience to be practical means of getting farmers to use fertilizer. They assume that enough experimental work has been done to indicate the need for fertilizer and give at least rough indications of the optimum rate of application.

Perhaps the most effective method of teaching farmers the value of soil fertility is through large numbers of actual field demonstrations and trials such as those carried out by the FAO Fertilizer Programme. This is especially true where a large percentage of farmers cannot read or understand printed material. To be most effective, the demonstrations and trials should be put out by the farmer himself on his own field. In addition to the farmers learning by personal experience, field demonstrations provide a means of testing experimental results and verifying the accuracy of fertilizer recommendations. Field trials usually are more complicated than demonstrations. They have the primary objective of providing more and better information on crop responses to fertilizer, but also have demonstration value in showing visually the physical and economic effects of different rates and combinations of plant nutrients.

Local meetings and tours of demonstrations are also effective methods of encouraging farmers to adopt practices to improve soil fertility. The opportunity to observe changes seems to be a necessary step in the adoption of new ideas. By seeing what one of his neighbours has done, the individual farmer often is stimulated to try it for himself.

The value of simple illustrated educational materials, such as pamphlets, posters, and charts is mainly in making farmers aware of new ideas. Combined with other methods, they can speed up the adoption of new practices.

To sum up, the experience of FAO and other organizations and agencies has demonstrated the great importance of a few basic techniques in getting farmers to use fertilizer. These include:

i) The involvement of individual small farmers in the demonstrations, trials, meetings and other activities is basic to all educational efforts. The farmer learns far more by doing and seeing than by hearing and reading.

ii) The cooperation of local groups interested in agriculture, such as merchants, salesmen, farmers' organizations, journalists (newspapers, radio, television) and bankers, can increase the effectiveness of programmes designed to improve agricultural efficiency.

iii) The results from fertilizer demonstrations, trials and experiments should be disseminated through all available means of communication - local leaders, local meetings, posters, newspapers, radio and television where possible and any others available.

iv) Follow-up visits, meetings, etc., to assist farmers in adapting and applying the results of demonstrations and trials are very important after the initial contacts.

v) Personal contact between individual farmers and advisers is the most effective technique for teaching, especially where farmers are just beginning to try new practices. Often it is more effective in the long run to work intensively with a smaller number of farmers than to try to reach a larger number without being able to give individual attention to local problems and conditions.

2.6 CONSTRAINTS TO FARMERS' ACCEPTANCE OF THE INCREASED USE OF FERTILIZERS

In every country there are certain conditions and factors which at any given time tend to act as a deterrent to the acceptance of improved production methods. A recognition of their effects in planning and conducting a fertilizer programme can assist in developing a more effective programme.

The general economic, social and political situation affects the use of fertilizer as it does all other activities. However, there appear to be certain obstacles that have particular significance in a fertilizer development programme. The most important constraints which require immediate attention if fertilizer consumption is to be increased include:

i) lack of information on the kinds and amounts of fertilizer needed;

ii) lack of adequate and timely supplies of fertilizer and inadequate credit and distribution systems;

iii) unfavourable relationships between value of agricultural products and the cost of fertilizer;

iv) the resistance of farmers to new ideas;

v) lack of suitable plant varieties, disease and insect control measures and other practices needed for the potential from fertilizer to be realized;

vi) farm lease arrangements that tend to discourage the economic use of fertilizers.

This list could be expanded further. However, the meaningful evaluation of factors limiting fertilizer use requires a detailed study of the circumstances of the individual country and an inherent part of an effective fertilizer development programme is a continuing study of those factors which limit progress.

3. RELATIONSHIP BETWEEN CROP PRODUCTION, CROP YIELDS AND FERTILIZER USE

The wide range of crop yields among countries cannot be explained only by the differences in physical environments such as climate and soil. Variations appear to be equally related to the stage of agricultural and economic development and to the application of improved methods of crop production.

Crop yields have been increased substantially in many areas of the world, particularly over the past two decades. Generally, increases in crop production have been due to a combination, or "package" of factors, including (a) improved crop varieties capable of producing higher yields; (b) effective control of weeds, pests and diseases; (c) improved cultural methods including cropping system; (d) conservation and controlled use of water; (e) soil improvement and conservation practices and (f) increased use of mineral fertilizers. The application of these technical agents has had to go hand-in-hand with an improved agrarian structure and relatively favourable economic conditions.

With the increased production of crops per unit of land area, farm management becomes increasingly important. Greater attention is given to such matters as timeliness of operations, cropping systems, keeping of farm records and the use of credit. Many excellent studies have been conducted showing the importance of and inter-relationships between, the whole complex of factors with which the individual farmer must deal.

Crop production patterns in the different countries show that high crop yields and high values of production per hectare are characteristic of areas of advanced economic development, where there is a high degree of application of improved farming methods, including the use of fertilizer.

There are several reasons for employing the element of fertilizer use in an appraisal of the ability to increase agricultural output. For one thing, comprehensive data on fertilizer use are available for most countries of the world. Comparable data, especially for total use, are not available to permit measurement of the impact of most other improved practices, such as the use of pesticides and changes in cultural practices. In addition the use of fertilizer is more directly under the individual farmer's control than are many other practices. The use of fertilizer can in fact be taken as a measure of the extent to which technology is applied to agriculture.

3.1 VALUE OF CROP PRODUCTION PER HECTARE IN RELATION TO FERTILIZER USE

That the proper use of fertilizer greatly increases crop yields is well established by agronomic theory, by field and greenhouse experiments and demonstrations and by individual farmers' experiments and experience throughout the world. Some concrete examples are given later in this publication. However, taken over a wide enough area, and under conditions representing a full range of climatic and environmental factors, the relationship between average crop yields and the use of fertilizers may provide information helpful in estimating the contribution of fertilizers to increasing crop production and the quantity of fertilizers required to achieve given levels of production.

To examine the fertilizer-crop production relationship, an analysis has been made relating an index of yield-value of crop production per hectare to fertilizer use.

The first information derived was an index relating price weights to aggregate crop production. For this purpose the production of each recorded crop was multiplied by its regional price weight, and these values were aggregated and divided by the total hectares of crops, to obtain a "yield-value index of crop production per hectare".

Such an index was calculated for 41 countries for the three-year period 1975-1977. The relationship between this index and fertilizer use in terms of kilograms of primary plant nutrients per hectare of arable land is shown in Figure 1.[1/]

Six of the ten countries with indices of less than 200 - Burma, Argentina, Syria India, Kenya and Australia - used less than 30 kg of plant nutrient per hectare of arable land. The four other countries - Pakistan, the Philippines, Brazil and Portugal - had an average use ranging from 32 kg in Pakistan to 85 kg in Portugal.

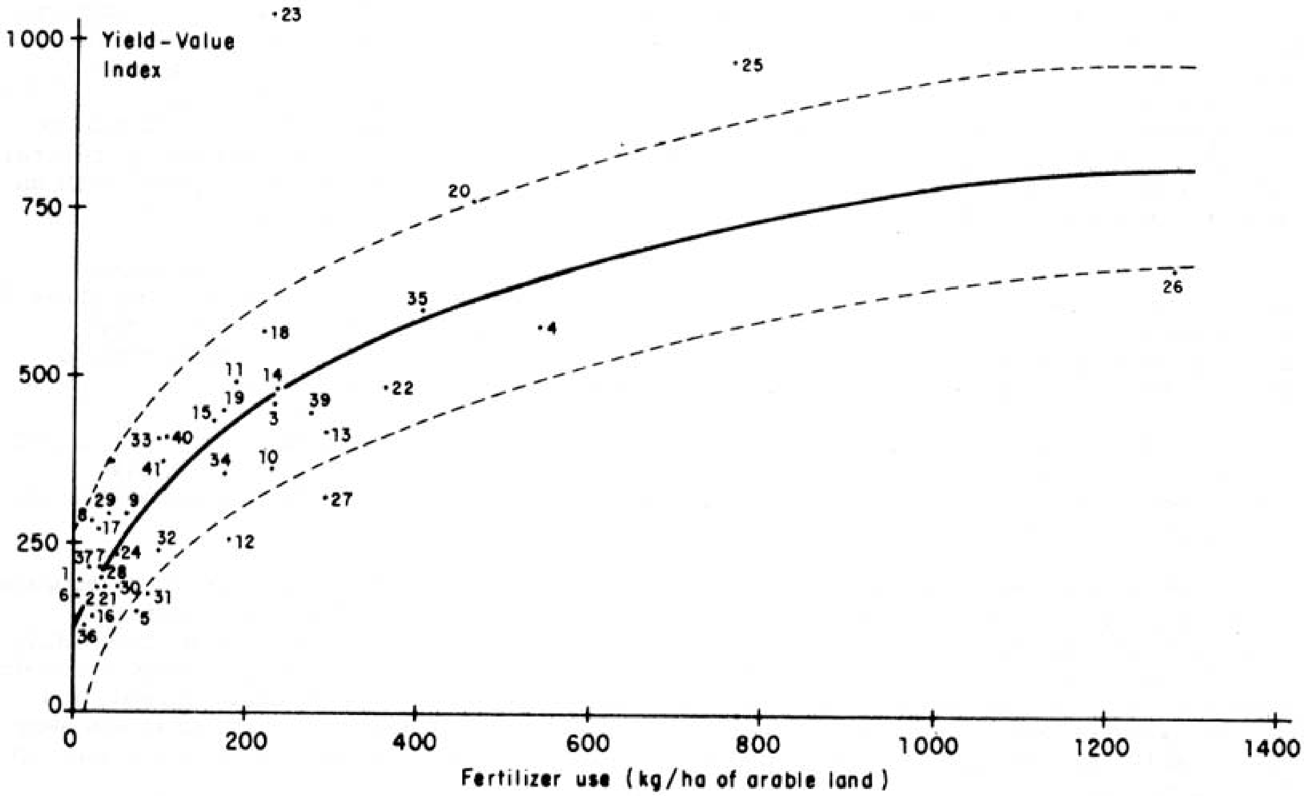


Figure 1: Average relationship between fertilizer use and yield-value index of crop production per hectare of arable land, 41 countries, 1975-1977

LEGEND

1 ARGENTINA	11 EGYPT	21 KENYA	31 PORTUGAL
2 AUSTRALIA	12 FINLAND	22 KOREA REP	32 SPAIN
3 AUSTRIA	13 FRANCE	23 MAURITIUS	33 SRI LANKA
4 BELGIUM+LUXEMBOURG	14 GERMANY FR	24 MEXICO	34 SWEDEN
5 BRAZIL	15 GREECE	25 NETHERLANDS	35 SWITZERLAND
6 BURMA	16 INDIA	26 NEW ZEALAND	36 SYRIA
7 CANADA	17 INDONESIA	27 NORWAY	37 THAILAND
8 CHILE	18 ISRAEL	28 PAKISTAN	38 TURKEY
9 COLOMBIA	19 ITALY	29 PERU	39 UNITED KINGDOM
10 DENMARK	20 JAPAN	30 PHILIPPINES	40 U S A
			41 YUGOSLAVIA

1/ Unless specifically stated, plant nutrients in this publication refer to the oxide form. Appendix Table 16 on page contains the conversion table to elemental form.

Most of the major countries where indices of yield-value of crop production were high had relatively high average rates of fertilizer use per hectare of arable land, e.g. Netherlands, Japan, New Zealand, Switzerland and Belgium - Luxembourg.

Of the 41 countries included in the analysis, eight showed a rather wide degree of divergence from the curve of the average relationship.[1/] Three of these - Mauritius, the Netherlands and Japan - had a higher level of indices, and five - Norway, Finland, Brazil, Portugal and New Zealand - had a lower level of indices than the range of plus or minus 131 index points from the curve of average relationship.

The divergency of these cases shows the importance of all the agents which contribute to production in any country and indicates the necessity of an analysis of local conditions in determining the effectiveness of fertilizer use in a given area. Mauritius had the highest yield-value index although the average rate of fertilizer use (230 kg) per hectare compares only with that of Norway (287 kg). This could be attributed to the more favourable growing conditions in Mauritius and the predominance of sugarcane, a crop which gives a high return.

The relatively low indices of yield-value compared with fertilizer use in five countries - Norway, Finland, Brazil, Portugal and New Zealand - could be the result of a combination of factors. Except for Brazil, most of these countries have relatively unfavourable environmental conditions for growing crops. Besides, Brazil and New Zealand have a high proportion of low value crops, the former mostly foodcrops and the latter forage crops.

Taken over the range of conditions indicated by the 41 countries, there is a high degree of relationship between the application of technology as indicated by fertilizer use and the yield-value index of crop production per hectare. Countries with a relatively low index used less fertilizer in terms of average application per hectare of arable land. In those countries where the yield-value index of crop production was relatively high, farmers on the average used relatively high rates of fertilizers. Figure 1 shows that the higher index values go hand-in-hand with higher levels of fertilizer use.

There appears to be a relationship between the use of modern methods (evidenced in this analysis by the level of fertilizer use) and the yield-value index of crop production, and the general level of economic development in the 41 countries. Generally, the countries with low fertilizer use and yield-value index of crop production are the developing countries, such as Burma, India, Indonesia, Kenya, Pakistan, Syria, Thailand and others shown on the lower end of Figure 1. Countries with high levels of fertilizer use and yield-value index of production, like the Netherlands, New Zealand, Japan, Belgium - Luxembourg, Switzerland and Federal Republic of Germany, are characterized not only by a well-developed and productive agriculture resulting from scientific farming but also by an efficient and productive industrial sector. This indicates that the application of the results of scientific effort is strongly associated with overall economic development, although there are, of course, exceptions to this general rule, e.g. Mauritius and Sri Lanka, which however mainly use fertilizers on high value crops.

As has been pointed out many times, the increase in yields in crop and livestock production can be taken as an expression of technological advances in agriculture. The average per hectare consumption of fertilizers can be taken in very general terms, as evidence of the total input effort in a country's agriculture.

1/ These are countries which are more than one standard error of estimate (131 index points) from the curve of average relationship. This range is indicated by dotted lines on Figure 1.

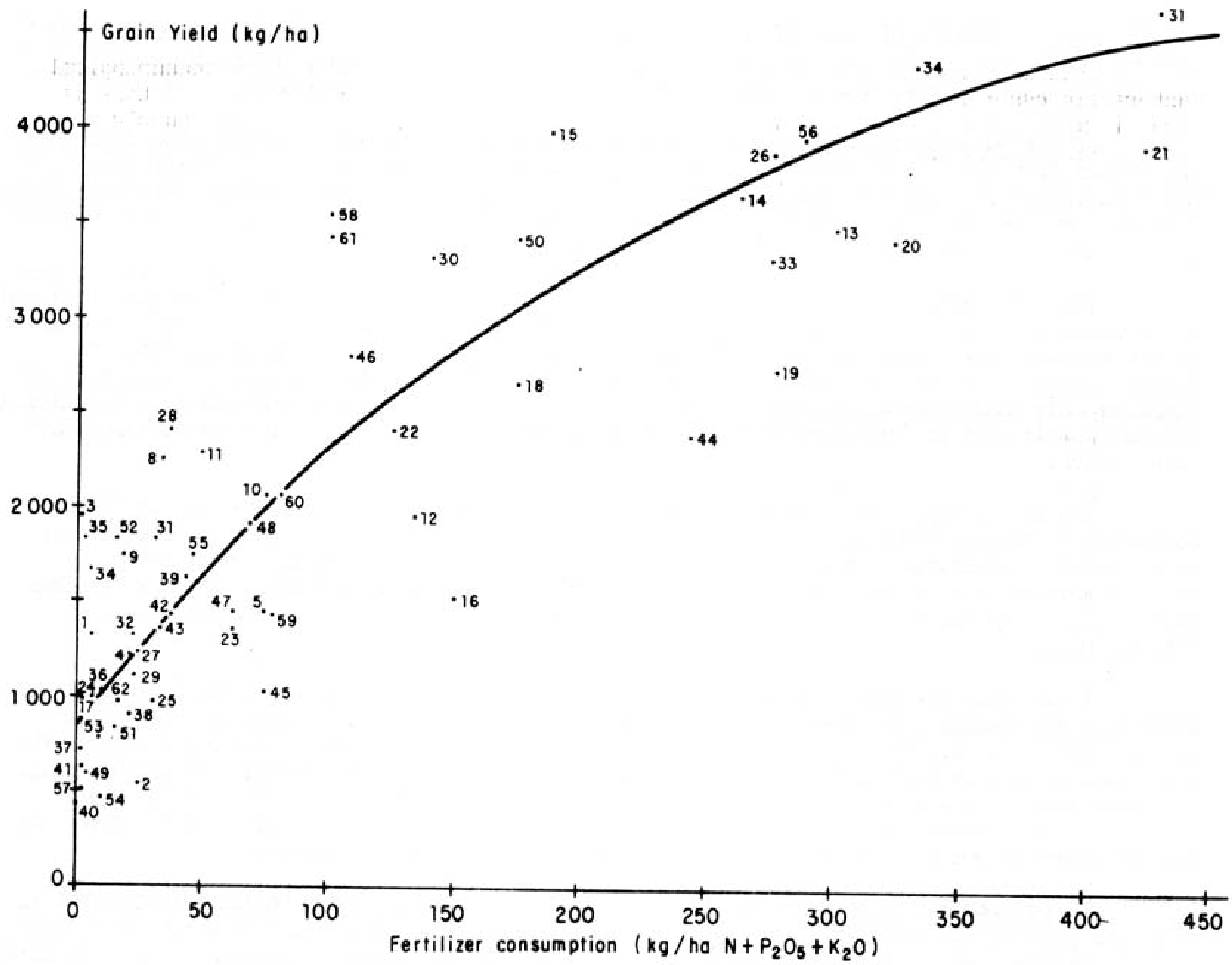


Figure 2 Cereal yield and national fertilizer use in 62 major cereal growing countries
Sources: FAO 1978. Production yearbook, Rome; FAO 1978. Annual fertilizer review, Rome.

LEGEND

1	AFGHANISTAN	17	ETHIOPIA	33	KOREA DPR	49	SUDAN
2	ALGERIA	18	FINLAND	34	KOREA REP	50	SWEDEN
3	ARGENTINA	19	FRANCE	35	MADAGASCAR	51	SYRIA
4	AUSTRALIA	20	GERMANY DEM R.	36	MALAWI	52	THAILAND
5	BANGLADESH	21	GERMANY FED R.	37	MALI	53	TANZANIA
6	BRAZIL	22	GREECE	38	MOROCCO	54	TUNISIA
7	BURMA	23	GUATEMALA	39	MEXICO	55	TURKEY
8	CANADA	24	HAITI	40	NIGER	56	UNITED KINGDOM
9	CHILE	25	HONDURAS	41	NIGERIA	57	UPPER VOLTA
10	CHINA	26	HUNGARY	42	PAKISTAN	58	U S A
11	COLOMBIA	27	INDIA	43	PHILIPPINES	59	U S S R
12	CUBA	28	INDONESIA	44	POLAND	60	VIETNAM
13	CZECHOSLOVAKIA	29	IRAN	45	PORTUGAL	61	YUGOSLAVIA
14	DENMARK	30	ITALY	46	ROMANIA	62	ZAMBIA
15	EGYPT	31	JAPAN	47	SOUTH AFRICA		
16	EL SALVADOR	32	KENYA	48	SPAIN		

This relationship indicates that fertilizers used along with other technological factors are essential for increasing the national level of crop production. If this is true, it must be because most arable soils are of limited fertility and the supply of plant nutrients is a major limiting factor in crop production. The observed relationship would not exist if half of the soils were so fertile that little or no fertilizer was required to achieve high levels of production.

Soil scientists generally agree that, as a result of major soil-forming factors, most soils are of low fertility. Certain soils of the temperate zone formed under grass and moderate rainfall are an exception. The level of fertility is usually lower in the tropics than in the temperate zone. In most soils therefore, a deficiency of nitrogen, phosphorus or potash, or adverse soil reaction, and frequently a combination of these, limit crop production. It is also well established that 50 to 100 years of cultivation generally will reduce the organic matter and nitrogen content of soils by 50 percent or more if nutrients are not replaced by mineral fertilizers and organic manure. Since most arable soils of developing countries have a long history of cultivation, we should not be surprised to find a rather uniform status of low fertility, and that crop yields tend to be stablilized at a low yield-value level.

3.2 ANALYSIS OF CROP YIELD DATA IN INDIVIDUAL COUNTRIES IN RELATION TO FERTILIZER USE

As pointed out earlier, the greater part of any increase in agricultural production in many countries in the future will necessarily have to come from increased productivity. The sound planning of a programme designed to increase agricultural productivity therefore requires a knowledge of the results already achieved under actual farming conditions as well as results from controlled experiments and trials. The high levels of fertilizer use in many countries are the result of years of research, the results of which have been applied and tested by individual farmers.

There is no substitute for the value of the experience of individual farmers. In examining the role of fertilizers in agriculture in areas without a long history of research on fertilizer use, results on farmers' fields are helpful in assessing whether or not the use of fertilizer can be practical and profitable.

In addition to the more detailed research work on fertilizers in recent years, a large number of trials and demonstrations have been conducted on farmers' fields, many of them within the FAO Fertilizer Programme which was started in 1961.

The relationship between fertilizer use and cereal yields in individual countries is illustrated in Figure 2. Although the factor considered here, i.e. grain yield of cereals rather than an overall yield-value index of all crop production, is different, the result is strikingly, but not unexpectedly, similar. The countries, which were selected on the basis of cereal area and geographical-ecological regions in an effort to represent almost all growing conditions, cover approximately 95 percent of the total world cereal area.

The general pattern of the scattered country data shows that higher national fertilizer consumption is closely related to higher cereal yields. Unfortunately there is no reliable way by which world-wide cereal yields can be compared with fertilizer use on cereals alone, as few such figures are available. Neither fertilizer producers, nor the responsible government departments, nor fertilizer traders - even those who sell direct to farmers - know exactly on which crop will be used the fertilizers that have been bought from them.

National average cereal yields can be used to illustrate the relationship between agricultural productivity and fertilizer use in individual countries because:

- almost all countries grow some cereal crops, and in many of these countries cereals are among the principal crops;
- approximately 50 percent of the world's arable land and land under permanent crops is devoted to cereals (approx. 745 million out of 1 488 million ha in 1976);
- data on cereals generally are more complete and reliable than those of other crops;
- data on area, production and yield of all cereals can be summed, since production is measured in a common unit (kg grain per ha), whereas yield data for other crops, such as cotton, tobacco, fruit, etc. cannot be aggregated except in terms of value or after conversion by means of arbitrary indices.

Even so, it must be borne in mind that, when using a collective group such as cereals, perfect correlation cannot be expected. Figure 2 shows that clearly. The scattering of the individual country data about the average curve is caused to some extent by just this collective nature of the group. The reasons are that:

- cereals comprise a number of rather different crops with basically dissimilar yields, e.g. rice and wheat;
- the fertilizer responses of some cereals and varieties are better than those of others, though this difference in responsiveness is steadily reduced by the breeding of high-yielding varieties and hybrids;
- cereals are grown under a wide variety of conditions the world over, from the dry farming conditions of South American pampas to the highest intensification standards of Japanese paddy fields.

Extreme deviations of some countries from the average can be explained by local conditions. El Salvador, a country with high fertilizer use and comparatively low cereal yield is an example. Here, the crops on which most of the national fertilizer consumption is concentrated are cotton and coffee - the country's main export products - whereas sorghum (occupying more than one-third of the country's cereal area) and the traditional small-scale farmers' maize (occupying almost the whole of the other two-thirds of the cereal area) do not receive the same attention. A typical example of the reverse situation, a country with extremely low national fertilizer consumption, yet rather high cereal yields, is Argentina. There, climatic conditions (unreliable rainfall, low temperatures, and high winds in large parts of the country) have tended to restrict fertilizer use to a limited number of zones and crops other than extensively cultivated cereals; on the other hand, good soils (the poorer soils generally are not cropped with cereals), well adapted crop varieties and appropriate cultivation practices still result in good average cereal yields. In Indonesia and Vietnam, the complementary use of mineral and organic fertilizers helped achieve relatively high cereal yields.

In general, the deviations from the average curve shown in Figure 2, indicate the extent of the productivity reserves which still remain to be mobilized. The average curve can gradually be pushed up towards higher yields and the scatter around that curve can be reduced through better use of more fertilizer, use of high-yielding varieties well adapted to local conditions and highly responsive to fertilizers, and through improved farm practices from irrigation to effective control of weeds, pests and diseases.

3.3 TIME, CROP YIELD, AND FERTILIZER CONSUMPTION RELATIONSHIP

Another approach, similarly based on national average data for individual countries, is to analyse developments over certain periods of time.

Figure 3 shows the development, in steps of 6 or 7 years according to data availability, of grain yield and national fertilizer consumption, in two Western European countries - France and the United Kingdom. To illustrate the relationship more clearly, the respective scales for fertilizer use and grain yield, here and in most of the following graphs, are in a ratio of 1 : 10. Once again, the close relationship between national fertilizer consumption and grain yield is striking.

Another country with a well developed agriculture, high fertilizer consumption, intensive cultivation practices and good crop yields, is Japan. The development of production of the country's principal crop, rice, since the beginning of the century, is illustrated in Figure 4. A remarkably steady and parallel growth of fertilizer use and paddy yield can be seen, except during the period centred on 1943/44 when mineral fertilizers were scarce. Small annual variations due to the weather were smoothed out by the use of data averaged over several years.

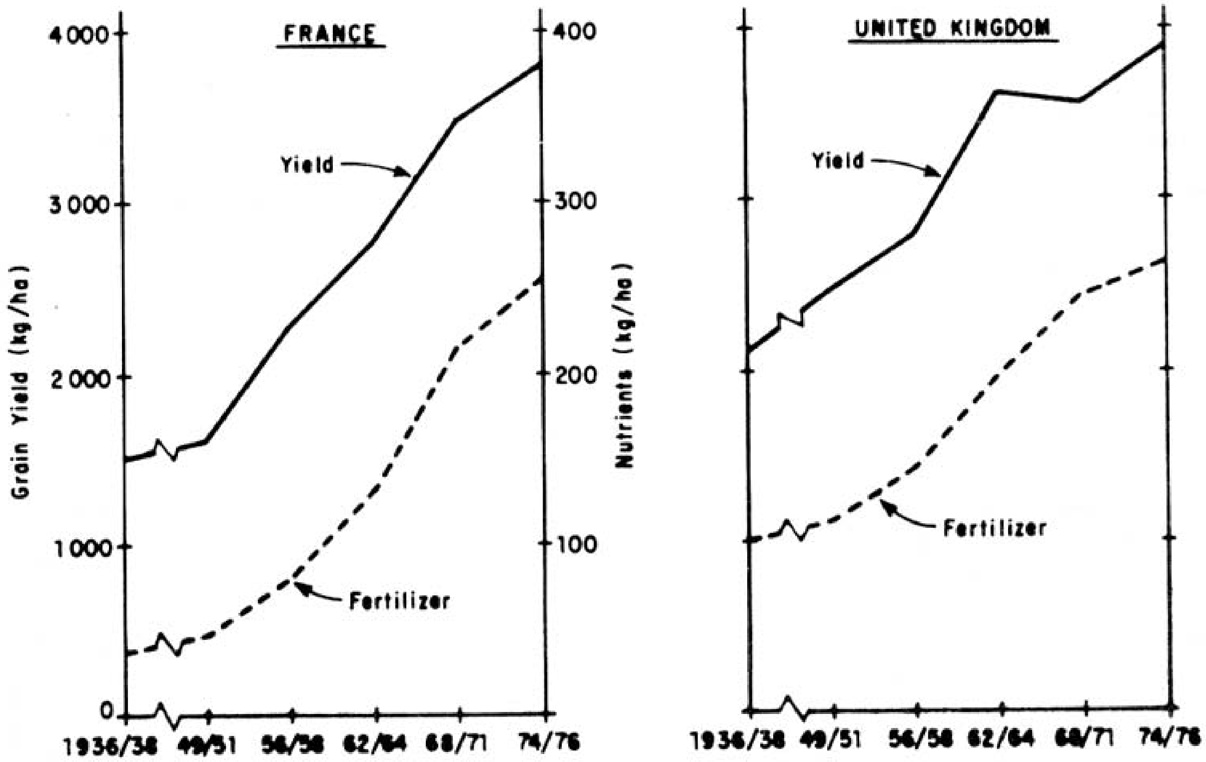


Figure 3 Average grain yield and fertilizer use in France and the United Kingdom, 1936/38 to 1975/76

Sources: USDA. Prewar world production and consumption of plant foods in fertilizers. USDA Misc. Publ. No. 593 (USA); International Institute of Agriculture. Yearbook of agricultural statistics. 1940. Rome; FAO Production yearbook, Rome; FAO Annual fertilizer review. Rome.

Figure 5 presents one of the few cases where fertilizer consumption data are available for one crop on a national base. Unfortunately, the figures concerning mineral fertilizer date back only to 1950, so that the impact of the earlier scarcity cannot be seen. The increased use of organic manure during that emergency period around 1943/44 is shown, however. Taking Figure 5 in conjunction with Figure 4, it is evident that, even in such a highly intensified agricultural system as that in Japan, increased use of organic manure could not counteract the temporary shortage of mineral fertilizer, though without it, of course, paddy yields would have declined even further.

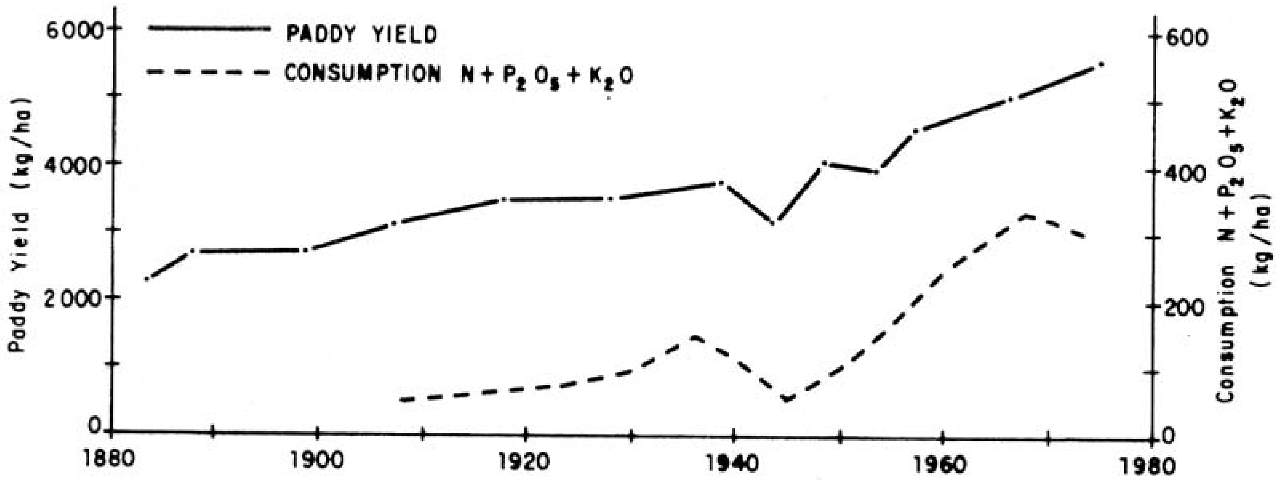


Figure 4 Long-term development of rice (paddy) yield and national fertilizer consumption in Japan

Sources: FAO Production Yearbook; FAO Annual Fertilizer Review; Abstract of Statistics on Agriculture, etc., Ministry of Agriculture $ Forestry, Tokyo 1961.

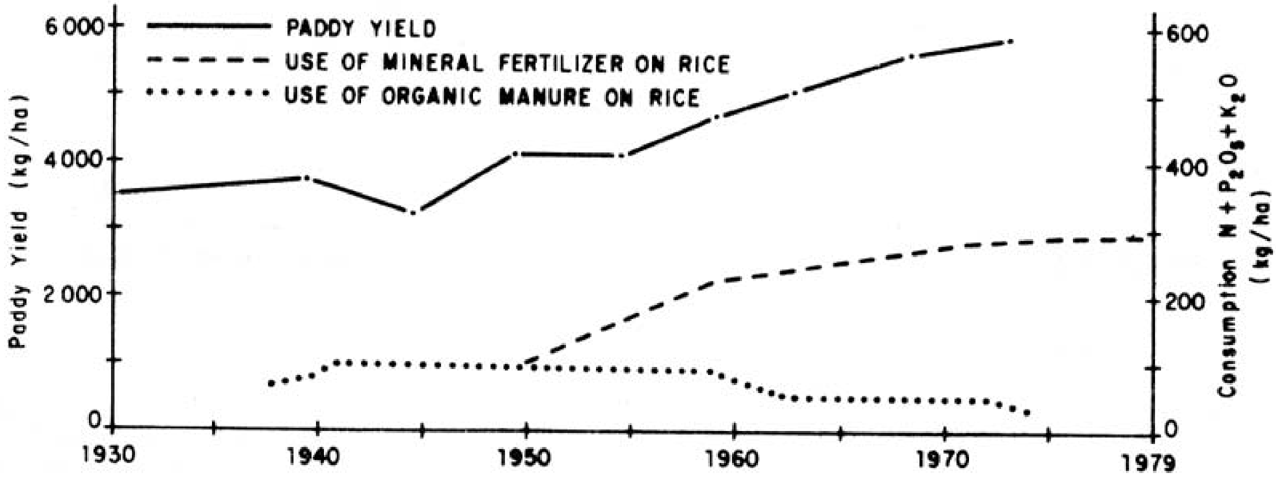


Figure 5 Development of paddy yield and the use of fertilizers - mineral and organic - on rice in Japan during the last five decades

Turkey and Mexico provide two good examples of countries with a long tradition of agriculture, which adopted modern practices only comparatively recently. This applies particularly to Mexico, where the high-yielding wheat varieties originated and where they now occupy about 90 percent of all wheat land. Figure 6 shows the wheat yields and national fertilizer consumption in both countries from 1962/63 to 1976/77. The impact of the improved wheat varieties, beginning in the 1960's, can be seen in each country, together with the rising use of fertilizer. The annual data used here, unlike the smooth data for Japan, demonstrate the yearly fluctuations which occur particularly in regions and with crops which depend on rainfall rather than on irrigation water.

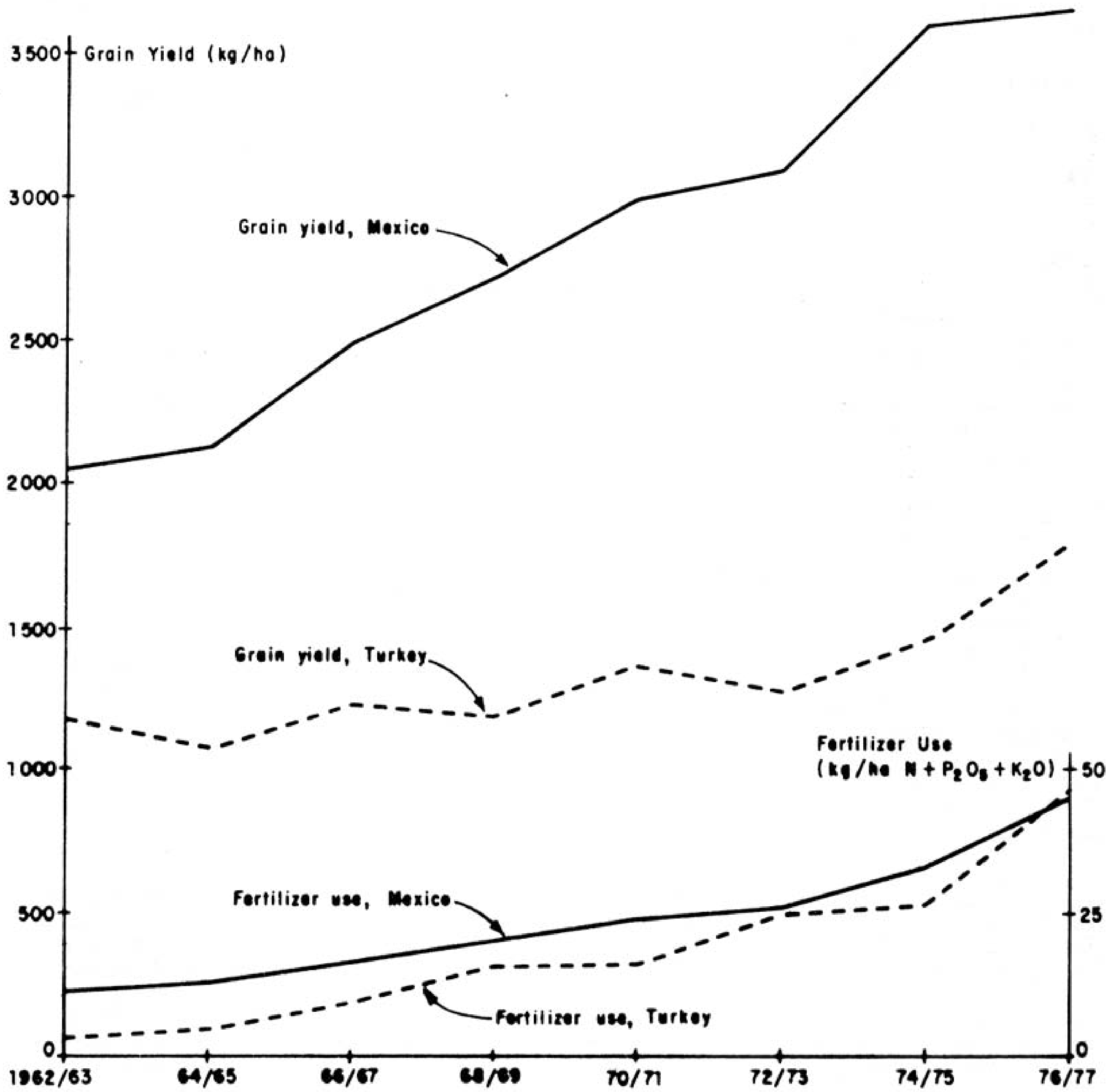


Figure 6 Development of wheat yield and fertilizer use in Mexico and Turkey, 1962 to 1977 (two-year averages)

Sources: FAO Production yearbook. Rome; FAO Annual Fertilizer Review. Rome.

For a world-wide look at the historical development of fertilizer use and agricultural productivity, and for the reasons explained in section 3.2, cereal yields again provide a convenient parameter. Figure 7 compares the use of the three major plant nutrients, nitrogen, phosphate and potash, with world average cereal yields from 1961 to 1977. A close relationship showing rising trends for both yield and fertilizer consumption can be seen clearly. Even the impact of the 1974 drop in fertilizer consumption is reflected in what must be considered a rather alarming manner. This demonstrates not only how much the world's output of food and other basic agricultural products is raised by means of fertilizer use, but also how much they can be lowered if this important input, for one reason or the other, is scarce.

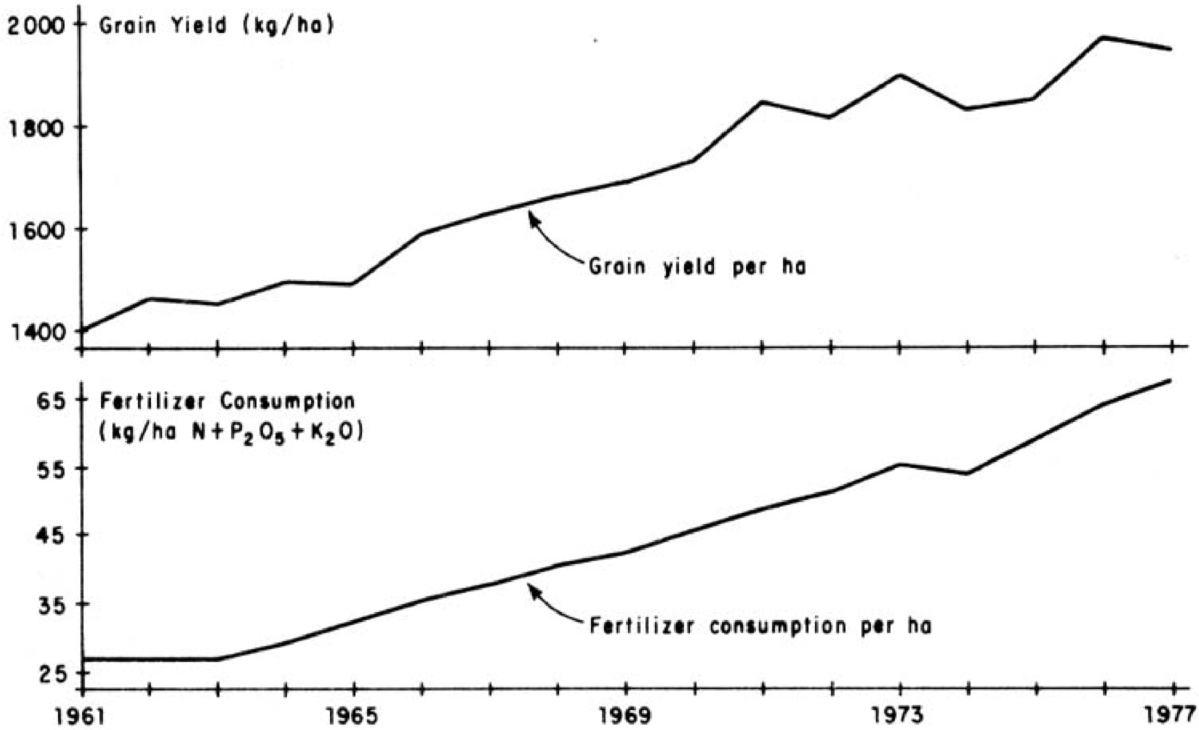
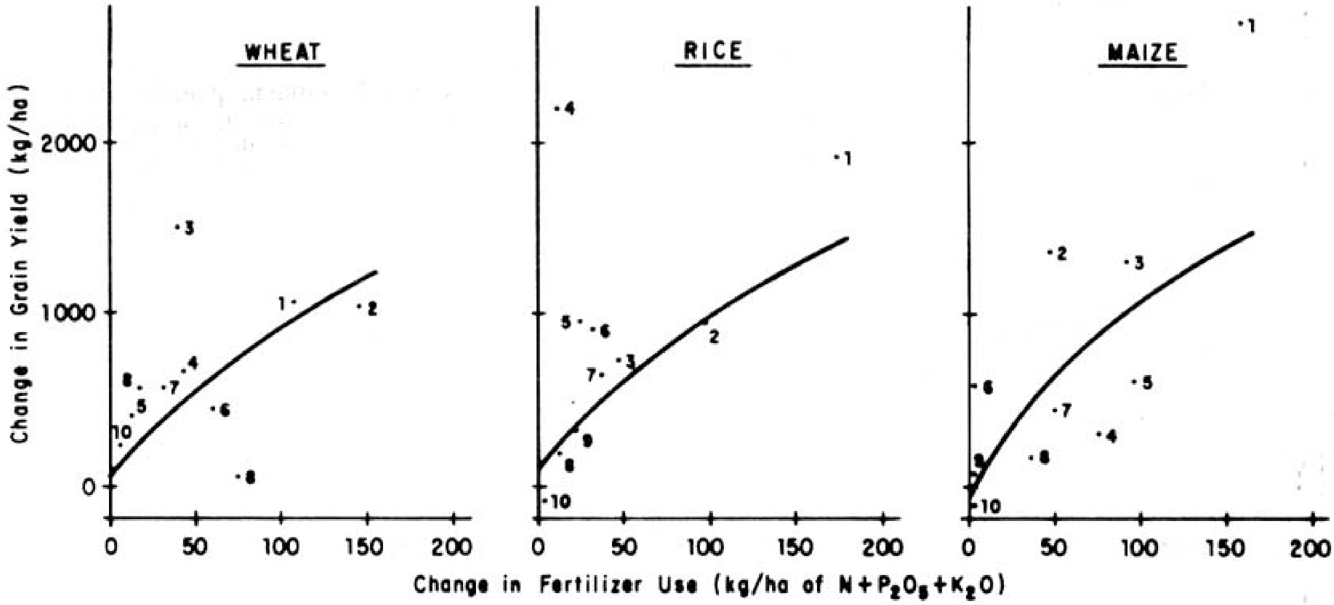


Figure 7 World fertilizer consumption and average grain yield, 1961 to 1967
Source: FAO, Rome

Another approach towards appraising the relationship between fertilizer use and crop yield levels in a given period of time is to compare the changes of both fertilizer use and crop yield within that time. These changes for the three major crops of the world in ten selected countries are shown in Figure 8. Here too, where the three principal cereals are shown individually, the scatter diagrams illustrate two facts: (a) the tendency towards grouping in the vicinity of an average curve similar to that of Figure 2 is repeated, and (b) the large deviation of some countries form the average line, particularly Mexico (wheat), Colombia (rice) and Austria (maize). The reason behind this is the introduction of high-yielding varieties of wheat and rice and of hybrid maize to which a large amount of the other farm inputs such as pesticides were also introduced. Besides, these high-yielding varieties were planted in irrigated fields and given better soil management and cultivation practices.



LEGEND

1 GERMANY, F.R.	1 KOREA, REP OF	1 AUSTRIA
2 FRANCE	2 JAPAN	2 U S A
3 MEXICO	3 U S A	3 ROMANIA
4 TURKEY	4 COLOMBIA	4 BRAZIL
5 KENYA	5 INDONESIA	5 EL SALVADOR
6 U S S R	6 PAKISTAN	6 ETHIOPIA
7 PAKISTAN	7 CUBA	7 GUATEMALA
8 INDIA	8 THAILAND	8 MEXICO
9 BRAZIL	9 INDIA	9 CAMEROON
10 TUNISIA	10 TANZANIA	10 LESOTHO

Figure 8 Changes in grain yield and fertilizer use of 3 major cereal crops in 10 selected countries - difference between 1961 and 1977

Sources: FAO Production yearbook. Rome; FAO Annual fertilizer review. Rome.

A quite different aspect of the relationship between time, crop yield levels and fertilizer use is the influence of fertilizer dressings beyond the harvest of the crop they were applied to. This touches a wide field, such as, the residual effect of fertilizers, the mobilization of natural soil fertility reserves by fertilizer-based measures, the effect of increased organic residues in the soil resulting from fertilizer applied to previous crops, etc. On the other hand, the extraction of nutrients from the soil by crops and, in particular the higher yields resulting from fertilizer use have to be taken into account. There is no doubt that the long-term effect of fertilizers is important for perennial crops where a strong fertilizer-supported early development of a young tree is the basis of its future productivity. But with annual crops too, the long-term effect of fertilizer cannot be neglected, but must be duly considered by research workers and taken into account by farmers.

The results of fertilizer trials in Malaysia and the Philippines which demonstrate how the time factor (in this instance, the consecutive growing of one crop on the same plot, year after year, with the same fertilizer application) can influence crop yields, as one or other nutrient becomes exhausted with the passage of time, is shown in Figures 9 and 10. In many cases, as in these two examples, this nutrient may be potash, a fact which is often not recognized, as witnessed by the still common belief in the "inexhaustible potash reserves" of certain soils. This provides yet another warning that one should not forget that good crop yields depend on a whole package of inputs, which begins with balanced use of the three major fertilizer nutrients.

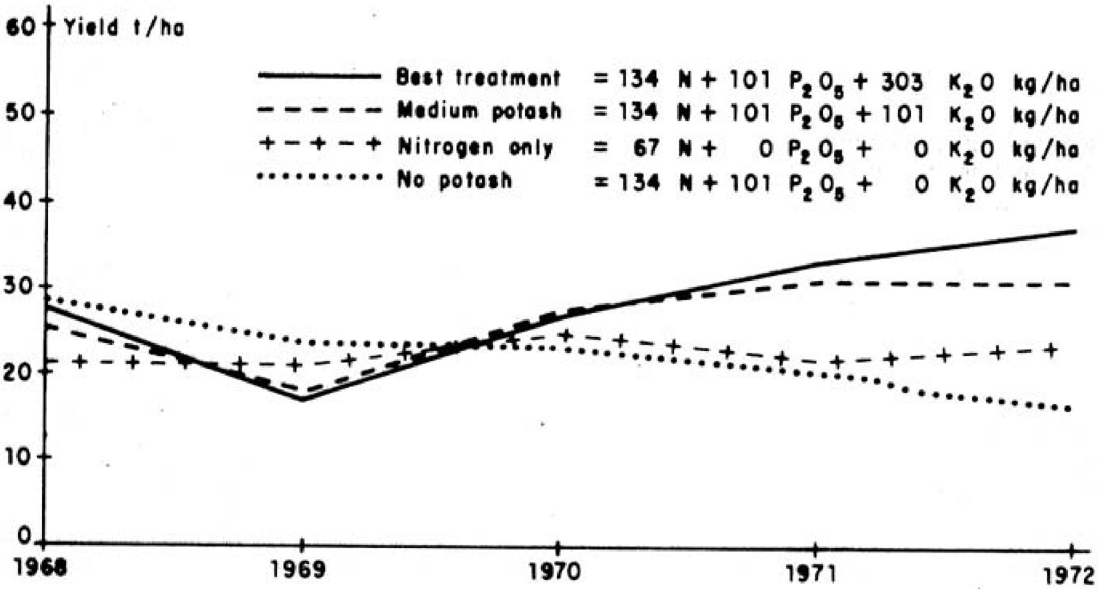


Figure 9 Yield of fresh cassava tubers at selected fertilizer treatments, five consecutive crops on the same site, Malaysia 1968-1972

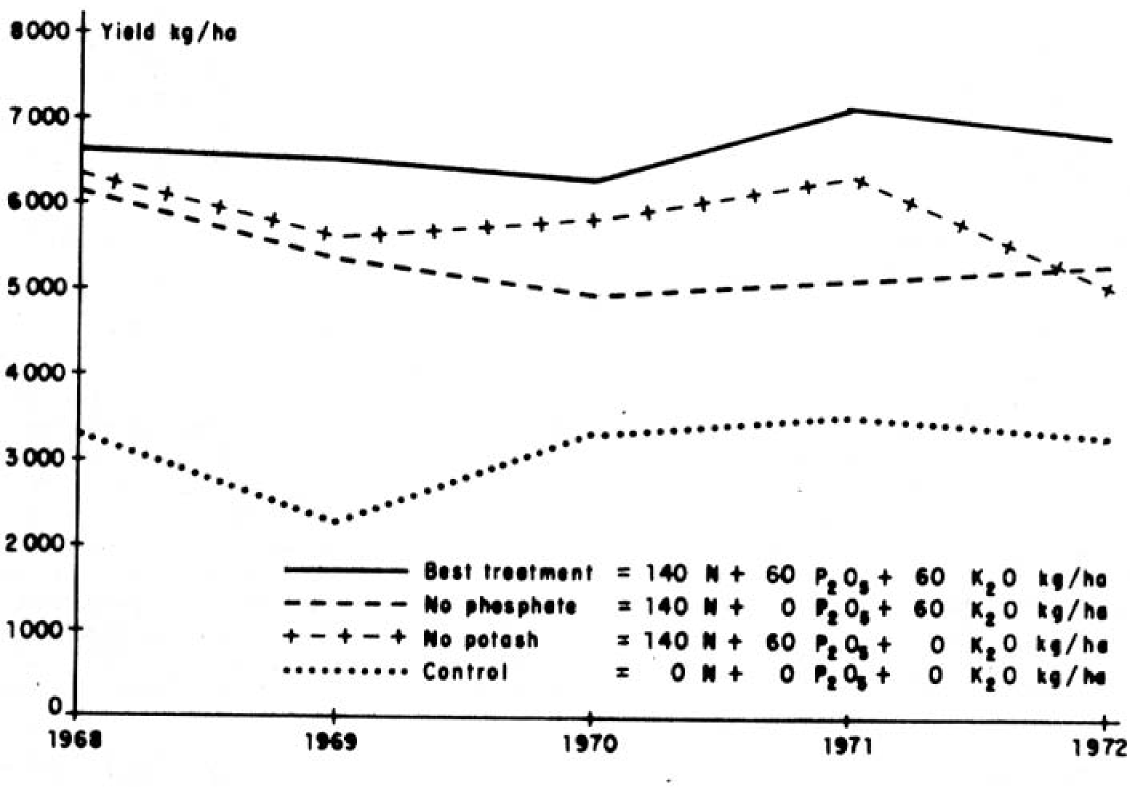


Figure 10 Effect of NPK on grain yield of flooded rice grown for five consecutive years in the Philippines, dry season, average of three varieties

Source: Kemmler and Melicornet. 1976. Fertilizer experiments - The need for long-term trials. IPI Research Topics No. 1. Berne.

3.4 CONTRIBUTION OF FERTILIZER TO INCREASE IN CROP PRODUCTION

Measuring the contribution of fertilizers to increasing the volume of farm output is a complex and even controversial undertaking, especially in view of the interactions and inter-dependency of all inputs and cultural practices. Nevertheless, an appraisal of the sources of increased production in countries with a high volume of agricultural output can be helpful to the developing countries as a guide.

As already mentioned, the contribution of fertilizer to increased crop yield extends beyond the crop actually being fertilized. There is also the long-duration effect on soil fertility. A convenient means of assessing the complex item, "soil fertility", is the amount of plant-available nitrogen present in the soil at a given time. Figure 11 shows the various sources of plant-available nitrogen from about 1800 to 1975/76. It shows that the various sources of plant-available nitrogen have steadily increased to more than three times their original level despite the yearly removal of substantial quantities of nitrogen in the harvested crop. This could be attributed to modern agricultural practices, including fertilizer use. The contribution of plant-available N from organic manure was still increasing up to 1965. In recent years, with the decrease in farm animals, the collection of farm yard manure also decreased. On the other hand, the increasing use of green manure greatly contributed to the supply of plant-available N. The main source of the latter, too, is from fertilizer use, i.e. the long-term effect of applied mineral fertilizer within the natural nitrogen cycle (more fertilizer - more plant production - more green manure, more plant residues - more humus - improved soil fertility, and so on). This principle is valid wherever sound farming practices prevail and it applies not only to nitrogen but to phosphate and potash as well.

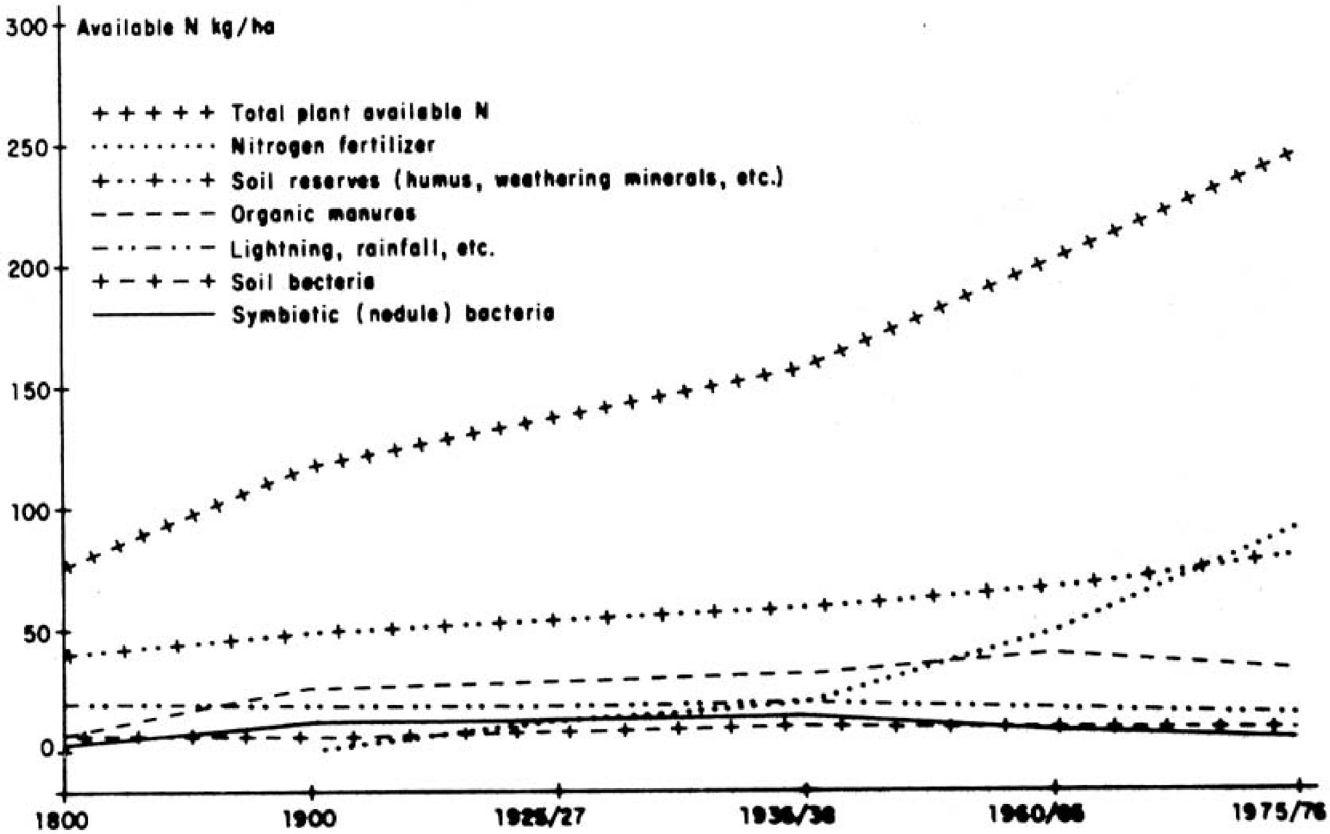


Figure 11 Plant available nitrogen in agricultural soils of Germany

Source: Huppert, Entwicklung der Ertrage. Feld und Wald No. 4. January 1978.

A comprehensive analysis of the sources of increase in farm output in the United States from 1870 to 1955, again embracing the country's "development" stage, was made in 1960 by the US Department of Agriculture. The United States' farm output in 1955 was nearly five times the output 85 years earlier. In 1976-78 this country accounted for over 17 percent of world cereal production. Until about 1914, expansion of the physical cropland base was the major factor in the growth of agriculutral output. During the period 1918 to 1941 on the other hand, it was relatively unimportant. The major factor was the shift from animal to mechanical power on the farm. At the same time, yield per hectare was an important source of additional farm output. According to the study, crop yield per unit area increased by 9 percent as a result of using more fertilizer, improved seed, more irrigation, and other improved and more timely practices. During the period 1919/21 to 1938/40 fertilizer may have accounted for around one-tenth of the total change in farm output, or as much as the increase from irrigation and hybrid maize combined. The period from 1941 to 1955 was characterized by accelerated adoption of improved production methods, resulting in increases in crop output per hectare. More than 40 percent of the increase in total farm output came from this source. Commercial fertilizers were the largest single factor, probably accounting for about half the increase in crop output per hectare and for more than one-fifth of the total additional farm output (Figure 12).

Similar calculations have been made in India, estimating the sources of increased food grain production during the Second Five-Year Plan which ended in 1961 (Figure 13). Fertilizers (both organic and mineral) were considered to be the most important source of increased volume of food grains. Fertilizer use was estimated to be responsible for 4.6 million tons out of the 11.2 million tons increase in food grain production achieved during the plan period. A calculation based on recent Indian figures (Table 1) ascribes an even higher percentage of increase in Indian food grain production to the use of fertilizer, namely as much as 75 percent. However, it underlines the fact that such performance of fertilizer is possible only with the use of high-yielding crop varieties, better control of pests and diseases, improved cultivation methods, irrigation etc., which means that the whole package of modern inputs and management practices is essential to obtain the maximum benefit from fertilizer.

Table 1 CONTRIBUTION OF FERTILIZER TO FOOD GRAIN PRODUCTION IN INDIA FROM 1961/65 TO 1971/75

	Four year period		Increase	Increase attributable to fertilizer 1/
	1961/65	1971/75		
Mean annaul food-grain production, million t	83.2	101.7	18.5	13.8
Mean fertilizer consumption, million t $N+P_2O_5+K_2O$	0.54	2.71	2.17	

1/ Assuming that (1) 75% of all fertilizer goes to food grain and
(2) on average, 1 kg of fertilizer nutrients ($N+P_2O_5+K_2O$) result in 8.5 kg extra grain.

Source: Tandon, H.L.S. 1979. European Nitrogen Service Programme. New Delhi, India.

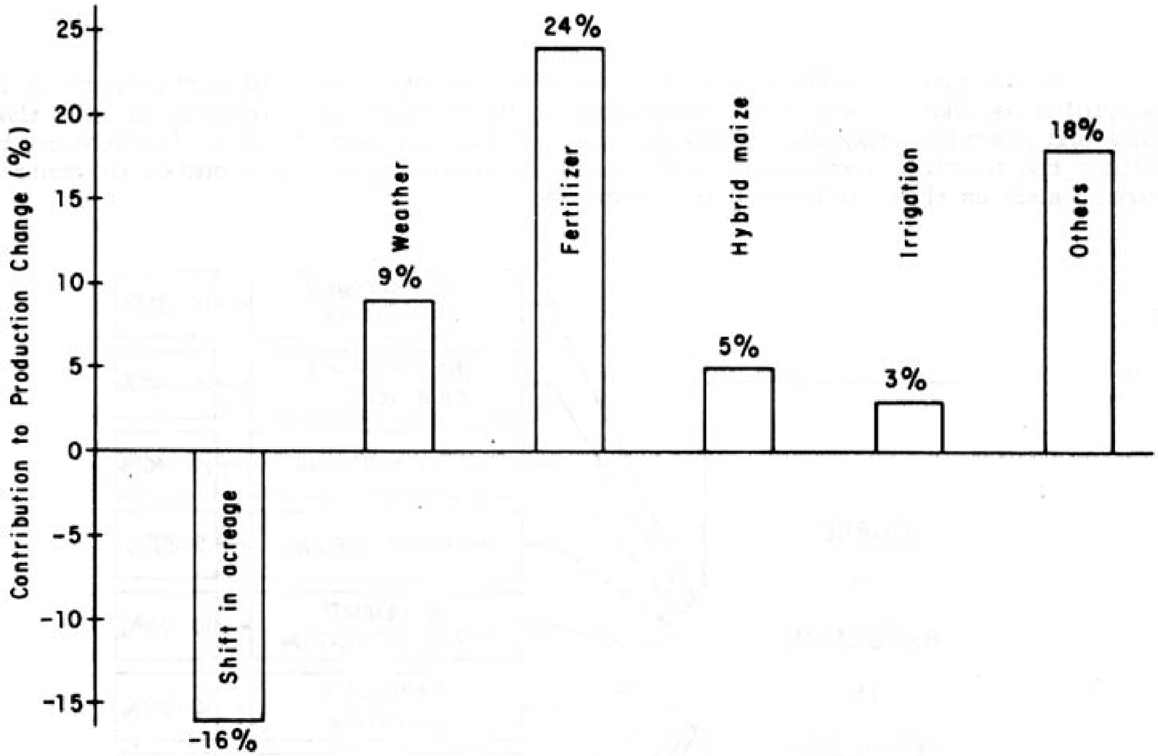


Figure 12 Sources of change in farm output in the United States, 1919 to 1955

Source: USDA. Farm Economics Division. Based on analysis done by D.D. Durost

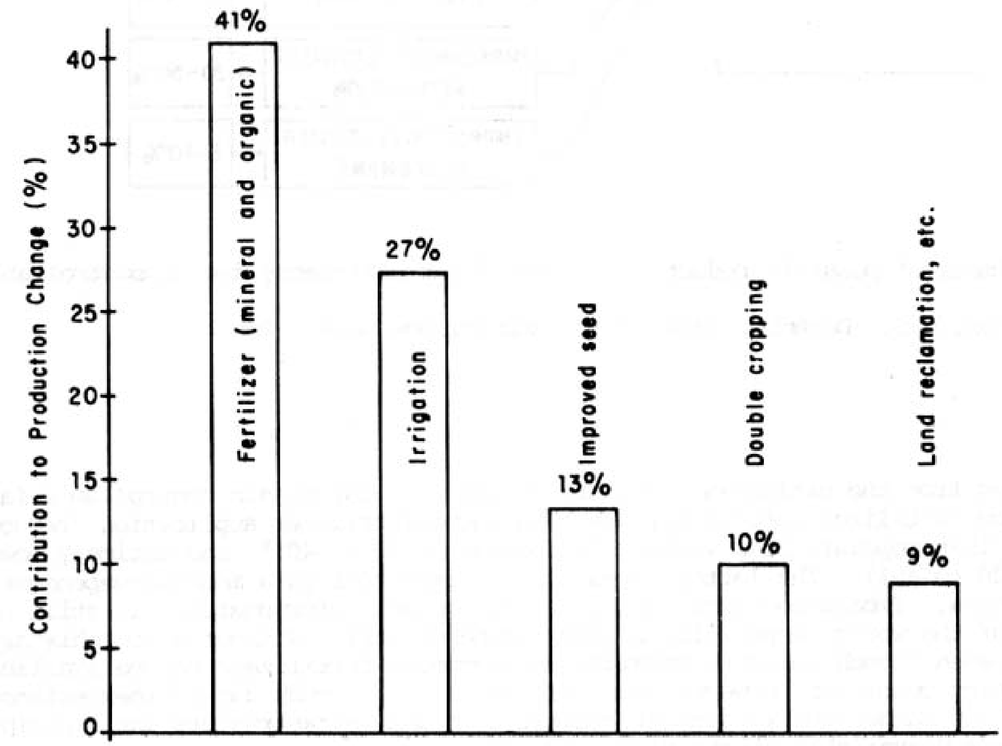


Figure 13 Sources of increased food grain production in India, Second Five-Year Plan 1956-61

Source: USDA. Foreign Agricultural Service Report.

It is just as difficult to isolate the separate effect of fertilizers in improving crop yields as that of any other individual input or practice. Bearing in mind that all inputs and practices together influence crop production levels, it is interesting to consider the possible reductions in fertilizer efficiency due to a number of controllable factors, such as those indicated in Figure 14.

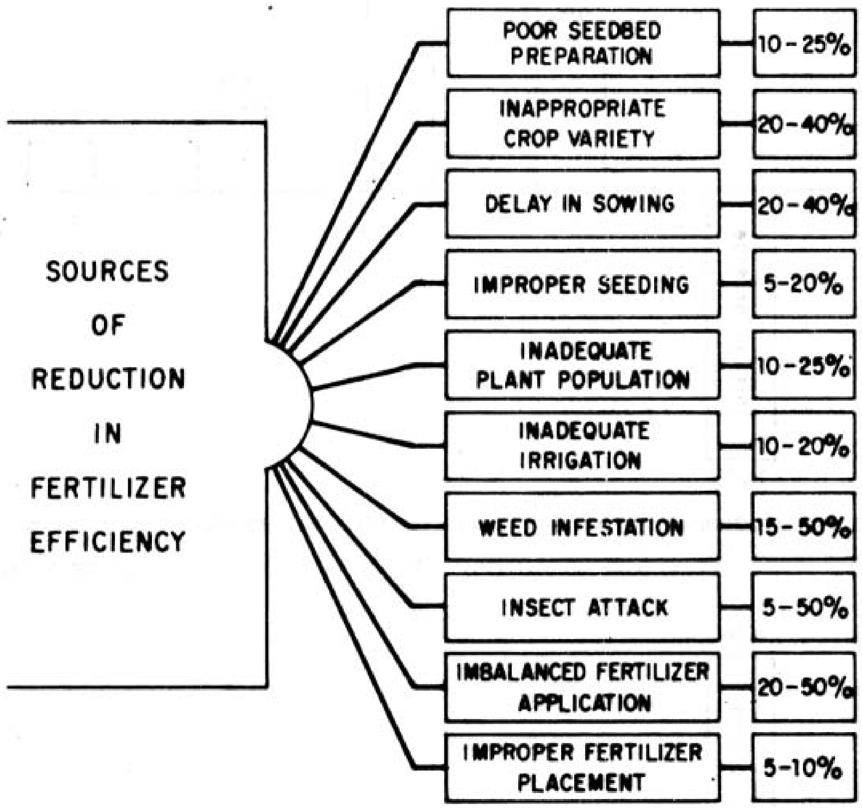


Figure 14 Estimate of possible reduction in fertilizer efficiency due to controllable factors

Sources: Sekhon, G.S. December 1976. FAI Seminar, New Delhi, India.

It shows from the estimates in Figure 14 that the three main controllable factors, which can reduce fertilizer efficiency, are imbalanced fertilizer application (reduction of 20 to 50%), inappropriate crop variety (reduction of 20 to 40%), and untimely sowing (reduction of 20 to 40%). The latter is especially important in a monsoon-dependent country like India. Imbalanced application of fertilizer, unfortunately, is still common in many parts of the world, especially in developing countries without a long history of fertilizer use even though suitable straight and compound fertilizers may be available. In many developing countries, however, the problem is not so much due to inexperience in fertilizer use but rather due to lack of organization and infrastructure for distribution, making fertilizer unavailable at the right time and place.

When appraising the contribution of fertilizer to increase in crop production, and when forecasting future crop production needs and fertilizer demand, there is one simple parameter that is conveniently used. This is the average response ratio between the amount of fertilizer applied and the increase in crop yield, i.e. a single factor indicating how much produce, like cereal grain, is expected from one unit of fertilizer nutrient applied. Much investigation has been done in this field. Table 2 shows a few examples of opinions and/or research findings, which indicates that it is not unreasonable to assume that 1 kg nutrients ($N+P_2O_5+K_2O$) produces around 10 kg cereal grain.

Table 2 RESPONSE RATIOS AS SEEN BY VARIOUS AUTHORS

Author	kg cereal grain produced by 1 kg $N+P_2O_5+K_2O$	Remarks
Bajwa and Randhawa	12.0	India/Punjab
Borlaug	20.0 to 25.0	High yielding varieties
Couston and Aspiras	10.0 to 15.0	High vielding varieties in Asia
Deichmann	11.0	
Herdt and Barker	10.0	
Huppert	12.0	Average 1800 to 1975/76 Germany
McCune	12.0	
Pinstrup-Andersen	10.0	
Shields	10.0	
Tandon	8.5	India

Sources: Papers prepared by respective authors indicating data on response ratios.

4. YIELD RESPONSE TO FERTILIZER

4.1 NUTRIENT NEEDS OF CROPS

In relation to a generalized fertilizer yield response ratio of around 1 : 10, i.e. the production of 10 kg cereal grain or equivalent per kg of plant nutrients ($N+P_2O_5+K_2O$) applied, it is appropriate to consider briefly the nutrient needs of crops. Figure 15 shows the quantities of the major plant nutrients removed by various crops where yields are just above average. These rather substantial amounts of nutrients, all well in excess of 100 kg/ha and some over 500 kg/ha, must be provided by the reserves of the soil itself (humus, weathering of minerals, decomposing organic material, etc.), organic manures of all kinds, and mineral fertilizers. If the nutrients removed are not replaced, soil fertility in general will decline and yields will suffer in spite of high-yielding seed, irrigation and other inputs and improved practices. There are few soils in the world which are capable of producing reasonable yields without regular replacement of the nutrients removed by annual cropping, and even these exceptional soils cannot produce indefinitely the yields that are expected today.

Though world average figures should be used with considerable caution, it is worth taking a rather simplified look at the overall situation. Table 3 shows the amounts of nutrients removed from the soil by just 10 crops in a single harvest. These 10 crops alone, which occupy just under 45 percent of the world's arable land and land under permanent crops (1977 figures) require about two-thirds of all the nitrogen (N) and over half of all the phosphate (P_2O_5) applied annually in the form of mineral fertilizer, whereas their potash (K_2O) needs are satisfied to the extent of only about 40 percent if the straw is not returned to the soil as compost or farm yard manure. If the yields of just these 10 crops had been only one-third higher as a result of irrigation or better varieties, they would have removed as much in total nutrients as was in fact applied in mineral fertilizers to all crops, with virtually nothing left over for the crops occupying the other half of the world's arable and permanently cropped land (Table 4). Theoretical as these reflexions may be - especially as they take no account of the amounts of plant nutrients lost each year by leaching and run-off etc. - they are indicative of the order of magnitude of mineral fertilizers involved. In a few countries, and for a few crops, fertilizer use is still low, indeed dangerously low as far as future production needs and maintenance of soil fertilizer are concerned. Returning to the soil as much organic residue as is possible and making up through the application of mineral fertilizer the difference between what they can replace and what is removed by crops, is the only long-term solution to the problem of providing for the world's food needs.

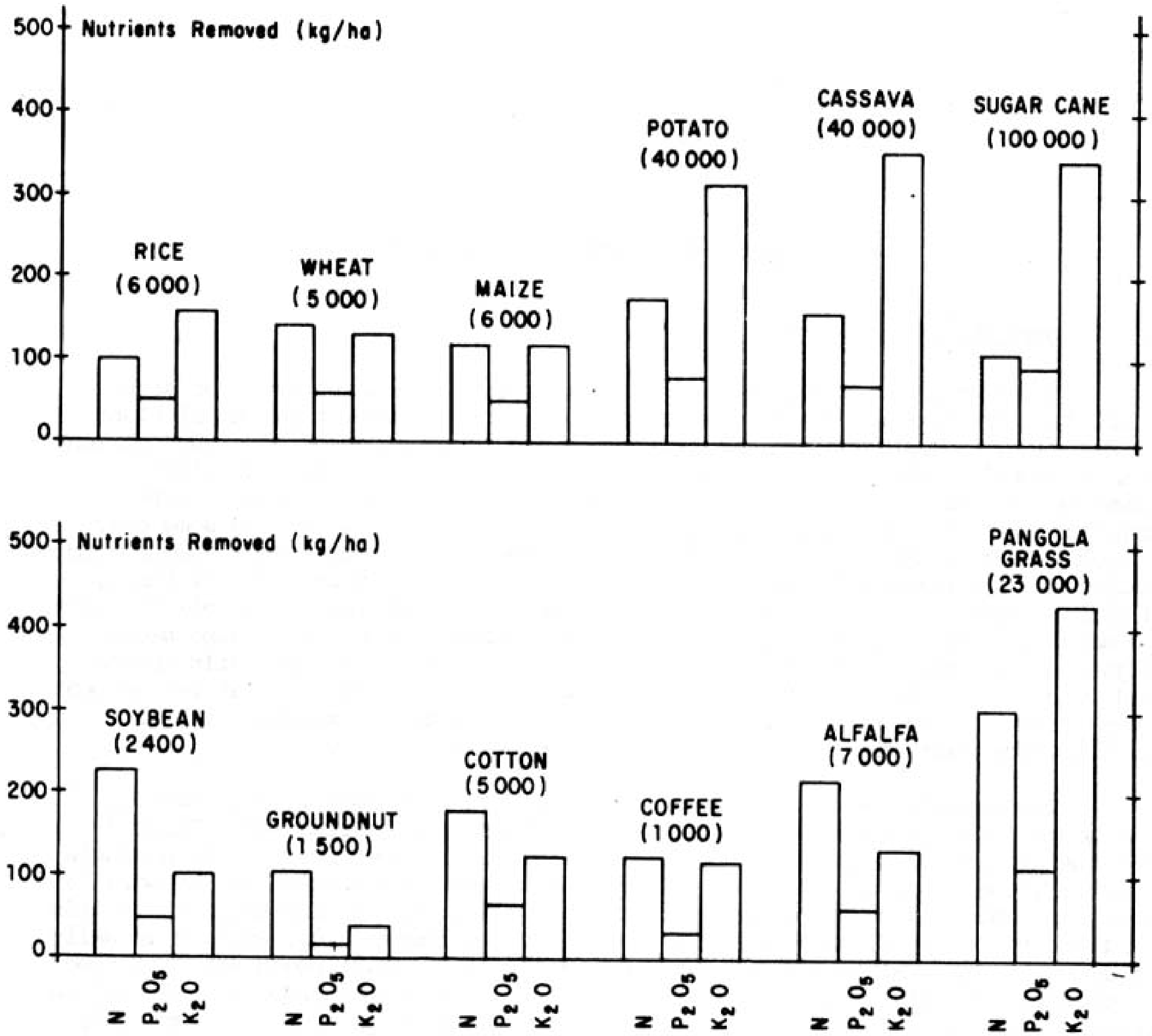


Figure 15 Approximate amounts of plant nutrients removed from the soil by 12 selected crops

Sources: FAO. 1978. Fertilizers and their use. Land and Water Development Series No. 8. Rome; De Geus. 1973. Fertilizer guide for the tropics and subtropics. Centre d'Etude de l'Azote, Zurich; Sanchez, P. 1976. Properties and management of soils in the tropics. Wiley, New York.

Notes:
- Figures in brackets represent yield in kg/ha.
- Removal figures refer to nutrients contained in the above-ground parts and the below-ground harvested portion where appropriate, at the indicated yields.
- The leguminous plants (soybean, groundnut and alfalfa) get most of their nitrogen from the air through symbiosis with micro-organisms.
- In the case of coffee, a permanent crop, the nutrients needed for the vegetative growth of the tree are included.

Table 3

PLANT NUTRIENTS REMOVED FROM SOIL BY THE 1977 HARVEST OF SELECTED CROPS COMPARED WITH THE QUANTITY OF NUTRIENTS APPLIED IN MINERAL FERTILIZERS, 1976/77

Crop	Yield t/ha 1/	Area mill. ha	Nutrients removed mill. t			
			N	P_2O_5	K_2O	Total
Rice	2.6	142.8	5.7	2.9	10.0	18.6
Wheat	1.6	232.4	10.4	4.5	9.7	24.6
Maize	3.0	118.5	7.1	3.0	7.1	17.2
Potato	14.0	21.0	1.3	0.6	2.3	4.2
Cassava	8.8	12.6	0.4	0.2	1.0	1.6
Sugar Cane	55.9	13.2	0.8	0.7	2.5	4.0
Soybean	1.6	49.4	0.7 2/	1.5	3.1	5.3
Groundnut	0.9	18.5	0.1 2/	0.2	0.4	0.7
Seed Cotton	1.3	33.2	1.6	0.6	1.1	3.3
Coffee, green	0.5	9.1	0.6	0.1	0.5	1.2
Total 10 selected crops			28.7	14.3	37.7	80.7
Mineral fertilizer (nutrients) consumption, world total 1976/77 - million t			45.1	26.5	23.1	94.7
Percentage of world total fertilizer (nutrients) consumption required to cover the needs of 10 selected crops			64	54		85
Percentage of nutrient needs of 10 selected crops not covered by fertilizer application				61		

1/ World Average

2/ Only 10% of actual needs as leguminous plants cover most of their nitrogen needs from the air

Source: FAO Production Yearbook: FAO Annual Fertilizer Review; and ref. to Figure 15.

Table 4

REMOVAL OF PLANT NUTRIENTS BY 10 SELECTED CROPS COVERING APPROXIMATELY 45% OF THE WORLD'S ARABLE AND PERMANENT CROP LAND WITH 1977 AND ASSUMED HIGHER FUTURE YIELDS

Nutrients removed with:	Million t per harvest			
	N	P_2O_5	K_2O	Total
1977 yields (Table 3)	28.7	14.3	37.7	80.7
+ 33.3% yield increase	38.3	19.1	50.3	107.7
+ 50% yield increase	43.1	21.5	56.5	121.2

Source: Ref. to Figure 15 and Table 3

4.2 YIELD RESPONSE OF SELECTED CROPS

Before considering in a selective manner the responses of individual crops to fertilizer application it is advisable to take a more general view of crop response in tropical regions. Figure 16 was based on an analysis of a large number of simple trials and demonstrations in farmers' fields carried out by the FAO Fertilizer Programme and related projects between 1976 and 1977. The fact that these data originated from developing countries in tropical and subtropical climates, and that they were the results of simple trials and demonstrations in small farmers' fields, shows how large are the reserves for increased food production and rural development that are still latent in these regions. The results of such simple trials and demonstrations in farmers' fields may well lack the exactness of scientific experiments, but they show us, and usefully demonstrate to farmers, that agricultural production can be increased and rural development can be furthered in the countries concerned, under the local climatic conditions and by the farmers themselves, through modern agricultural practices which include, as a principal item, the use of mineral fertilizers.

Of the world's nearly 1 500 million ha of arable land and land under permanent crops, cereals occupy about half or, just over 750 million ha, of which almost two-thirds are devoted to the "Big Three": wheat, rice and maize. These three crops have therefore been taken as examples. This does not imply that the many other crops growing on the rest of the area of arable land and land under permanent crops are considered to be of less importance. The performance of apple or citrus trees, of grapes or tobacco, of soybeans or sunflowers, of cotton or sugar cane, is as important to some districts and countries as is that of the big three cereals to the world, not to mention grassland which, in some countries, is heavily fertilized yet in others is almost neglected.

4.2.1 Wheat

In considering its response to fertilizer, one has to bear in mind that wheat is an almost universal crop. From its complex botanical background many different varieties have been developed of both winter and spring wheat, with the result that wheat is grown from near the Arctic Circle to tropical highlands.

Table 5 lists the 12 largest wheat producers in the world (together producing about 80 percent of the world wheat crop), arranged in descending order of their grain yield per hectare. It also shows the national average of fertilizer use on wheat alone. The relation between the level of wheat yield and national fertilizer consumption is clear. At the top of the list are the heavy users of fertilizers, the countries with highly intensive agriculture which have been growing "high-yielding varieties" of wheat for many years. China is an exception which does not fit the general pattern - because it uses large quantities of organic wastes and green manures. In the less intensively cultivated countries, where yields and national fertilizer consumption differ little between one country and another, the order is not as strict as that at the top of the list. Overall, the Table shows once again that there are production reserves in many countries which can be mobilized by means of modern agricultural methods including the use of fertilizers.

The results of trials and demonstrations in Haryana State, India, listed in Table 6 show that, even on soils considered medium to high in available potash, a balanced NPK application gives better response than N only or NP dressings. In both districts the overall response ratio to the balanced NPK application fell short of the 1 : 10 previously mentioned, possibly for various reasons, but the general conclusion remains valid.

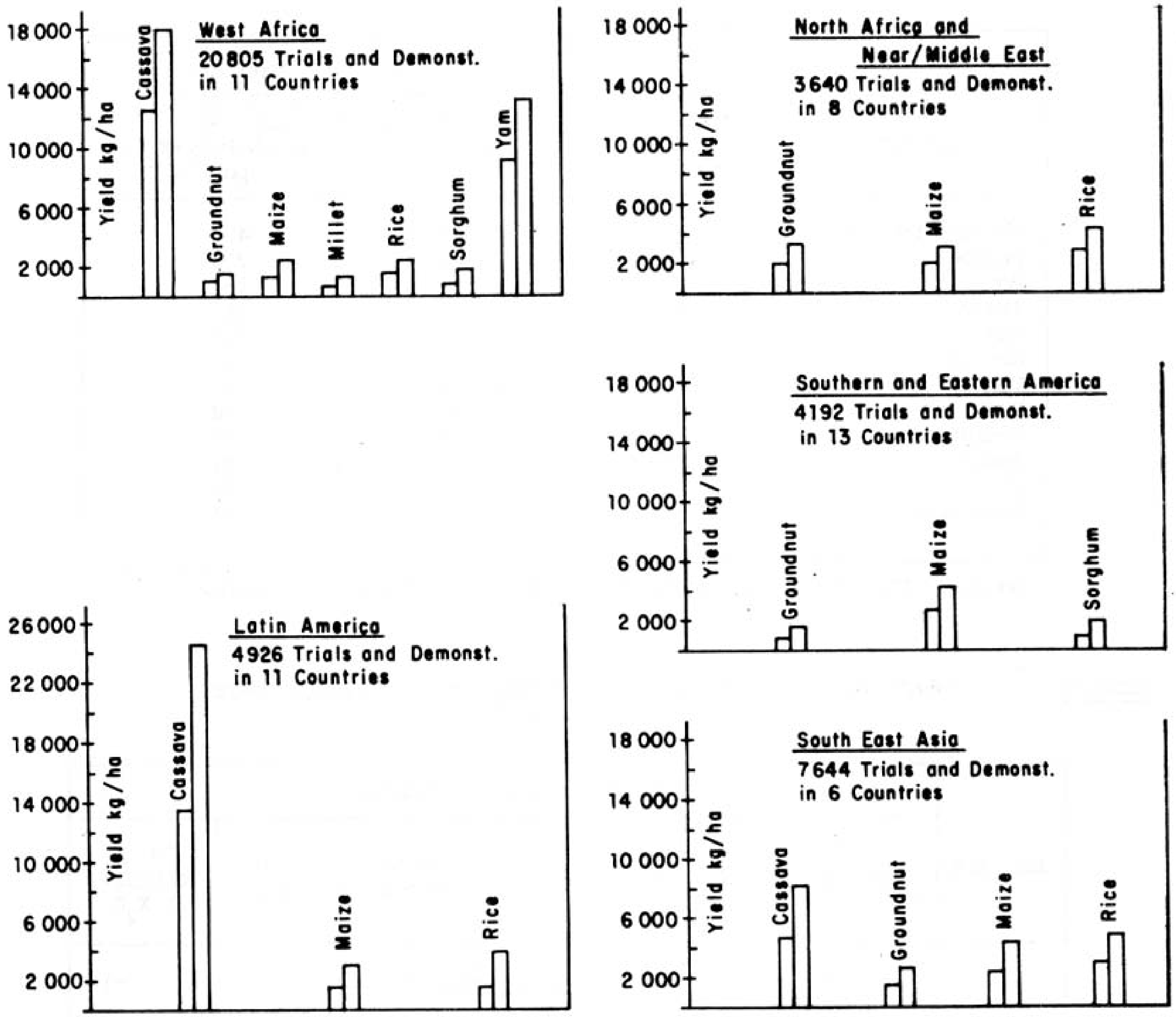


Figure 16 Average control and highest yields in fertilizer trial and demonstration data of seven crops, FAO Fertilizer Programme 1961/1977

Source: Phosphorus in Agriculture. 1979, Sept. (76): 147-156.

Table 5 FERTILIZER CONSUMPTION OF THE 12 LARGEST WHEAT PRODUCERS IN THE WORLD, ARRANGED IN THE ORDER OF THEIR AVERAGE GRAIN YIELD PER HECTARE

Country	Wheat production 1977 (million t)	Average grain yield 1975-77 (kg/ha)	National fertilizer use 1977 (kg $N+P_2O_5+K_2O$ per ha)
Germany Fed. Rep.	7.2	4 366	422
France	17.5	3 961	278
Romania	6.5	2 590	107
Italy	6.3	2 556	141
USA	55.1	2 050	100
Canada	19.7	1 946	34
Turkey	16.1	1 724	47
USSR	92.0	1 394	78
Pakistan	9.2	1 391	35
India	29.1	1 381	25
China	40.0	1 341	74
Australia	9.4	1 209	24

Source: FAO Production Yearbook and FAO Annual Fertilizer Review

Table 6 WHEAT YIELDS IN TRIALS AND DEMONSTRATIONS IN HARYANA STATE, INDIA 1978[1/]

District	Nutrients applied (kg/ha)						
	Control	35 N	70 N	35 P_2O_5	35 N+ 35 P_2O_5	70 N+ 70 P_2O_5	70 N+ 70 P_2O_5+ 35 K_2O
	(- - - - - - - - - - - - Grain yield (kg/ha) - - - - - - - - - -)						
Hissar	1 960	2 250	2 838	2 259	2 688	3 090	3 186
Ambala	1 315	1 732	2 024	1 440	1 783	2 057	2 222

1/ Haryana soils are considered to be medium to high in available K

Source: Chaudhry and Karwasra. 1979. Results of a few trials/demonstrations on the question of balanced fertilizer application. Haryana Gr. University/FAI Workshop. Chandigarh, India.

Figure 17 features the classic response curve of two wheat varieties to increasing nitrogen application, illustrating in a convincing way one of the most important developments in modern agriculture - the introduction of the high-yielding varieties of cereals which has extended intensive cereal cropping, hitherto a domain of temperate climates and developed countries, to tropical and subtropical countries. The graph demonstrates the main property of the new varieties, their good response to heavier dressings of fertilizer. "Sonora 64", one of the first short-strawed wheat varieties developed by CIMMYT in Mexico, yielded well over 6 000 kg grain per hectare with application of 160 kg N/ha, while the traditional tall variety "C 306" could not make use of more than 100 kg N/ha because of lodging at heavier rates.

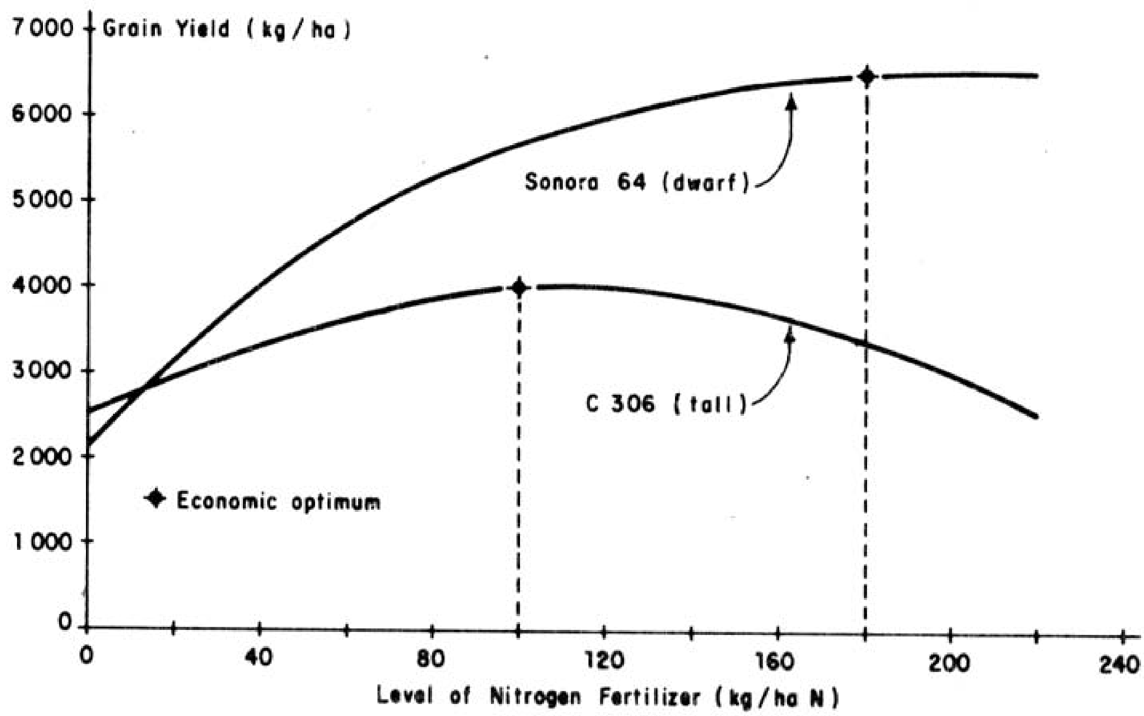


Figure 17 Response of high-yielding (dwarf) and local (tall) wheat varieties in India

Source: CEA, World Food Congress Proceedings. 1970. Zurich.

4.2.2 Rice

Approximately 90 percent of the world's rice is grown in Southern and Eastern Asia. With over 8 000 varieties belonging to basically two botanical types, rice ranges from the tropics (Indica-type varieties) into the warmer parts of the temperate regions (Japonica-type varieties). Results of experiments and trials, therefore, are somewhat more uniform, especially as most research and breeding efforts, until recently, have been on the classic flooded (water, low-land etc.) rice rather than on upland rice and floating rice, which are both now beginning to attract attention.

Table 7 lists the 12 largest rice producers in the world, arranged in descending order according to intensity of fertilizer use. These 12 countries produce just under 90 percent of the world's rice crop. As with wheat, the top producers are also those with the highest national average fertilzier consumption. At the lower end of the table, however, the relationship is less clear. This is mainly because total national fertilizer consumption figures are not a good indicator of consumption on rice alone. In some of the countries concerned, rice receives much of the total fertilizer consumed in the country (Japan, Korea, etc.), while elsewhere (Brazil) its use is divided between several other crops, some of which may be of greater national importance. An additional complicating factor is the varying degree of introduction of high-yielding varieties between one country and another.

Table 7

INTENSITY OF FERTILIZER USE IN MAJOR RICE PRODUCING COUNTRIES, 1977

Countries 1/	Rice production 1977 (million t)	Average grain yield 1975-77 (kg/ha)	National fertilizer use 1977 (kg nutrients per ha)
Japan	17.0	5 952	428
Korea Rep.	8.4	6 023	330
Korea DPR	4.6	5 496	276
USA	4.5	5 094	100
Vietnam	11.2	2 127	80
Brazil	8.9	1 512	77
China	131.5	3 524	74
Bangladesh	19.3	1 859	37
Indonesia	23.2	2 718	35
India	74.0	1 799	25
Thailand	13.6	1 816	16
Burma	9.5	1 811	6

1/ Arranged according to intensity of fertilizer use

Sources: FAO Production Yearbook and FAO Annual Fertilizer Review

Table 8, featuring a number of fertilizer trial results collected from various Indian sources, again illustrates the good performance of balanced NPK fertilization. This is of special interest in India where the majority of the soils are thought by many advisors to be amply supplied with natural reserves of plant-available potash. The evaluation of fertilizer demonstrations on rice carried out by the FAO Fertilizer Programme in small farmers' fields in Bangladesh in 1976 (Table 9) provides another example underlying the advisability of balanced fertilizer use.

In Indonesia, the FAO Fertilizer Programme trial and demonstration results gave the following fertilizer-grain yield ratios for flooded rice:

	Ratio (kg nutrient : kg grain)	Rate of Application (kg nutrient/ha)
N	1 : 14.8	90
	1 : 8.1	180
P_2O_5	1 : 12.4	30
K_2O	1 : 3.2	30

In the Philippines, the overall response ratio for $N+P_2O_5+K_2O$ in 1867 fertilizer demonstrations on rice, carried out between 1973 and 1978 under the FAO Fertilizer Programme, averaged 1 : 9.1 based on the three fertilizer levels which showed the highest increases in paddy yield in each regional group of demonstrations.

Table 8 RESPONSE OF RICE TO FERTILIZER IN INDIA DERIVED FROM VARIOUS SOURCES 1967 TO 1977

Period	Treatment (kg/ha N + P_2O_5 + K_2O)				Overall Increase kg/ha Response to $N+P_2O_5+K_2O$
	(0+0+0)	(120+0+0) Yield kg/ha Incr. kg/ha Response to N	(120+60+0) Yield kg/ha Incr. kg/ha Response to P_2O_5	(120+60+60) Yield kg/ha Incr. kg/ha Response to K_2O	
(1) Kanwar *et al.* January 1973. Fertilizer News, Trials 1967 to 1971					
Kharif	2913	4161 +1248 10.4	4887 + 726 12.1	5169 + 282 4.7	+2256 9.4
Rabi	3101	4337 +1236 10.3	5393 +1056 17.6	5885 + 492 8.2	+2784 11.6
(2) Singh *et al.* March 1976. Fertilizer News, Trials 1971/72 to 1973/74					
Kharif 1346 trials	2957	3725 + 768 6.4	4445 + 720 12.0	4691 + 246 4.1	+1734 7.2
Rabi 947 trials	3227	3887 + 660 5.5	4625 + 738 12.3	4901 + 276 4.6	+1674 7.0
(3) Prasad Rajendra. September 1977 Trials 1974/75					
Kharif 256 trials	2486	3986 +1500 12.5	4718 + 732 12.2	5492 + 774 12.9	+3006 12.5
Rabi 370 trials	2919	4167 +1248 10.4	4845 + 678 11.3	5535 + 690 11.5	+2616 10.9
(4) Fertilizer News, August 1978					
Kharif	2725	4141 +1416 11.8	5005 + 864 14.4	5413 + 408 6.8	+2688 11.2
Rabi	3286	4378 +1092 9.1	5194 + 816 13.6	5554 + 360 6.0	+2268 9.45

Table 9

RICE RESPONSE TO FERTILIZER OBTAINED FROM FERTILIZER DEMONSTRATIONS IN BANGLADESH, 1976

Treatment $N+P_2O_5+K_2O$ Kg/ha	Yield kg/ha	Response over control kg/ha			
		N	P_2O_5	K_2O	Total
		(1) Aus (March/August) Paddy			
0+ 0+ 0	2217				
75+ 0+ 0	3617	1346			
75+60+ 0	4308		693		
75+60+45	4540			232	2323
Response ratio		17.6	11.5	5.2	12.9
		(2) Aman (July/December) Paddy			
0+ 0+ 0	2433				
75+ 0+ 0	3369	936			
75+60+ 0	3748		379		
75+60+45	4054			306	1621
Response ratio		12.4	6.3	6.8	9.0

Source: FAO Fertilizer Programme

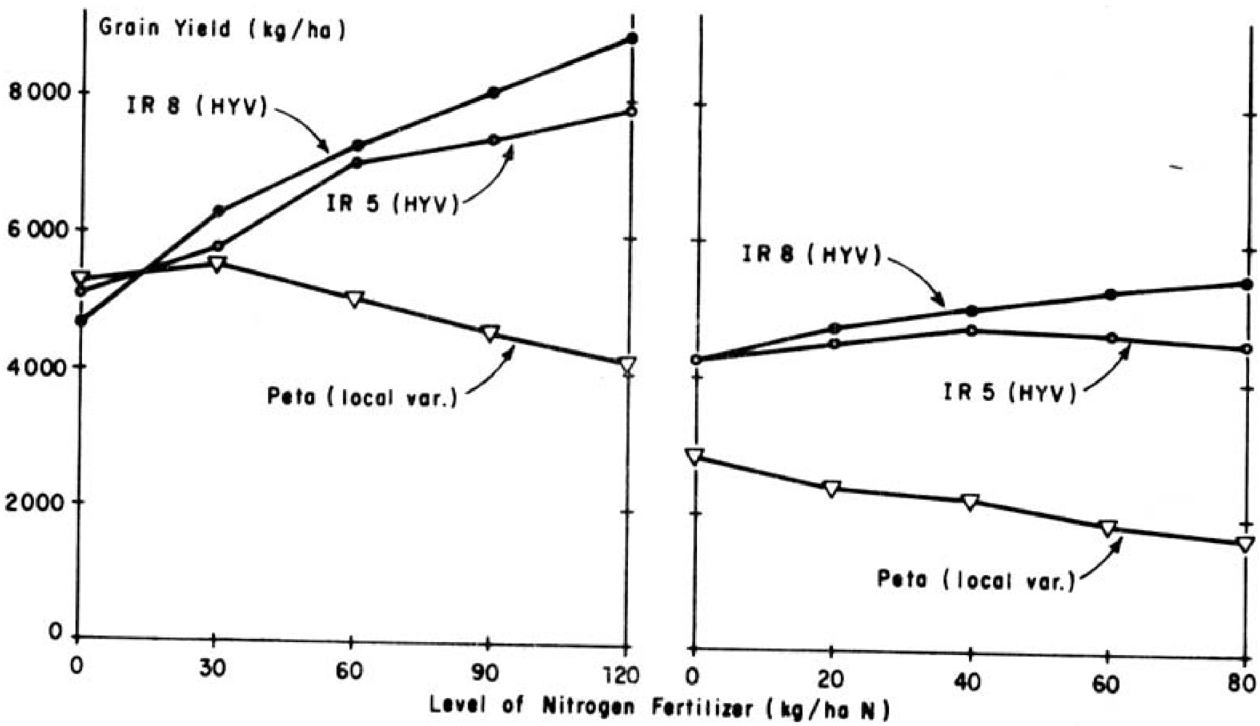


Figure 18 Effect of levels of nitrogen on the grain yield of high-yielding and local varieties of rice in the Philippines, dry and wet season, 1966 to 1968

Source: University of the Philippines College of Agriculture and International Rice Research Institute. 1970. Rice production manual. Los Baños, Laguna.

The fundamental prerequisite for greater rice production through the effective use of fertilizer is the adoption of improved high-yielding varieties. Figure 18 illustrates the effect of various N levels on the grain yield of two of the original high-yielding (dwarf) rice varieties, the famous IR8 and IR5 (which have since been partly replaced by further improved varieties as stated earlier), and of one typical tall rice variety (Peta). The rapid depression of yield of Peta beyond 30 kg N/ha in the dry season, and the yield depression which occurred with 20 kg N/ha in the wet season were due to early lodging of the crop which was not able to cope with being "well fed" with nitrogen. Figure 18 clearly shows the quite different behaviour of the improved varieties, though even IR5 shows a decline in performance with 60 kg N/ha in the wet season. This and the generally poorer performance in the wet season is mainly due to lack of light with the normally heavier overcast wet season skies.

4.2.3 Maize

With about 118.5 million ha, maize is the world's third largest crop in respect of area and production, but the highest in respect of grain yield per hectare. In many countries, where climatic conditions are unfavourable for grain maize, the crop is widely used as an important fodder plant, mainly for silage, this area being in addition to the 118.5 million ha mentioned. Extending from the wet tropics right into the temperate zones, and serving two different purposes - grain and fodder - many varieties have been developed over the years, and in modern times much attention has been paid by breeders and hybrid seed producers to maize.

A general view of the world's 12 main maize grain producers is presented in Table 10 which illustrates just as strikingly as with wheat and rice the relationship between national average fertilizer consumption and maize yield. The exception is Argentina, where mainly climatic conditions distort the statistical picture; large parts of the cultivated land are devoted to extensive, dry-farming type agriculture using little or no fertilizers, while the bulk of the relatively small total national fertilizer consumption goes to a few crops, maize being among them.

Because so much of the world's maize is grown by small-scale farmers still using traditional, relatively safe but low-yielding local varieties and antiquated methods of cultivation, and because of the rather low market price for maize in many countries, the question of the profitability of recommended fertilizer use on maize can be a somewhat controversial matter. However, where there is a safe market with reasonable ex-farm prices, fertilizer use on maize definitely pays.

Maize response is exceptionally noteworthy with nitrogen. Experiments in Burma with five different maize varieties, for example, showed an average response to 50 kg N/ha of 1 872 kg/ha of additional grain (236 percent over the control yield of 793 kg/ha) equivalent to 37.4 kg grain per kg N. Although this response ratio seems to be extremely high and might be expected to drop at higher N levels, a trial in Madagascar gave similar results. There, the response to 40 kg N/ha was equivalent to 30.3 kg grain per kg N and the yield increased with each successive 40 kg N/ha up to a total of 200 kg N/ha when the overall response of 5 218 kg/ha of additional grain was equivalent to 26.1 kg grain per kg N.

Figures from the United States indicate that 1 kg N produces an average of 23 kg maize grain and results from Zimbabwe/Rhodesia as long ago as 1957 gave figures of well over 20 kg grain per kg N under various conditions.

Table 10

INTENSITY OF FERTILIZER USE IN MAJOR MAIZE PRODUCING COUNTRIES, 1977

Country	Maize production 1977 (million t)	Average grain yield 1975-77 (kg/ha)	National fertilizer use 1977 (kg nutrients per ha)
France	8.6	4 501	278
Italy	6.5	6 164	141
Romania	10.1	3 076	107
Yugoslavia	9.9	4 018	101
USA	161.5	5 546	100
USSR	11.0	3 034	78
Brazil	19.1	1 599	77
China	33.6	2 984	74
South Africa	9.7	1 530	60
India	6.8	1 123	25
Argentina	8.3	2 634	2

Source: FAO. 1978. Production Yearbook; FAO. 1978. Fertilizer Yearbook.

Some results achieved under somewhat less favourable conditions in farmers' fields in the FAO Fertilizer Programme are shown in Table 11. These appear rather modest compared with those mentioned above, but they are still good and of practical significance to countries where maize cultivation, despite a long tradition, has not yet fully adopted the practices of modern technology. Once again it can be noted that the best results were obtained with balanced NPK fertilization which is necessary if good performance is to be maintained over a long period of time.

Table 11

SOME RESULTS OF MAIZE TRIALS AND DEMONSTRATIONS IN CULTIVATORS' FIELDS

Country	Control Yield (kg/ha)	Best Fertilizer Treatment			Overall Response ratio
		$N+P_2O_5+K_2O$ (kg/ha)	Yield (kg/ha)	Increase (kg/ha)	
Ghana	1 110	23+23+23	2 010	900	13.0
Ecuador	900	28+45+15	2 200	1 300	14.7
Indonesia	815	67+45+50	2 111	1 296	8.0

Source: FAO Fertilizer Programme

4.3 HIGH-YIELDING VARIETIES AND FERTILIZER USE

The term "high-yielding varieties" usually refers to improved varieties of tropical and sub-tropical cereals. This is correct in the sense that the development of modern high-yielding varieties of wheat, rice and maize (including hybrids in the case of maize) initiated what generally is known as the "Green Revolution", much debated and often misunderstood by the general public, but crowned by the honouring of an agronomic research worker, Dr. Norman Borlaug, with the 1970 Nobel Peace Prize. For a number of reasons breeding research in the tropics and sub-tropical regions had concentrated on exportable cash crops, while basic food crops, which for many years had received much attention in the industrialized countries, were relatively ignored in the developing countries. From the mid-1940s onwards, this Breeding Programme in 1943 - which subsequently developed into the Centro Internacional de Mejoramiento de Maize y Trigo (CIMMYT) - was one of the take-off points, perhaps the most important. At present, many international, national and regional agricultural research institutes are working on the improvement of food crops ranging from the principal cereals to tubers and pulses.

"High responsive" would be as apt a term as "high-yielding" varieties, because their high yields are mainly due to their high capacity to make use of water, light, fertilizers and improved farming practices. Indeed, fertilizers form an essential part of their definition as "varieties which can give a linear response up to at least 100 kg nitrogen per hectare".

The common morphological characteristic of high-yielding cereal varieties is their reduced plant height; simply because the short straw of "short-strawed" or "dwarf" varieties reduces the danger of lodging at increasing levels of available plant nutrients, especially nitrogen. The responsiveness of high-yielding varieties of rice and wheat compared with local varieties is illustrated in Figures 17 and 18.

The introduction of high-yielding varieties can, in many instances, raise a number of problems, examples of which were already mentioned. Thus without further breeding they may not be well adapted to the local climate; they may be subject to attacks by local pests and diseases which were not common in the country where they were developed; their grain may not suit the taste of local consumers and they may require the adoption by farmers of a whole set of new cultivation practices hitherto unknown to them, such as heavier fertilizer application and plant protection measures. For these reasons high-yielding varieties usually need to be adapted to local conditions by further breeding and improvement, as is now done in many places (e.g. "Mexipak" wheats). The introduction of high-yielding crop varieties is, in many countries, the basic step from traditional subsistence farming to modern market-oriented agriculture. This in turn calls for adequate infrastructure, development of the market, an incentive relationship between input and output prices, availability of farm credit, high skills amongst farmers, efficient extension work, and the ready availability of inputs, of which one of the most important is fertilizer supply - in the right quantity, of the right type, at the right place and time.

5. ECONOMICS OF FERTILIZER USE

The first concern of a farmer who wishes to use fertilizer is to determine what type to use and how much to apply. Since he needs to know how much he can expect to gain if he spends money on fertilizer, the primary economic test is an estimation of the increase in crop production - and its value - that will result from the application of a given quantity of plant nutrient. The cost of the fertilizer must be weighed against either the increased value of the crop or even against alternative uses of the money, possibly with a greater potential rate of return.

Because of the law of diminishing returns the aim of the farmer should be to use fertilizer at the most profitable or economic optimum rate.

Since the economics of fertilizer use is quite a broad subject, only a brief description is given here of the concepts commonly used in measuring the economic returns or benefits from fertilizer. It is essential however, that extension workers and planners of fertilizer use development should have a thorough understanding of what each economic concept means, and under what conditions they apply.

5.1 NET RETURN

As indicated above the farmer must compare the expected value of the additional yield obtained by the application of fertilizer with the cost of the fertilizer responsible for the added crop production. He estimates the additional value by multiplying the additional amount of crop expected to be harvested by the price he might reasonably expect to receive for his crop. The cost of the fertilizer is simply the product of the amount of fertilizer applied to the crop and the unit price paid for the fertilizer. The difference between the added value of the crop and the cost of fertilizer is known as the net return. In practice, because of the element of risk, a relatively large net return is usually needed to convince farmers to use fertilizers.

Marginal analysis shows the level of net return from each successive unit of fertilizer applied increases in relation to the cost of the fertilizer. The marginal net return is the increase in net return which can be obtained from a given increment of fertilizer. It depends on the value of the crop response to the increment of fertilizer and the cost of that increment, i.e. the marginal cost of fertilizer. The marginal rate of return to a given increment of fertilizer is the marginal net return divided by the marginal cost of fertilizer. Expressed as a percentage, the marginal rate of return (MRR) is as follows:

$$\text{MRR} = \frac{\text{Marginal net return}}{\text{Marginal cost}} \times 100$$

As a general rule, farmers do not want to use fertilizer beyond the point at which the MRR is at least 40 percent in one crop season, since at a lower MRR the value of the additional yield might not cover the cost of the additional fertilizer applied. This percentage assumes that there would be very little cost of capital in the form of interest for borrowed money. The economic optimum rate which gives the highest net return, however, is where the marginal rate of return is nil, i.e. where the value of the last crop yield increment exactly equals the cost of the last increment of fertilizer required to obtain that additional yield.

5.2 VALUE-COST RATIO

Another commonly used indicator of profitability of fertilizer use is the <u>value-cost ratio</u> (VCR) - the quotient obtained from dividing the expected value of the yield increase by the cost of fertilizer applied to bring about the increased yield. It is an average and is calculated as follows:

$$\text{VCR} = \frac{\text{Value of the yield increase}}{\text{Cost of fertilizer applied}}$$

If the VCR is more than 1, it means that a profit is to be expected. However, because of the risk element, most farmers in the developing countries would not use fertilizer unless the expected VCR is at least 2. This is equivalent to a 100% return on the money spent on the fertilizer. As a general rule, because of the nature of the typical response curve showing diminishing marginal returns, VCRs are higher on the lower and steeper part of the curve, where the marginal net return is also higher.

A farmer should aim for a higher VCR if he intends to apply fertilizer at a rate lower than the recommended optimum. FAO/FIAC (1974) explains that, "In practice, farmers use less than recommended rates. This is because the amount of fertilizer which a farmer will use depends on the anticipated yield response, crop prices expected, fertilizer availability and cost, level of financial resources and credit availability, tenure considerations, the degree of risk and uncertainty and the farmers' ability to bear them. At the time the farmer buys his fertilizer, only one of these, the cost of fertilizer, is accurately known. An average figure, based on experimental or farm trials, or the farmer's own experience, is used to estimate the probable increase in yield, but the actual response varies with the weather, and in turn affects the cost of harvesting and marketing. The price of the crop when it is harvested some months later may also be an estimate, unless a fixed support price is effectively implemented. The price may be substantially reduced on a free market if favourable weather or the widespread use of fertilizers leads to a sharp rise in yields and total output. A farmer thus has to be cautious and allow what he considers a fair safety margin when deciding how much fertilizer to use on his crops."

5.3 FERTILIZER-CROP PRICE RATIOS

The ratio between the purchase price of a unit weight of fertilizer and the selling price of the same weight of the harvested crop indicates the increase in crop production that is necessary to pay for the cost of a given amount of fertilizer.

While high farmgate prices for fertilizers tend to discourage farmers from using them, the basis for applying them should depend much more on the expected fertilizer-crop price ratio.

Price relationships for a specific crop vary by country. For example, among the developing countries listed in Table 12, whose price relationships for rice were examined, the situation was more favouarable in Bangladesh, Indonesia and Pakistan than in Brazil, Madagascar or the Philippines. Farmers in the former group of countries needed less than 2 kg rice to pay off 1 kg fertilizer nutrient, while those from the latter group need 3.5 kg rice to cover the cost of 1 kg fertilizer nutrient. The same table also shows the extent to which the price relationship is affected when the prices of crop and fertilizer change, as occurred in most of the countries between 1978 and 1979.

Table 12 FERTILIZER AND RICE PRICE RELATIONSHIPS

Country	Fertilizer Price[1/] (US$ per t $N+P_2O_5+K_2O$)		Rice Price[2/] (US$ per t)		Price Relationship[3/]	
	1978	1979	1978	1979	1978	1979
Bangladesh	571	485	168	255	3.4	1.9
Brazil	544	431	136	123	4.0	3.5
Indonesia	367	241	193	185	1.9	1.3
Madagascar	595	595	170	170	3.5	3.5
Pakistan	232	232	122	122	1.9	1.9
Philippines	495	620	150	177	3.3	3.5

1/ Farmgate price of recommended fertilizer $N+P_2O_5+K_2O$ mix.

2/ Farmgate price of unmilled rice.

3/ Could be interpreted as number of kg rice to buy 1 kg fertilizer $N+P_2O_5+K_2O$.

Source: FAO/FIAC ad hoc Working Party on the Economics of Fertilizer Use. February 1980 Economics of Fertilizer Use in Developing Countries. Paper for Discussion.

To sum up, the three most commonly used indicators of profitability of fertilizer use are: 1) net return, 2) value-cost ratio, and 3) fertilizer-crop price ratio. Each of these have specific uses. The use of the economic optimum net return is appropriate for farmers who have the money to buy fertilizers and are concerned about how to maximize the return from the application of fertilizers on their crops. On the other hand, farmers with more limited resources would tend to be more conservative. They would only apply the amount of fertilizer at the level that would provide them with a good value-cost ratio or an acceptable marginal rate of return on the money spent on fertilizers. Knowledge of the third indicator, the fertilizer-crop price ratio and the most likely yield response provides the farmer with an idea of the likely return and helps him to decide whether or not it would be profitable to use fertilizer on a particular crop.

6. GOVERNMENT PROGRAMMES AND POLICIES AFFECTING FERTILIZER USE

6.1 GENERAL CONSIDERATIONS IN PRICE POLICIES

As already indicated, the major consideration influencing the amount of fertilizer bought by the farmer is the relationship between the cost of fertilizer and the price of the crop on which it is used. A favourable cost/price relationship encourages higher fertilizer usage. An unfavourable relationship restrains greater fertilizer use and leads to lower yields and crop production. Because of the now widely recognized importance of fertilizer in crop production, governments of many countries control its price one way or another.

Reflecting different production costs, import costs and government policies, fertilizer prices vary markedly from country to country. In principle, price difference should reflect the nutrient concentration and the efficiency of the fertilizer. However, in countries where many farmers are unfamiliar with fertilizers, it is desirable to have a simplified pricing system. For example, the Indonesian Government in its effort to popularize fertilizers, set identical prices for urea, triple superphosphate and 15-15-15 compound, thus providing the farmers with nitrogen, phosphate and potash at virtually equal unit prices.

The evaluation of fertilizer price at the farm level is incomplete without due consideration of the cost of other agricultural requisites/inputs to the farmer and of the prices obtained by him for farm produce. It is only in the context of input/output prices that a government can make meaningful decisions regarding the raising or lowering of fertilizer prices.

6.2 DEVELOPMENT IN FERTILIZER PRICES

Import prices for fertilizers rose dramatically in late 1973 and in 1974: this affected the prices farmers paid in 1974/75 and subsequently - though government subsidies, where in operation, cushioned the direct impact on farmers. The fertilizer price situation since 1970 for selected Asian countries is shown in Table 13.

World prices for all fertilizers declined in 1975 and for urea - the principal N-fertilizer - remained at around US$110 f.o.b. in bags throughout most of 1976 and the early part of 1977. However, there was an increase averaging nearly 10% in the first half of that year as compared with the second half of 1976. The trend of rising prices continued in the second half of 1977 but was not sustained in January-June 1978. From then on, prices steadily increased, rising substantially in 1979 due to increased production costs and strong demand. Table 14 compares farmgate prices, per metric ton N, in the main consuming and producing countries in the five year period, 1973/74-1977/78.

6.3 MARKETING AND DISTRIBUTION COSTS

Costs incurred in the distribution chain between factory and farmgate (or port and farmgate in the case of imports) account for a substantial proportion of the final cost to the farmer.

Table 15 shows that there is wide variation in marketing and distribution costs when related to final cost, from about 10% as in India and Mexico to over 50% as in Brazil and Thailand.

Table 13 INDICES OF WEIGHTED FERTILIZER PRICES PAID BY FARMERS, 1970-71 TO 1977-78 [1/]
(1970-71 = 100)

Particulars	1970-71	1971-72	1972-73	1973-74	1974-75	1975-76	1976-77	1977-78
Bangladesh								
N	100	103	132	218	278	171	207	216
P_2O_5	100	102	116	189	269	167	178	179
K_2O	100	100	120	210	300	186	220	223
All nutrients	100	102	129	210	272	171	202	210
India								
N	100	105	116	118	195	185	182	180
P_2O_5	100	103	106	107	207	167	160	154
K_2O	100	103	108	109	197	177	168	165
All nutrients	100	104	112	115	196	181	179	174
Indonesia								
N	100	102	110	136	205	192	185	188
P_2O_5	100	107	136	138	207	192	182	180
K_2O	100	99	125	127	165	150	145	147
All nutrients	100	102	115	136	198	191	183	182
Philippines								
N	100	103	80	206	208	218	265	282
P_2O_5	100	112	110	227	366	274	270	274
K_2O	100	115	92	124	203	194	191	188
All nutrients	100	107	92	196	233	223	269	271
Sri Lanka								
N	100	97	112	168	342	285	288	282
P_2O_5	100	107	147	182	441	324	325	320
K_2O	100	111	100	218	233	227	228	228
All nutrients	100	100	118	180	347	292	293	291

1/ Prices were weighted by the share of each kind of fertilizer in total consumption for each year (by nutrient). "All nutrients" prices were derived from the weighted price for each nutrient weighted by the yearly $N-P_2O_5-K_2O$ consumption mix for each country as given in FAO's Annual Fertilizer Review.

Source: - Couston, J.W. 1977. A review of input-output price relationships and subsidies and their impact on fertilizer consumption. FAO, Rome.
- Annual Fertilizer Review. 1978. FAO, Rome.

Table 14 FARMGATE PRICES OF NITROGEN FERTILIZER IN SELECTED COUNTRIES
(US$/t N in Urea)

	1973/74	1974/75	1975/76	1976/77	1977/78
Egypt	338	338	338	361	248
USA	439	585	398	410	407
Brazil	-	747	525	414	526
Chile	364	233	664	456	356
Philippines	144	268	208	446	473
India	290	545	465	421	406
Japan	284	346	382	420	496
Saudi Arabia	207	246	226	210	209
Turkey	185	374	392	354	285
Italy	224	283	303	276	281
Netherlands	267	397	402	447	516

Table 15 APPROXIMATE MARKETING AND DISTRIBUTION COST FOR UREA
(percentage of final cost to farmer)

Brazil	57
India	8
Iran	23
Mexico	11
Nepal	25
Thailand	62
Venezuela	20
Zambia	25

Source: FAO surveys.

The main elements of the marketing cost are transportation, merchants' commission, handling and storage costs, usually in the order of their influence on the retail fertilizer price.

An indirect but often significant cost is the physical loss of fertilizer between factory and farmgate. In many instances this has been found to be as high as 10 to 15%; in some places even reaching 30%.

6.4 SUBSIDIES

The cost of fertilizer to the farmer is often reduced by government subsidy in many developing countries which is primarily to promote agricultural development through the wider adoption and economically more efficient use of fertilizer. The general aim of lowering prices is to raise demand for fertilizer.

Subsidy policy can be classified as direct or indirect. Direct subsidy is public financial assistance given directly to the farmer, fertilizer distributor, importer or manufacturer and is in use in almost all parts of the world: at least one-half and probably closer to two-thirds of the countries of the developing world operated such a scheme sometime between 1968 and 1974 (FAO/FIAC 1978). Examples of indirect subsidy are tax and tariff concessions on fertilizer imports, quantitative controls on imports/exports, etc. Table 16 indicates the fertilizer subsidy policy of some developing countries.

Table 16 FERTILIZER SUBSIDY IN SELECTED DEVELOPING COUNTRIES, OCTOBER 1979

Country	Kind of Fertilizer and Crop[1/]	How Subsidy Granted
Afghanistan	All fertilizers for all crops	Government pays difference between import and farmgate prices to fertilizer importer/ distributor.
Bangladesh	Urea, TSP, DAP, MP for all crops	Fertilizers sold to farmers at controlled price, about 44% less than unsubsidized price.
Brazil	All fertilizers for all crops	Government pays interest on loan obtained by the farmers, usually about 15% per annum.
Burundi	Urea, MAP, KCl for all food crops	As rebate to the farmers usually at the rate of 40%.
Gambia	Urea, SSP, Compound fertilizers for all crops	Government pays difference between landed cost and retail price to fertilizer distributors, including cooperatives.
Indonesia	All fertilizers for all crops	Mainly on transport cost to fertilizer producers/importers usually about 15-30% of landed cost.
Madagascar	All fertilizers for all crops	As rebate to farmers at the rate of 50%.
Pakistan	All fertilizers for all crops	Government absorbs cost related to distribution and marketing to arrive at fixed retail price all over the country. Cost is about 45-58% of landed cost, paid to producers/wholesalers.

1/ TSP = Triple superphosphate; DAP = Diammonium phosphate; MP = Muriate of potash
KCl = Potassium chloride; SSP = Single superphosphate

Source: FAO/FIAC ad hoc Working Party on the Economics of Fertilizer Use. February 1980. Economics of fertilizer use in developing countries. Paper for discussion.

Subsidy schemes are designed to meet one or more specific objectives in the context of a government's agricultural policy. There is a great variation in the type and scope of subsidy schemes in operation, as a scheme can apply to all or only selected farmers, crops, areas and fertilizer grades. Most frequently the subsidy is paid to the fertilizer importer/distributor and less typically directly to the farmer.

The rate of subsidy differs widely from country to country: it is as low as 15% on some fertilizers in Brazil, Colombia, South Korea and more than 50% in Bangladesh, Burma, Nigeria (Kano) and Upper Volta. Rates do not remain fixed for many years, they are changed as a matter of government policy, e.g. to pass on higher import prices; to alter or maintain fertilizer costs or crop price ratios; to further stimulate fertilizer consumption.

The following examples are cited to illustrate the variety of the schemes used:

The Philippines introduced the socialized pricing policy in 1973 consisting of a two-tier pricing structure according to crop priorities. Food crops (rice, maize etc.) were accorded Priority I status and fertilizer was made available at subsidized prices to farmers in this sector. These prices were set by the Government and from time to time adjusted.

Export crops (banana, pineapple, tobacco, sugar) were considered Priority II status and fertilizer prices for these crops were set to reflect import prices after allowing for warehousing and related costs and a 5% margin. This price was frequently adjusted as import costs fluctuated. The farm price was controlled by additional allowances for costs and profit margin at the retail end for the two categories of fertilizers. The scheme was in operation for over 3 years until September 1976, when it was replaced by a single price scheme, setting nearly all fertilizers at or below Priority I prices. Fertilizer consumption in the period 1973-77 increased by 39%.

In New Zealand subsidy schemes are used not so much as encouragement for raising the level of fertilizer consumption, but rather as an instrument of government policy to maintain the proper balance between various agricultural sectors. At the time of rapidly rising import costs the subsidy was also used to cushion all farmers from drastic cost increases.

There have been several programmes in operation in the last two decades; of these, that for Fertilizer Transport Assistance has been the most durable. The transport subsidy was originally introduced in 1965 to help farmers who were situated far from the fertilizer factories. The Government paid 66% of transport cost over and above the first NZ$3 per ton. In 1977, after several modifications to the formula, the scheme was designed to benefit all farmers who were more than 30 km away from the nearest fertilizer factory. For the average haul of 108 km, the weighted average transport cost was NZ$11.80 per ton, the average subsidy payment being NZ$4.20 per ton.

In 1974 the Government introduced a subsidy to enable manufacturers to maintain the same ex-factory prices as those ruling before the dramatic jump in international prices for raw materials needed for fertilizer manufacture. This scheme is still in operation though it was possible to reduce subsidies gradually, reflecting the prevailing lower phosphate rock and sulphur import prices.

Fertilizer subsidies cost US$125-130 million in 1977/78, accounting for three quarters of all Government payments made to agriculture.

6.5 EFFECTIVENESS OF SUBSIDY POLICY

Subsidy schemes can be highly effective particularly if complemented by crop-price support programmes; however their retention beyond a few years is sometimes questioned on economic grounds.

As a planning guide, Table 17 provides a comparison of relative suitabilities of fertilizer subsidy programmes for specific purposes.

Table 17

COMPARISONS OF RELATIVE SUITABILITIES OF FERTILIZER SUBSIDY PROGRAMMES FOR IMPLEMENTATION OF VARIOUS AGRICULTURAL POLICIES[1/]

Type of Subsidy	Adaptability (1) for Specified Purposes							Composite Suitability Rating (2)
	Encourage Efficient Fertilizer Use (3)	Import-substitution Food	Import-substitution Fertilizer	Stimulate Production of Selected Crops	Develop Specific Farming Areas	Offset Cost Price "Squeeze"	Reduce Farm Income Inequity	
DIRECT SUBSIDY PROGRAMMES								
UNCONDITIONAL PROGRAMMES, CLASSIFIED CONJUNCT FERTILIZER PRICE CONTROLS								
Single National fertilizer price	2-3	2	2	4	4	2	3	A
Nutrient content price equity	1	2	2-4	4	4	1-2	4	A
Regional price schedules	2	2-4	2-3	4	4-5	3	4	B
ALTERNATIVE CONDITIONAL PROGRAMMES CLASSIFIED BY RESTRICTIONS IMPOSED								
Limited to specific fertilizer grades	2-3	4	2-3	1-4	5	3	5	B
Limited to specific crops	1-3	2-3	2	2	3-4	2	3-4	A
Limited to specific farming areas	1-3	3	4	3-4	3	2	3	A
INDIRECT SUBSIDY PROGRAMMES								
Preferential treatment of fertilizer imports (4)	2-3	2	3-5 (5)	2 (6)	4	2	3-4	B
Favourable exchange rates on fertilizer imports	2-3	2	3-5 (5)	2-4 (6)	4	2	3-4	B
Quantitative controls on fertilizer imports (7)	2-3 (8)	4	2 (9)	5	5	3 (9)	5	D
Rebates on direct taxes assessed on fertilizer users/suppliers	2-3	4	2-4	2-4 (10)	2-4 (10)	2-3	5	B
Taxes on fertilizer exports (11)	2-4 (12)	3-4	n.a.	4	3-5	3-5	5	D
Quantitative controls on fertilizer exports (11)	2-3	3-4	n.a.	4	5	2-3	5	C
Over-valued domestic currency (11)	3-4	3-4	n.a.	4	5	3-5	4	D

1/ See next page for the Notes to the Table.

Notes to Table 17

(1) The ratings 1, 2, 3, 4, and 5 used in these seven columns mean excellent, good, fair, indeterminate, and poor, respectively. Ranges rather than single ratings are used in indistinct and indeterminable situations. Particularly ambiguous ratings are explained in other footnotes.

(2) Essentially an average of each programme's capabilities to achieve each of 7 specific policy objectives enumerated in previous columns. The letter ratings may be interpreted from these classification guidelines as follows:

A: excellent adaptability for achieving at least one policy objective; at least fairly well adapted to attain all others;
B: fairly well adapted for achieving most policy objectives, but poorly suited to attain one of the seven;
C: adaptabilities evenly balanced between fair, poor, and indeterminate;
D: poor or indeterminate adaptability to achieve most policy objectives; well adapted to attain one or two objectives if used in conjunction with appropriate complementary policies.

(3) A programme's adaptability to encourage efficient fertilizer use depends on its suitability for (a) persuading fertilizer suppliers to increase or improve manufacturing or distribution capabilities; or (b) encouraging farmers to buy more fertilizer when supplies are ample to meet effective demand at prevailing prices; or (c) preferably both.

(4) Nominal tariffs; preferential port fees and transportation charges.

(5) Rating if fertilizer raw materials are granted preferential treatment.

(6) Preferential treatment limited intentionally to specific grades.

(7) Licensing quotas on imports of complex (mixed) fertilizers.

(8) Rating if appropriate incentives for indigenous fertilizer manufacturers are provided by other programmes.

(9) Rating if flexible controls are used and appropriate incentives for indigenous manufacturers are provided.

(10) Rating if tax rebates are limited intentionally to selected crops or areas.

(11) Applicable only to countries which are traditional fertilizer exporters.

(12) Rating in short-run periods following implementation of programme; rating in the long-run is highly dependent on other policies and programmes.

Source: FAO. 1976. Fertilizer subsidies: Alternative policies. Issued by FAO/FIAC ad hoc Working Party on the Economics of Fertilizer Use. Rome, Italy.

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APPENDIX TABLE 1
RELATIONSHIP BETWEEN FERTILIZER USE AND YIELD-VALUE INDEX
OF CROP PRODUCTION BY COUNTRIES, 1964-66 and 1975-77

	1964 - 1966		1975 - 1977	
	Fertilizer Use (kg/ha of arable land)	Yield-Value index[1/]	Fertilizer Use (kg/ha of arable land)	Yield-value index[1/]
Argentina	2.1	152.0	2.9	195.0
Australia	28.8	171.0	21.5	180.0
Austria	205.8	328.0	234.1	452.0
Belgium-Luxembourg	474.5	482.0	543.0	567.0
Brazil	8.2	146.0	77.4	149.0
Burma	0.6	151.0	5.9	167.0
Canada	15.9	165.0	31.8	211.0
Chile	25.9	206.0	19.4	278.0
Colombia	27.9	180.0	63.0	292.0
Denmark	184.1	347.0	230.0	356.0
Egypt	115.5	447.0	189.2	486.0
Finland	122.4	192.0	180.2	257.0
France	155.0	349.0	290.0	416.0
Germany F.R.	340.8	368.0	235.7	472.0
Greece	65.6	269.0	160.9	426.0
India	5.6	83.0	21.4	136.0
Indonesia	6.3	185.0	35.2	270.0
Israel	97.3	384.0	219.3	561.0
Italy	68.5	314.0	167.6	446.0
Japan	325.9	386.0	465.0	743.0
Kenya	14.6	131.0	27.9	182.0
Korea Rep.	162.9	252.0	361.9	481.0
Mauritius	235.9	1 011.0	230.0	1 037.0
Mexico	14.3	137 0	50.1	236 0
Netherlands	593.1	563.0	767.2	958.0
New Zealand	540.8	672.0	1 283.7	562.0
Norway	199.2	353.0	287.5	318.0
Pakistan	3.3	174.0	31.6	199.0
Peru	28.6	305.0	40.0	287.0
Philippines	12.9	118.0	48.0	181.0
Portugal	38.0	132.0	85.3	174.0
Spain	39.4	182.0	96.2	234.0
Sri Lanka	40.6	336.0	93.2	402.0
Sweden	121.4	290.0	176.4	349.0
Switzerland	322.8	526.0	401.6	585.0
Syria	3.1	126.0	13.4	130.0
Thailand	3.9	200.0	14.7	217.0
Turkey	5.5	154.0	44.3	318.0
UK	209.3	382.0	277.3	440.0
USA	62.8	288.0	103.3	363.0
Yugoslavia	57.2	231.0	104.2	321.0

1/ Yield Value Index = an index relating price weights to aggregate crop production

Sources: 1) FAO. Production Yearbook, Rome
2) FAO. Annual Fertilizer Review, Rome

APPENDIX TABLE 2
CEREAL YIELDS AND NATIONAL FERTILIZER USE IN
SIXTY TWO MAJOR CEREAL GROWING COUNTRIES, 1977

Country	Cereal Area Harvested, 1977 ('000 ha)	National Fertilizer Use, 1977 (Kg $N+P_2O_5+K_2O$/ha arable land and perm. crops)	Grain Yield 1975/77 Average (kg/ha)
AFRICA NORTH			
Morocco	4 864	23	893
Algeria	3 276	24	551
Egypt	1 972	188	4 028
Tunisia	1 403	10	469
AFRICA WEST			
Nigeria	13 429	3	644
Niger	2 541	0	426
Upper Volta	2 254	2	501
Mali	1 537	1	742
AFRICA EAST & CENTRAL			
Ethiopia	4 833	2	970
Sudan	4 074	4	630
Tanzania	2 042	7	780
Kenya	1 690	23	1 331
AFRICA SOUTH etc.			
South African Rep.	7 832	60	1 435
Zambia	1 268	14	912
Madagascar	1 227	3	1 837
Malawi	1 165	9	1 084
AMERICA NORTH			
USA	71 368	100	3 552
Canada	18 358	34	2 195
Mexico	9 821	46	1 638
AMERICA CENTRAL & CARIBBEAN			
Guatemala	705	63	1 353
Haiti	511	4	1 039
Honduras	508	31	975
El Salvador	401	150	1 535
Cuba	231	133	1 937

Sources: 1) FAO. 1977, 1978 Production Yearbook. Rome.
2) FAO. 1978 Annual Fertilizer Review. Rome.

APPENDIX TABLE 2 (cont.)
CEREAL YIELDS AND NATIONAL FERTILIZER USE IN
SIXTY TWO MAJOR CEREAL GROWING COUNTRIES, 1977

Country	Cereal Area Harvested, 1977 ('000 ha)	National Fertilizer Use, 1977 (Kg $N+P_2O_5+K_2O$/ ha arable land and perm. crops)	Grain Yield 1975/77 Average (kg/ha)
AMERICA SOUTH			
Brazil	20 283	77	1 447
Argentina	10 609	2	1 992
Colombia	1 219	51	2 285
Chile	929	18	1 767
ASIA SOUTH & SOUTH EAST			
India	103 081	25	1 252
Indonesia	10 958	35	2 386
Bangladesh	10 207	37	1 841
Thailand	8 745	16	1 835
Vietnam	5 676	80	2 081
Burma	5 660	6	1 698
ASIA EAST			
China	117 640	74	2 075
Philippines	7 095	32	1 371
Japan	2 959	428	5 713
Korea DPR	2 214	276	3 309
Korea Rep.	1 878	330	4 399
NEAR & MIDDLE EAST			
Turkey	13 478	47	1 756
Pakistan	10 433	35	1 437
Iran	8 030	21	1 153
Afghanistan	3 312	7	1 332
Syria	2 597	15	820
EUROPE NORTH			
Denmark	1 811	261	3 662
Sweden	1 606	176	3 410
Finland	1 185	172	2 669
EUROPE WEST & CENTRAL			
France	9 701	278	2 735
Germany Fed. Rep.	5 254	422	3 911
Germany Dem. Rep.	2 431	322	3 450
United Kingdom	3 714	288	3 988
EUROPE SOUTH			
Spain	7 038	69	1 903
Yugoslavia	4 555	101	3 418
Italy	4 457	141	3 300
Greece	1 525	126	2 387
Portugal	1 054	76	1 027

APPENDIX TABLE 3
AVERAGE GRAIN YIELD AND FERTILIZER USE IN FOUR WESTERN EUROPEAN COUNTRIES, LATE 1930s TO 1974/76

	late 1930s 1/	1949/51	1956/58	1962/64	1968/70	1974/76
AVERAGE GRAIN YIELD kg/ha						
Belgium	2 410	3 110	3 220	3 770	3 630	4 200
France	1 490	1 620	2 280	2 760	3 490	3 780
Netherlands	2 720	3 120	3 310	3 920	3 900	4 760
United Kingdom	2 110	2 470	2 800	3 640	3 560	3 930
AVERAGE FERTILIZER USE kg NUTRIENTS/ha ARABLE LAND AND PERMANENT CROPS						
Belgium	178	261	349	443	538	545
France	37	46	81	134	216	254
Netherlands	337	386	439	535	660	755
United Kingdom	59	111	142	198	245	265

1/ Late 1930s figures France and UK 1936/38, Belgium 1935/37, Netherlands 1937/39

Sources:
1) USDA. Prewar world production and consumption of plant foods in fertilizers. Misc. Publ. No. 593. Washington DC.
2) International Institute of Agriculture. (1930s) Yearbook of agricultural statistics, Rome.
3) FAO. Production Yearbook. Rome.
4) FAO. Annual Fertilizer Review. Rome.

APPENDIX TABLE 4
LONG-TERM DEVELOPMENT OF FERTILIZER USE AND RICE YIELD IN JAPAN, 1904 - 1975

Period	Average annual consumption (kg/ha)				Rice Yield (kg paddy/ha)
	N	P_2O_5	K_2O	Total	
1904-13	16.8	19.1	2.7	28.6	3 120
1914-23	25.5	21.0	4.2	50.7	3 500
1924-33	37.0	35.2	8.5	80.7	3 500
1934-38	55.7	49.9	18.3	123.9	3 750
1943-45	30.9	10.3	0.3	41.5	3 410
1946-50	63.3	30.3	21.6	115.1	4 090
1951-55	83.0	51.4	41.0	175.4	4 080
1956-60	103.2	65.2	73.0	241.4	4 710
1961-65	120.6	80.6	93.9	295.1	5 010
1966-70	150.9	112.4	112.0	375.3	5 550
1971-75	134.2	125.0	113.1	372.3	5 830

Sources: 1) FAO. Annual Fertilizer Review. Rome
2) Ministry of Agriculture and Forestry. Fertilizer Pocket Manual. Tokyo
3) Kawano and Tobata. 1956. Economy and Agriculture in Japan. Tokyo.
4) Ministry of Agriculture and Forestry. 1961. Abstract of statistics of agriculture etc. Tokyo.
5) FAO. Production Yearbook. Rome.

APPENDIX TABLE 5
APPLICATION OF MINERAL FERTILIZER ON RICE IN JAPAN, 1950 - 1977

Year	Plant Nutrients, kg/ha			
	N	P_2O_5	K_2O	Total
1950	65.0	33.0	19.0	117.0
1951-55	68.6	40.0	42.2	150.8
1956-60	83.8	58.4	69.9	212.1
1961-65	86.0	70.4	73.5	229.9
1966-70	98.3	97.4	86.3	282.0
1971-75	97.5	102.6	87.8	287.9
1976-77	102.5	107.5	93.5	303.5

Source: Ministry of Agriculture and Forestry. Abstract of statistics on agriculture, forestry and fisheries. Tokyo.

APPENDIX TABLE 6
APPLICATION OF ORGANIC MANURES ON RICE IN JAPAN, 1926 - 1974

Year	Organic manure t/ha	Plant nutrients, kg/ha			
		N	P_2O_5	K_2O	Total
1926/35	3.90	29.5	7.8	19.5	46.8
1936/40	6.10	30.5	12.2	30.5	73.2
1941/45	8.87	44.4	17.7	44.4	106.5
1946/50	8.52	42.6	17.0	42.6	102.2
1951/55	8.08	40.4	16.2	40.4	97.0
1956/60	8.14	40.7	16.3	40.7	97.7
1960	6.31	31.5	12.6	31.5	75.6
1966/70	5.48	27.9	10.4	29.6	67.9
1971/74	3.84	19.8	7.1	21.6	48.5

Sources:
1) Ministry of Agriculture and Forestry. Abstract of statistics on agriculture, forestry and fisheries. Tokyo.
2) Ministry of Agriculture and Forestry. 1960. Recent status of soil and fertilizer in Japan. Paper prepared for Far East Fertilizer Workshop. Tokyo.
3) Ministry of Agriculture and Forestry. Crop Production Division. Survey of production cost of rice. Tokyo.

APPENDIX TABLE 7
DEVELOPMENT OF WHEAT YIELD AND FERTILIZER USE IN MEXICO AND TURKEY, 1962 - 1977

Period	Mexico		Turkey	
	Wheat yield (kg/ha)	National fertilizer use, (kg/ha $N+P_2O_5+K_2O$)	Wheat yield (kg/ha)	National fertilizer use, (kg/ha $N+P_2O_5+K_2O$)
1962/1963	2 013	11.4	1 176	2.9
1964/1965	2 100	12.3	1 065	4.7
1966/1967	2 481	15.9	1 225	8.9
1968/1969	2 695	19.5	1 181	15.2
1970/1971	2 982	23.6	1 355	16.8
1972/1973	3 067	25.7	1 263	24.2
1974/1975	3 575	33.3	1 441	26.0
1976/1977	3 613	44.0	1 782	46.4

Source:
1) FAO. Production Yearbook. Rome
2) FAO. Annual Fertilizer Review. Rome

APPENDIX TABLE 8
WORLD FERTILIZER CONSUMPTION AND AVERAGE
CEREAL YIELD, 1961 - 1977

Year	Fertilizer Consumption (kg/ha arable land)				Yield (kg grain/ha)
	N	P_2O_5	K_2O	Total	
1961 1962 1963	))10.7)	9.0	7.3	27.0	1 389 1 467 1 451
1964	11.6	9.9	7.8	29.3	1 501
1965	13.3	10.5	8.7	32.5	1 495
1966	15.2	11.3	9.2	35.7	1 591
1967	16.7	11.8	9.8	38.3	1 629
1968	18.3	12.5	10.1	40.9	1 667
1969	19.5	12.8	10.5	42.8	1 693
1970	21.6	13.5	11.3	46.4	1 734
1971	22.5	14.2	11.9	48.6	1 850
1972	24.0	15.1	12.6	51.7	1 821
1973	25.8	16.1	13.9	55.8	1 902
1974	25.8	15.1	13.2	54.1	1 834
1975	28.7	16.0	14.2	58.9	1 856
1976	30.3	17.8	15.5	63.6	1 974
1977	32.8	19.4	16.0	68.2	1 957

Sources: 1) FAO. 1961 to 1977. Production Yearbook, Rome

2) FAO. 1961 to 1977. Annual Fertilizer Review, Rome

APPENDIX TABLE 9
EFFECT OF NPK ON THE GRAIN YIELD OF THREE RICE VARIETIES
GROWN FOR FIVE SUCCESSIVE YEARS (DRY SEASON, 1968 - 1972)
IN THE PHILIPPINES
AVERAGE FROM THREE EXPERIMENT STATIONS

Treatment, kg/ha	Grain yield in tons/ha						0-0-0 = 100
N*-P_2O_5-K_2O	1968	1969	1970	1971	1972	Mean	
0- 0- 0	3.20	2.20	3.28	3.63	3.26	3.11	100
140- 0- 0	6.13	5.22	4.95	5.30	4.80	5.28	169
140-60- 0	6.46	5.70	5.85	6.43	5.33	5.95	191
140- 0-60	6.20	5.50	5.06	5.30	5.40	5.49	176
140-60-60	6.84	6.02	6.62	7.07	6.73	6.65	214
140-60-60**	6.88	6.46	6.34	7.26	6.96	6.78	218
NPK-effect in kg/ha	3 640	3 820	3 340	3 440	3 470		
N-effect in kg/ha	2 930	3 020	1 670	1 670	1 540		
P-effect in kg/ha	330	480	900	1 130	530		
K-effect in kg/ha	380	320	770	640	1 400		
N-effect in % of NPK effect	80	79	50	49	44		
P-effect in % of NPK effect	9	13	27	33	16		
K-effect in % of NPK effect	11	8	23	18	40		
kg grain/kg NPK	14	15	13	13	13		-
kg grain/kg N	21	22	12	12	11		
kg grain/kg P_2O_5	6	8	15	19	9		
kg grain/kg K_2O	6	5	13	11	23		

* 100 kg N as basal dressing and 40 kg as top dressing at panicle initiation
** 30 kg K_2O as basal dressing and 30 kg as top dressing at panicle initiation

N-effect = 140- 0- 0 minus Control
P-effect = 140-60- 0 minus 140- 0- 0
K-effect = 140-60-60 minus 140-60- 0

Source: Kemmler and Malicornet. 1976. Fertilizer experiments - the need for long-term trials. IPI Research Topics No. 1. IPI, Berne.

APPENDIX TABLE 10
DEVELOPMENT OF PLANT-AVAILABLE NITROGEN AND CROP PRODUCTION IN GERMANY FROM ABOUT 1800 to 1975/76

	About 1800	About 1900	1925/27	1935/38	1960/65	1975/76
	(- - - - - Plant-available nitrogen kg/ha - - - - -)					
Soil reserves (humus, weathering minerals, etc)	40	50	55	60	70	85
Organic manure	8	26	30	36	46	40
Symbiotic (nodule) bacteria	3	12	12	12	9	6
Soil bacteria	5	8	10	10	10	10
Lightening, rainfall, etc	20	20	20	20	20	20
Fertilizer	-	3	12	20	50	92
TOTAL	76	119	139	158	205	253
	Crop Production 1/					
Crop yields (kg GE/ha	710	1 860	2 280	2 680	3 540	4 440
Response ratio (kg GE/kg nutrient)	9.3	15.6	16.0	17.0	17.3	17.5

1/ Total, converted into GE or Getreideeinheit (cereal unit)

Source: Huppert. 1978. Entwicklung der Ertrage. Feld und Wald No. 4.

APPENDIX TABLE 11
SOURCES OF CHANGE IN FARM OUTPUT IN THE USA,
SPECIFIED PERIODS, 1919 to 1955

Sources of Change	Percentage of total			
	Interwar (1919/20) to 1938/40		Second world war and 1940/41 to 1955	
Reduction of farm-produced power		51		23
Changes in crop production per acre:		34		43
Shifts in crop acreage	0		-16	
Weather	-15		9	
Fertilizer	10		24	
Hybrid maize	7		5	
Irrigation	1		3	
Other	31		18	
Change in crop land use		-4		7
Change in product added by livestock		15		25
Changes in pasture consumed by livestock		4		2
TOTAL		100		100

NOTE: Farm output in the United States increased about 26% from 1920 to 1940 and about 34% from 1940 to 1955. The percentages of this increase, due to the various factors, are shown for the two periods in the above table. In each column, the increase is shown as 100% so the imputation to the various factors accounts for all of the change. The breakdown under "Changes in crop production per acre" shows the percentage of the total increase due to these factors, e.g. fertilizer accounted for 24% of the increase from 1940/41 to 1955 (but for 58% of the increase due to changes in crop production).

Source: US Department of Agriculture, Farm Economics Division. Analysis done by D.D. Durost.

APPENDIX TABLE 12
SOURCES OF INCREASED FOOD GRAIN PRODUCTION IN INDIA,
SECOND FIVE-YEAR PLAN 1956-61

Source	Percent of increase attributable to this source
Fertilizer (organic and inorganic)	41
Irrigation	27
Improved Seed	13
Double-cropping (due in part to irrigation)	10
Land reclamation, other improved practices, etc	0
TOTAL	100

Source: Eastern Economist. 3 February 1961. Planning and agricultural production (cited from USDA, Foreign Agricultural Service Report). India.

APPENDIX TABLE 13
PLANT NUTRIENTS REMOVED FROM SOIL BY SOME CROPS[1/]

Crop	Yield (kg/ha)	Approximate amount of nutrients removed (kg/ha)		
		N	P_2O_5	K_2O
Rice (Paddy)	6 000	100	50	160
Wheat	5 000	140	60	130
Maize	6 000	120	50	120
Potato	40 000	175	80	310
Cassava	40 000	160	70	350
Sugar Cane	100 000	110	90	340
Soybean[2/]	2 400	225	45	95
Groundnut	1 500	105	15	40
Cotton (seed & lint)	5 000	180	65	125
Coffee (dry beans)[3/]	1 000	125	30	115
Alfalfa (hay)[2/]	7 000	215	60	130
Pangola grass (fresh)	23 000	300	110	430

1/ Removal figures refer to nutrients contained in the above-ground parts, and the below-ground harvested portion where appropriate, at the indicated yields.

2/ Leguminous plants can get most of their nitrogen from the air through symbiosis with various micro-organisms.

3/ With coffee, the only permanent crop mentioned here, the nutrients needed for the vegetative growth of the tree are included.

Sources: 1) FAO. 1978. Fertilizers and their use. FAO Land and Water Development series No. 8, 3rd ed. Rome.

2) Sanchez, P. 1976. Properties and management of soils in the tropics. Wiley, New York.

3) De Geus, U.G. 1973. Fertilizer guide for the tropics and subtropics. Centre d'Etude de l'Azote, Zurich.

APPENDIX TABLE 14
AVERAGE YIELD OF CONTROL AND BEST TREATMENT IN TRIAL AND DEMONSTRATION, FAO FERTILIZER PROGRAMME PROJECTS, 1961 TO 1977

	Number of trials and demonstrations	Average Yield (kg/ha)	
		Control	Best Treatment
NORTH AFRICA AND NEAR/MIDDLE EAST (8)			
Groundnut (4)	414	1 999	3 123
Maize (3)	2 148	1 779	2 851
Rice (2)	1 078	3 308	4 494
WEST AFRICA (11)			
Cassava (2)	477	12 296	18 304
Groundnut (8)	3 929	1 008	1 525
Maize (7)	11 905	1 361	2 287
Millet (4)	1 437	565	950
Rice (6)	6 267	1 411	2 019
Sorghum (4)	1 213	767	1 468
Yam (5)	1 577	8 823	12 642
SOUTHERN AND EASTERN AFRICA (4)			
Groundnut (5)	356	897	1 345
Maize (4)	3 026	3 262	5 114
Sorghum (4)	816	1 080	2 071
LATIN AMERICA (11)			
Cassava (1)	66	11 875	24 884
Maize (10)	3 995	2 249	3 454
Rice (6)	865	1 944	3 908
SOUTH EAST ASIA (6)			
Cassava (1)	158	4 460	7 997
Groundnut (1)	144	1 008	1 540
Maize (2)	430	2 223	3 925
Rice (6)	6 912	2 872	4 610

Numbers in brackets indicate the number of countries involved. The countries are:

NORTH AFRICA AND NEAR/MIDDLE EAST

Afghanistan
Algeria
Iran
Lebanon
Morocco
Syria
Tunisia
Turkey

AFRICA (except NORTH AFRICA)

Botswana
Burundi
Cameroon
Ethiopia
Gambia
Ghana
Ivory Coast
Kenya
Lesotho
Nigeria
Senegal
Sierra Leone
Togo
Upper Volta
Zaire

SOUTH EAST ASIA

Bangladesh
Indonesia
Kampuchea
Nepal
Sri Lanka
Thailand

LATIN AMERICA

Brazil
Chile
Colombia
Costa Rica
Ecuador
El Salvador
Guatemala
Honduras
Nicaragua
Panama
Peru

Source: see p. 68

APPENDIX TABLE 15
ABSOLUTE AND RELATIVE YIELD RESPONSES IN TRIAL AND DEMONSTRATION DATA, FAO FERTILIZER PROGRAMME AND RELATED PROJECTS, 1961 to 1977

Crop and Region	Average yield (kg/ha)		Yield Increase		
	Control	Best Treatment	kg/ha	percent	percent average
RICE					
North Africa & N. East	3 308	4 494	1 186	35.9	
West Africa	1 411	2 019	608	43.1	
Latin America	1 944	3 098	1 964	101.0	60.1
South East Asia	2 872	4 610	1 738	60.5	
MAIZE					
North Africa & N. East	1 779	2 851	1 072	60.3	
West Africa	1 361	2 287	926	68.0	
Southern & East Africa	3 262	5 114	1 852	56.8	63.1
Latin America	2 249	3 454	1 205	53.6	
South East Asia	2 223	3 925	1 702	76.6	
SORGHUM					
West Africa	767	1 468	701	91.4	91.4
MILLET					
West Africa	565	950	385	68.1	68.1
GROUNDNUT					
North Africa & N. East	1 999	3 123	1 124	56.2	-
West Africa	1 008	1 525	517	51.3	
Southern & East Africa	897	1 345	448	49.9	52.6
South East Asia	1 008	1 540	532	52.8	
CASSAVA					
West Africa	12 296	18 296	6 000	48.8	
Latin America	11 875	24 884	13 009	109.5	79.2
South East Asia	4 460	7 997	3 537	79.3	
YAM					
West Africa	8 823	12 642	3 819	43.3	43.3

Source: Richards, I.R. 1979. Response of tropical crops to fertilizer under farmers' conditions: Analysis of results of the FAO Fertilizer Programme. Phosphorus in Agriculture 76: 147-156.

APPENDIX TABLE 16
CONVERSION FACTORS OF PLANT NUTRIENTS[1/]
(FROM OXIDE TO ELEMENTAL AND FROM ELEMENTAL TO OXIDE FORM)

P_2O_5	x	0.44 (0.4364)[2/]	=	P
P	x	2.29 (2.2919)	=	P_2O_5
K_2O	x	0.83 (0.8302)	=	K
K	x	1.20 (1.2046)	=	K_2O
CaO	x	0.71 (0.7147)	=	Ca
Ca	x	1.40 (1.3992)	=	CaO
MgO	x	0.60 (0.6030)	=	Mg
Mg	x	1.66 (1.6582)	=	MgO
SO_3	x	0.40 (0.4005)	=	S
S	x	2.50 (2.4971)	=	SO_3

[1/] Source: Handbook of Chemistry and Physics, The Chemical Rubber Co., Cleveland, Ohio 1973

[2/] The figures in brackets can be used as conversion factors for some calculations when very high accuracy is necessary (in research papers, plant nutrient balance, etc.)

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