Fertilisers

by Peter Collins

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Fertilisers

Fertilisers are the most spectacular single method of increasing food production. But they are little help if used alone. All sorts of factors besides the actual fertilisers go into an effective and economic fertiliser programme; weed control and pest control, better roads to market increased crops, better storage facilities, credit arrangements and, most of all, perhaps, education in better husbandry.

This pamphlet is intended to bring some of the implications of a fertiliser programme before the people who have to make decisions about it. It explains simply but authoritatively, what fertilisers are and how they are made. It examines both economic and social considerations; it points to the kind of returns that may be expected from a successful programme and estimates some of the initial outlay in soil surveys, subsidies, experiments and demonstrations. It deals with the problem of whether to import or manufacture locally. It shows how fertilisers may be used to introduce other changes towards better farming.

The pamphlet lays down no single 'correct' way of mounting a successful fertiliser programme; that must depend on factors that vary from country to country. Rather it gives the facts about fertilisers and outlines other points to be considered when formulating a fertiliser programme.

Its value is not only to agricultural advisers and administrators; it is important also to people in related fields such as transport, finance, education and journalism. It is of use in fact to all who wish to speed their country's economic development through the fruitful application of scientific knowledge.

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Foreword

by Sir William Slater

The speed and the efficiency of economic development in any country depend on the wise application of science and technology. The ill-considered use of these powerful tools will, with equal certainty, delay progress and lead to waste. Almost every step to improve the standard of living and the general welfare of a nation involves, in the modern world, the proper application of the basic principles of some branch of science or technology. It is not enough to *adopt* that which has proved successful elsewhere, it must be *adapted* to local conditions of physical environment, to the state of economic development and to the character of the people. It is vitally important, therefore, that the Ministers who decide national policy, the Government Servants who implement it and as many as possible of those who are affected by it, should have a broad general knowledge of what is involved in any scheme of development.

There is never enough either of money or of men to do at one time everything which seems desirable or even necessary. A choice must be made between rival plans, each appearing to offer advantages and each supported by technical evidence from the experts putting it forward.

A Minister, with the help of the senior administrators in his department must make the decision; to do so with reasonable confidence, he and his immediate staff must master at least the elements of the underlying science. He will, of course, have his technical advisers, but they are almost always involved as the advocates for one of the rival plans. Moreover, each speaks in his own technical language often only partially understood by those who listen.

Time is always pressing; a decision must be made, not some years ahead after careful study, but today or at best tomorrow. There is no time to browse in a library, to try to learn the technical language, to find amongst the great mass of scientific knowledge just those simple facts which will enable the conflicting evidence to be understood and fairly judged.

Those who have to make and implement major policy decisions need a simple chart, which will enable them to find their way with reasonable certainty in the complicated and changing world of science and technology. They must know the right questions to ask and be able to understand answers expressed in the language of technology.

It is the object of the series of pamphlets published by the Overseas Development Institute (of which this is the first) to provide such a chart. Each pamphlet deals with a limited field of development explaining in non-technical language the scientific principles involved, the results which may be expected from the application of these principles, the order of the steps which must be taken to achieve their successful implementation and, perhaps most important of all, the pitfalls to be avoided.

No attempt is made to state any definite path to progress because this, in the end, must be determined by economic and sociological factors which differ for each nation. The way to success can be found only in the skilful use of science and technology to exploit the economic strength of the nation, its natural resources, its geographic position and the qualities of its people.

Rapid development often calls for sacrifices from the people. It may be that for a time harder living conditions must be accepted or that long cherished traditions and ways of life will have to be forgotten. It is vital that the people should know what is involved in any change and be able to weigh immediate loss against future gain. However wise a decision may be, if the people do not accept it, the plan involved is doomed to failure. To tell the people the full story in simple language the Minister must himself have mastered fully the details of any scheme of development. Those which arise from economic and other conditions peculiar to his country he will know, the basic science and technology he must learn.

His task, however, will be made far lighter if a section of public opinion is already well informed. Herein, it is hoped, lies the second and equally important use for the Overseas Development Institute pamphlets, in making available to the leaders of public opinion – politicians, professional men and teachers – in a cheap and easily comprehended form the basic knowledge required to form considered judgments on Government policy. These will help to prepare the people as a whole for policies, which although wisely chosen may at first seem to offer little or even to call for the loss of some of the advantages they already enjoy.

The production of these pamphlets has been inspired by the experience of some of those responsible for the establishment of the Overseas Development Institute. They know how the desks of every Minister and senior Government Servant are showered with papers which must be ready for tomorrow's meeting and how long reports and technical books lie collecting dust on the side table awaiting the spare day that never comes when they can be ready. The aim has been to keep the pamphlets so condensed that they can be read virtually as committee papers immediately before the information they contain is required. It is hoped that they will find their place on a shelf in the office of every administrator, for ready reference when they are most urgently needed.

Introduction

Reckoned at almost 3,000 millions in 1960, the world's population is expected to top 4,000 millions by 1980 and to have doubled by the end of the century. Feeding, clothing and housing these people is the most important problem of the world today, for in one way or another it affects everyone, of whatever colour, creed or nationality. In the effort to solve this problem, the 1960s may well prove critical.

In spite of all efforts to improve their nutritional status, most of the world's people, and especially the populations of the less developed countries of Asia, Africa, and Latin America are not appreciably better fed than before the war. Certainly the gap between their living standards and those of the advanced countries of North America, Oceania, and Europe, is steadily widening. Probably one third of the present population of the world, in fact, still suffers from chronic malnutrition, or undernourishment or both. Yet in the crop years 1959–61, world food production increased less rapidly than population, with which it had kept pace for some years. Even *gross* agricultural production (which includes non-food crops) rose by only 1% in 1960–61, in contrast to a population increase of 1.6%.

Evidently, if the challenge of rising population is to be met, some quicker way of accelerating food production must be found. The possibilities of doing this by bringing new land under cultivation on a large scale are remote, and in any event, this is essentially a long-term operation. Widespread improvement of cultural practices, large-scale mechanisation, or the development of new systems of land and water use cannot be expected to give results much more quickly.

There are, however, three ways in which more rapid improvement may be brought about: the introduction of new, high-yielding varieties of crop plants; the control of pests and diseases of crops and stock; and the use of fertilisers. Of these three, the last may under many circumstances bring the quickest and certainly the most dramatic improvement in agricultural output. It is a significant fact that the countries with the highest standards of living, as indicated by the calorie and protein intake of their populations, are also those with the highest fertiliser consumption.

The widespread use of 'artificial' or chemical fertilisers (as contrasted with animal manures, composts, etc.) is therefore attracting the attention of more and more governments, especially since the remarkable results already obtained by some of their number (e.g. Japan) have begun to be more widely appreciated. But the introduction of fertilisers on a scale sufficient to make a real difference to a nation's food supplies is much more than a matter of official encouragement or propaganda, no matter how skilful or well-directed. Indeed, it is more than likely to require decisions at the highest level, often based on consideration of factors outside the normal experience of many members of planning commissions and most government offices.

The first fundamental question, once a deliberate policy of increasing fertiliser utilisation has been decided on, may well concern the crop or crops to which priority is to be given in the proposed programme. Is the aim to increase export crops, with a view to acquiring more foreign currency? Or should priority go to food crops, in order to raise the living standards of the population as a whole? Fertilisers do not benefit all crops equally, and especially if their use is being subsidised, it may be necessary first to apply them to export or plantation crops. On the other hand, if the need for high-protein foods is most acute, it may be better to use fertilisers to provide better cattle feed, and thus increase milk and meat production; or to confine their use to crops giving a high yield of vegetable protein. In either case, are there real incentives to the farmer to grow more of the desired crops when fertilisers do become available?

These key questions are tied up with that of what fertilisers to use, which again depends on soil and crop surveys, field experiments and laboratory research. But quite apart from them, there are others on which decisions must be made at an early stage. The distribution of fertilisers requires reasonably good transport and communications, operating cheaply enough not to add materially to the cost, or, the extra cost may have to be covered by subsidies. Successful fertiliser application, especially by the peasant farmers who make up the bulk of the population of the underdeveloped countries, presupposes an agricultural advisory or extension service and a network of experimental stations and demonstration farms. For example, even so comparatively highly organised a culture as that of cocoa in Ghana made no use of fertilisers until quite recently, largely, it appears, because too few experiments had been done to show that it would be worth while.

Then there is the vital question of whether to import fertilisers or to manufacture them in the country; if the latter is the ultimate aim, at what point in the country's development should manufacture start? Fertiliser manufacture ranks as a heavy industry, and until a country is consuming fairly considerable quantities, or has ample supplies of cheap energy and raw materials, it is probably not worth while considering setting up plant at home. The requirements in terms of raw materials and energy are considerable, and the costs of operating and maintaining small plants are relatively very much higher than those for much larger factories.

The provision of the necessary technical staff for such an enterprise is in itself a formidable problem. As it is, most fertilisers are made for export by a number of countries, and can be bought more cheaply in the open market than they can be manufactured in small quantities by countries whose industry is only beginning to develop.

Moreover, the use of fertilisers cannot be isolated from other improvements in a country's agriculture. Thus, some crops can only make full use of additional nutrients if more water is available, possibly through the development of irrigation. It may be necessary to introduce higher yielding strains of crop plants, to take full advantage of the greater quantity of nutrients. Land tenure systems may be such that it is not worth the farmers' while to grow heavier crops, or insect or other pests may be so rampant as to consume most of the extra that is grown. Cultural practices will in any event almost certainly have to be improved in most countries when fertilisers are introduced. Above all, a considerable educational campaign may be needed before farmers are persuaded that fertilisers are of any real value. And once they are so persuaded, ample supplies of fertilisers, at a price they can afford, must be readily available if initial enthusiasm is not to be allowed to wane. Even more important may prove to be the need to revise or improve marketing systems. It is already appreciated that outputs of some agricultural products in certain countries could easily be increased, even doubled, with the application of knowledge the farmers already have. But if they cannot market their produce at a reasonable price, they cannot be expected to increase productivity. When fertilisers are brought into the picture, marketing must be thoroughly examined, well in advance, to make sure that anything extra the farmer is encouraged to grow, can be profitably sold by him. Otherwise, his disillusionment will make the task doubly difficult later on.

In general, it is accepted that if a fertiliser programme increases agricultural output by 100%, one half of that increase will be due to the fertilising materials themselves, and the other 50% to improvements that come with the introduction of these materials. These include such things as better cultural practices, improved pest control, more and better storage facilities, better marketing and transport arrangements.

All of these things may affect decisions and policies involving a wide range of governmental activities. Some of the more important of these, and the facts on which they are based, are discussed in the chapters which follow. No excuse is made, however, for returning here to one consideration which must be borne in mind whatever aspect of a fertiliser programme is being considered. This is the real urgency of using every means at our disposal to increase food production in the underdeveloped countries. The latest figures from FAO's annual situation report, *The State of Food and Agriculture*, 1962, coming to hand since this pamphlet was drafted, add emphasis to this need for haste In the crop year 1961/62, world agricultural food production scarcely increased at all over the level of the previous year – while population rose even faster, by 1.8%.

When it is remembered that quite apart from the need to feed the new human beings coming into the world each year, there is an equally pressing need to provide *better* food (as well as more of it) for two-thirds of those here already, it is evident that increased fertiliser use is an absolute 'must'. In evidence of this, the great co-operative programme, launched in 1961, between FAO and the world's fertiliser industry under the Freedom From Hunger Campaign. By the time this pamphlet appears, some 10,000 demonstrations and trials will have been carried out under this programme; by the end of 1964, the number should exceed 25,000 in 15 countries of Asia, Africa and Latin America. This great programme will help to provide evidence for countries setting up their own programmes. But only if such programmes are designed *now* and implemented with foresight and determination, can the world's hungry people be fed.

1 The Case for Fertilisers

Definitions

Fertilisers may be thought of as materials used to increase or maintain the yield from the land. This can be considered either in terms of crops harvested, or where fertilisers are applied to grazing land or to specially grown forage crops, as more meat, milk or other livestock products. It is even conceivable that fertilisers might be used to make possible the better feeding of draught animals, thus to place more energy at the disposal of peasant farmers, but this is not likely to be a main objective.

These materials may be conveniently classified in two main groups: natural or organic fertilisers or manures and 'artificial' or chemical fertilisers. It is with the latter that this booklet is concerned, but before describing them, something on organic fertilisers or manures may not be out of place.

Organic Fertilisers

Organic fertilising materials may be grouped under three main headings: *manures* (animal or human excreta, with or without added vegetable matter, straw, etc. Human excreta are usually known as 'night soil'); *composts*, usually decomposed vegetable matter, the decomposition of which is sometimes assisted or accelerated by the use of chemicals; and *sewage sludge*, the (normally) liquid refuse from urban drainage systems, treated to render it innocuous when used on farm crops.

To these three must be added 'green manures', plant material from crops specially grown to be dug or ploughed into the soil in order to improve its natural fertility.

Chemical Fertilisers

The chemical fertilisers are also divided into three principal groups, according to the nutrient elements they are designed to provide – nitrogen, phosphorus and potassium. Sulphur, calcium and magnesium comprise a group often referred to as secondary nutrients; the two last are made available in liming materials, sulphur being supplied usually in combination with other necessary elements.

Grouped together as 'micronutrients' or 'trace elements', because of the very small quantities needed by plants, are a number of other elements. These include iron, manganese, copper, boron, molybdenum, zinc. Under certain conditions and in certain soils, the absence of one or other of these can be as serious for crop production as that of one of the major nutrients.

Liming Materials

Intermediate between the two main groups of fertilisers may be mentioned liming materials, sometimes referred to as 'soil amendments'. They are used to correct acidity in the soil, as well as to improve its texture; they also may provide certain elements as nutrients. While not organic material, lime is acceptable to farmers who do not believe in the use of 'artificial' fertilisers, since it is a naturally occurring material, and is usually derived from limestone of one kind or another.

Fertilisers Increase Production

All of these materials, in greater or lesser proportions, may be thought of as plant nutrients, part of the food all plants need if they are to grow and provide food for Man or his livestock. Not all crops require the same amounts of these materials, nor do all soils lack them. But in general, for whatever purpose crops are being grown, they can be produced in greater quantity if fertilisers are used. Indeed, to achieve the high levels of productivity (which can be defined as production per unit of land, of manpower or of money invested in those things) which are the rule in many countries, fertilisers are essential. It is certainly no coincidence that the countries in which farming is most highly developed, and in which people generally are best fed, are also those that have the highest consumption of artificial fertilisers. Thus, Europe, the United States, Canada, and Japan used in the 1958/59 crop year 6.6 million tons of the total world consumption (excluding USSR) of 8.0 million tons of nitrogen consumed for agricultural purposes. The figures for the amounts of phosphatic fertilisers are similar. Of the countries of Asia, where standards of living and levels of agricultural production are generally low, only Japan, with some of the world's most intensively cultivated land and most highly organised farming, used quantities per acre of fertiliser comparable with those of the advanced countries of the Western Hemisphere or of NW Europe.

Examples of actual increases in crop production through the use of fertilisers can be found wherever the practice has been introduced. Many of these results, however, have been obtained by scientists, often working under what are, from the farmers' point of view, 'un-natural' conditions. They have been obtained on experimental plots, usually on expertly cultivated farms. Such conditions do not accurately reproduce those under which fertilisers would be used by the vast majority of farmers.

Better indications of what can be expected in actual practice are given where trials of fertilisers are carried out by the farmers themselves, on their own farms, under the supervision of agricultural extension officers. Such trials in India have shown that the application of quite moderate amounts of nitrogenous and phosphatic fertiliser to rice on farmers' own fields led to a 50% increase in yield as a reasonable average figure. Other figures given by the Food and Agricultural Organisation (FAO) show that fertilisers really can be effective over a wide range of crops. Using balanced fertilisers (i.e. those containing carefully calculated amounts of the major nutrients required): yields of rubber in Malaya were increased 30%; yields of coconuts in Ceylon were increased 25%; yields of paddy have been increased 50–100% in Thailand; of maize, 100% in Indonesia; of sugar cane, 45% in the Philippines.

Other evidence from other Continents supports these figures from Asia. Wheat production in Mexico, for example, has risen enormously since farmers took to using fertilisers regularly, the average yield per acre being doubled since World War II, while some farmers are getting five or six times their former yield.

Although many of the most impressive results have been achieved with cereals, it has been shown that other crops, too, can benefit enormously from fertiliser application. The staple West African root crops, yams and cassava for example, can give 50% higher yields with quite low rates of fertiliser application. Almost wherever they have been introduced, or been the subjects of experiments, fertilisers have given much higher yields of all sorts of crops.

Other Factors to be Considered

In spite of these impressive figures, however, it must be realised that the simple application of fertilisers to a crop will not of itself necessarily result in an *economic* increase in yield. It is true that, as FAO has pointed out in *The Efficient Use of Fertilisers*, 'where low nutrient supply is the predominantly unfavourable factor, fertilisers can give an enormous return'. Indeed, the results produced under these conditions may be so encouraging as to be quite misleading, and cause fertilisers to be regarded as an immediate cure for low productivity. In general, however, 'the effectiveness of manures and fertilisers depends upon selecting land with suitable conditions, selecting adapted plants, and perhaps correcting one or more conditions at the time the fertiliser is used'.

In fact, a good proportion of the increased crop yields resulting from fertiliser application are due to the improved cultural practices which such application makes necessary. A very simple case in point is provided by the need for improved weed control: if this is not carried out, a large proportion of the fertiliser may in effect be used to grow bigger and more pernicious weeds rather than the crop for which it is intended.

In considering the development of fertiliser use, however, two main agricultural factors have to be borne in mind; the soil, and the crops which it is intended to fertilise. Owing to the innumerable soil types, which vary from country to country, district to district, and sometimes, even from field to field, it is impossible to make specific recommendations on the materials required for different places. On the other hand, fertiliser policy cannot wait upon detailed soil surveys, which indeed have not been carried to completion in many of the world's most advanced countries, let alone those in which fertilisers are only just being introduced. Nonetheless, the requirements of broad soil groups are becoming reasonably well known, and a very large amount of information is contained in agricultural journals and research establishments, many of them in the less developed countries themselves.

Basic Considerations

The same can be said of the requirements of different crops, which are in fact a good deal better known than is the case with soils. But quite apart from these two major factors, there are others which need to be considered, at varying degrees of urgency, when fertilisers are to be used. These include:

Climatic conditions and extent and periodicity of rainfall.

Availability of water from other sources

Methods of cultivation employed (hand-hoeing, deep-ploughing, degree of mechanisation, etc.)

Existing state of the soil (as opposed to its chemical composition and physical nature): is it cultivated regularly, exhausted by years or cropping, or newly broken to the plough?

Are organic manures used or available?

What crops are at present grown and under what system?

State of education, agriculturally speaking, of the population (especially if fertilizers are to be introduced at the individual farm level).

Existence of endemic pests and diseases and measures for their control.

Availability of good seed or of strains of crop-plant that will respond to fertilisers.

All these and many other factors must be considered sooner or later. For this reason, authorities are unanimous that extensive field trials, if possible by farmers themselves, but at any rate on their actual fields, are a prerequisite to the introduction of chemical fertilisers at farm level. Without such trials, results may even be such as to discourage the farmer from their use, a situation which must be avoided at all costs.

Such trials are separate from, though based on, those undertaken at experimental stations and demonstration farms, which are used to supply basic information on the fertiliser requirements of soils and crops, and the techniques for satisfying them. Moreover, these trials can help to demonstrate the need for improved cultural practices as an essential concomitant of fertiliser application at the farm level. This situation was well summarised by Dr R. A. E. Galley, (at the time Director of the Tropical Products Institute) when he wrote: 'More often than not the African grows his crops under very poor husbandry conditions and by proper cultivation yields could be increased without fertilisers. If fertilisers were used without improved husbandry conditions, responses would still be relatively small. We had examples of this on cotton in Tanganyika, not with fertilisers but with insecticides. Our yields from *untreated controls* were better than the African-grown with the optimum insecticide treatment. Whereas our increased yields with insecticides far more than paid for the application, the increased yields in the African-grown cotton did not do so. I have a feeling that this would also happen with fertilisers. Therefore the first thing the farmers must do is learn how best to grow the crop.'

The other side of this picture is seen when, using fertilisers *as well as* improving his farming methods, the peasant farmer begins to reap the benefits of both advances. Then, it is generally reckoned, he may expect to double the output of most crops normally grown at present under primitive conditions on peasant farms, for example, in the underdeveloped countries of Asia, Africa or Latin America. Of that increase, half will be due to the improved plant nutrition provided by the fertilisers; the other half will be the result of the improved cultural practises insisted on by Dr Galley. This whole aspect of the agricultural improvement, as a background to fertiliser use, will be considered in more detail later, and the ways in which this may be brought about will be discussed. But what is important to appreciate from the start, is that there should be no intention of introducing fertilisers by themselves: with them must come better cultural practices, better pest control, the better use of water and many other things that the farmer as his production rises, will begin to take for granted. In other words, the use of fertilisers must always be seen not as an end in itself, but as a part of better farming.

Meanwhile, if the scientist may be said to have proved his point, that fertilisers lead to greater production, it remains for the economist to decide in what sector of the country's agriculture that greater production shall first be sought – should fertilisers be used first for export crops to earn foreign currency, or on local food crops to save imports? He will wish too, to look more closely at the cost of increased agricultural imports from overseas as the population rises. Besides the economist, the politician will have something to say, perhaps at variance with what both scientists and economists suggest. With some of these things we are concerned in the next chapter.

2 Economic Considerations

Information Required

Although in many of the more advanced countries the practice of using fertilisers has spread gradually throughout the farming community, in the rapidly developing countries of Asia, Africa and Latin America this is less likely to be the case. There, the present urgent drive for higher food production as an answer to rising population means that the introduction of fertilisers is more than ever likely to be a matter of government policy. Under these circumstances it is the administrator who has to make the final decisions. What he decides, will be based on what the scientist can tell him about the probable results of using fertilisers on the crops grown in the country, and with the country's soils. From the economist, he will have estimates of the real value to the farming community, and to the national economy as a whole, of increased agricultural production. The sociologists, if asked (which often they are not) should be able to give him some idea of any serious social difficulties to what he has in mind, or whether his plans can only succeed if there is a complete revolution in the agrarian system. But in the end, the decision will have to be his, and probably it will be largely based on economic considerations.

As we have already seen, the case for the use of fertilisers as a means of increasing gross crop production can be taken as proven. This takes account of the evidence, not only of scientists, but also of the men who have applied their theories and used their recommended materials in the field. But this does not mean that fertilisers will necessarily be worth introducing into the country's agriculture, from the strictly economic viewpoint. Indeed, to go ahead on the evidence of the scientist alone might well be to court disaster. The administrator has to consider the situation from three points of view: technical, economic, and sociological.

There is, for example, little to be gained by increasing the output of an export crop if this is already scarcely able to compete in world markets, and is unsellable at home. If fertilisers add to the cost of producing a staple food crop, this may either put it above the purchasing power of the mass of the people who need it most; or it may make it more expensive than the same foodstuff imported from abroad. Again – and this is a frequent situation in the less developed countries – it may be quite easy and even economically feasible, to get farmers to use fertiliser on a crop. But if they cannot get their increased output to market, or sell it when they have taken it there, the exercise will be useless, and the farmers less willing to try again when conditions have been improved.

Nor are all the problems purely economic. It may indeed be possible to double the output of a crop, and a market may exist. But unless the necessary control services are available, pests may destroy it before it ever reaches the market. It may deteriorate or be devoured by insects in store. The extra amount of crop grown may make demands for additional farm labour that cannot be fulfilled. The transport system may not be sufficient to get the crop off the fields in time.

These are only a few of the sorts of problems that are almost certain to arise, in one form or another, when the large-scale use of fertilisers is being contemplated in an agriculturally under-developed country. To deal with them the administrator must have available a great deal of information, all of which will be needed sooner or later if his programme is to succeed in bringing in the extra food or currency which fertilisers promise.

Briefly the subjects on which information is needed include the following:

(A) *Agricultural*

Crops grown: where and how much; nutrient requirements
Soils: extent and nutrient requirements
Fertilisers or other nutrients already in use or available locally
Pests and diseases, actual and potential
Storage facilities on farms
Irrigation: available or intended
Level of farming and farmer education
Extension services: existing or planned
Social factors: credit, land tenure systems
Meteorological data

(B) *General and Economic*

Level of nutrition of both urban and rural population
Marketing facilities at home (food crops)
Marketing situation, international (export crops)
Communications and bulk storage facilities, down to port-level and if home-manufacture of fertilisers is contemplated
Possible methods of financing a programme

(C) *Industrial*

Raw materials: for all types of fertiliser. Available or imported
Energy: actual or planned
Man-power, technological as well as administrative in industry
Types and costs of production processes and plant

Not all this information is required at once, nor by the same persons. But without it, the major decisions, on how big a fertiliser programme to initiate, and on how soon – if at all – to begin domestic manufacture, cannot reasonably be made.

Different Aims of a Fertiliser Programme

Once the decision to go ahead has been taken, the advantages to be expected from the full use of fertilisers throughout a country's agriculture are two-fold: an overall increase in agricultural production, and an increase in productivity, per unit of land, of labour, and of capital investment. However, these effects are not likely to be felt throughout the agriculture for many years, and in the first instance fertilisers will probably be introduced with one of two narrower aims in view: either the improvement of the country's export trade, by increasing profitability of export crops, or an improvement in the nutritional status of the mass of the people by concentrating on staple food crops for home consumption.

As an example of the first, the application of fertiliser to the cocoa crop in Ghana, or to rubber in Malaya may be cited. Both of these crops are of great importance to the economies of their respective countries, but an increase in production of cocoa or rubber will not necessarily raise the standards of living of the people as a whole.

The outstanding example of the second approach is that of India, where the deliberate aim is to encourage the use of fertiliser for the paddy crop, which provides the staple food of the majority of the population. Not only can this result in a sufficient increase in production to offset the rapid rise in population, but it can also be expected gradually to provide more food for the farmers themselves.

A third approach is exemplified by the situation in Singapore, where European dairy cattle are kept throughout the year on up to twelve cuts of grass grown on pastures which receive heavy doses of fertilisers, one every month. This sort of specialised use of fertilisers to produce a comparatively high-priced commodity for local consumption, however, is not likely to be the subject of large scale government planning, although such schemes as those for supplying milk to the big cities of India may be based in part on the use of fertilisers for fodder production.

Impediments to the Use of Fertilisers

Although to the government planner, the agricultural economist, the research worker, the advantages noted above may be obvious enough, this is not necessarily the case with the farmer, and more particularly with the small peasant farmer, although he may stand to gain most, personally, once fertilisers have been successfully introduced. The difficulties in the way of widespread adoption of fertilisers at the peasant level spread far outside the field of agriculture, and many of them are of more concern to economic planners than the agriculturists. A recent FAO publication* has listed them as follows:

1 *Lack of distribution facilities*, including transportation and storage in rural areas.

2 *Lack of crop price stability* and low price levels.

3 *Lack of security of tenure* (and unsatisfactory land tenure systems generally). Share-cropping, wherein the costs of fertiliser may have to be borne entirely by the tenant, is an example of this. Often, too, as much as 50% of any crop goes to the landlord, and the incentive to produce more than the farmer requires for his own immediate needs is therefore very low.

4 *Lack of credit facilities*. This is quoted as being of particular importance in Asia and the Far East. Peasant farmers as a whole can seldom afford the expense of things such as fertilisers, and interest rates may well be so high as to cancel any advantage that extra production may give.

5 *Lack of research and experimental services*. This may extend from an absence of knowledge of soil types and the fertilisers needed for them, to data on the reactions of different strains to fertilisers. Another factor is often an absence of seed of the varieties that can give the best results once fertilisers have been introduced. Economic research that will show just how much farmers may expect to gain from an investment in fertilisers is also completely lacking in many of the less developed countries.

6 *Lack of managerial skills*. Good farm management is essential to the optimum use of fertilisers. It is by no means universal in the more advanced countries, and in those where fertilisers are only now beginning to be used, may be almost completely absent. The need to improve cultural practices is emphasised again and again in the literature as an essential pre-requisite for fertiliser use; even where the best results possible under existing conditions are being produced, the improved yields expected when artificial fertilisers are introduced may not be achieved unless new cultural methods are also adopted.

7 *Lack of extension services*. Perhaps the most important aspect of the whole problem of fertiliser introduction in the less developed countries.

Although most of these factors impeding the wider use of fertilisers operate to a greater or lesser extent in probably all the developing countries, their existence varies according to which of the two lines of approach mentioned above, is being adopted: the

* "The Fertiliser Economy of Asia and the Far East Region", FAO, Rome, 1960.

improved fertilisation of plantation or cash crops for export, or the introduction of fertilisers to the peasant farming community as a whole.

Fertilisers and Export Crops

In the days when encouragement of agriculture in the less developed countries was largely confined to export crops, it was solely on such crops that fertilisers were applied. This system still exists today in many countries: since these crops are often grown as plantation crops, fertiliser application, and the research on which it is based, is normally in the hands of the agencies, private or otherwise, concerned solely with their production and marketing. Such agencies would promulgate the results of their own research on their own plantations. Even where the crop is grown by individual small farmers, there is often some form of growers' association, through which the use of fertilisers is encouraged and fertilisers themselves are supplied. Where this is the case, there may be little or no extension service other than that provided for growers of the favoured crop, nor may there be any contact, in so far as fertilisers are concerned, with the bulk of the peasant farming population.

Very often, too, the crops which receive fertiliser because they contribute most to the country's economy are not food crops, but such things as rubber, cotton or other fibres. Official action and propaganda for the greater use of fertilisers may be successfully directed towards increasing the yields of these. But any increased yield will benefit no one who grows anything else, except indirectly through an improvement in the country's foreign exchange position. Such improvement is liable to take a long time to seep down to the level of the normal peasant farmer. Even so, there are plenty of examples of a main export crop, on which a country largely depends for foreign exchange, still being grown without any appreciable use of fertilisers. Such is the case in Ghana, where despite the 4 million acres of cocoa grown by peasant farmers to produce a third of the world's crop, a writer noted as late as 1959 that 'it is at least an opportune time for the *introduction* of the use of mineral fertilisers'.

Whatever the difficulties – and they are considerable – in fertilising this particular crop, it is evident that the four million acres of cocoa can absorb the country's possible fertiliser imports for a good many years to come, without directly contributing to the welfare of farmers other than those growing this particular crop.

Fertilisers for Staple Crops

In contrast to the previous concentration, in many countries, on the use of fertilisers for export crops, many governments are now beginning to encourage the use of fertilisers on staple food crops. This approach may have very different requirements in so far as extension and advisory services are concerned. Instead of efforts directed towards the growers of one particular crop, forming probably a distinct and easily identifiable group, the need is now to inform and encourage a great mass of farmers, probably with no central organisation, and almost certainly containing a large proportion of illiterates. Moreover, many of the peasant farmers are living at bare subsistence level; they do not have a cash economy, and the absence of the profit motive removes the usual spur to high productivity. An example of this has been quoted from an African territory where the increased yields possible by using fertiliser were demonstrated, with apparent success, in a number of villages. To show the differential effects, only one row of the maize in each holding was fertilised, but enough fertiliser was left with the farmers to provide for the whole of the following maize crop.

When the village was visited later, to see the effects of this policy, it was found that only one row of maize had again been fertilised. The correct amount of fertiliser had been used and the remainder carefully stored. When a farmer was asked why he had done this, he replied: 'There was enough maize in only one row to provide the season's needs. I don't need more than that, so I planted only one row and gave it the fertiliser'.

Although this was hardly the result expected, such an attitude on the part of the farmer might still be turned to good advantage. If the introduction of fertilisers means that less land is used for essential food crops, the farmer may be persuaded to grow cash or export crops on the rest of his plot. These might have to be grown and marketed under supervision, perhaps through a co-operative, but if the result was an overall increase in production the advantage would be gained. Moreover, once the farmer saw that growing other crops was worthwhile, and was able to see the use of a cash economy, instead of bare subsistence farming, a very important step towards the whole improvement of agriculture would be taken. This in itself, taken advantage of by an efficient extension service, would pay handsomely for the cost of fertiliser in the first place.

The freeing of land for other crops can be beneficial in another way. If the prime need of a country is for more protein in the diet, land freed by economy in its use for staple food crops can be used for growing other, high protein crops. Better still, as is already planned in some areas, a gradual change over to mixed farming may be possible, the newly available land being used for livestock production. Decisions in this field, it is true, may have to be made only after a full nutritional survey of the country has been carried out. But it is an undoubted fact that protein deficiency is the major nutritional problem in very many of the less developed countries, and the use of fertilisers to economise in land may be a way of starting to solve it.

But whatever the administrator decides on economic or other grounds, incentives will have to be there before the farmer will adopt the practice of using fertilisers. Bigger output, it is true, means probably increased productivity and also a better balanced diet. But unless the farmer is convinced that he will earn more or eat better – and preferably both – he will probably not be susceptible to other arguments. The task of convincing him may in part depend on social factors, on which the administrator will also need to seek advice. But above all, it is most likely to be done successfully if there is a really efficient demonstration and extension service.

3 Government Services and Social Problems

Greatest Need for Extension Service

Good agricultural services are essential if fertiliser use is to be increased in any country. This is so, whether the intention is to raise production of food or of export crops, and quite apart from other considerations such as the improvement of marketing facilities, transport, etc.

Such services comprise research, demonstration and extension. all of which are closely linked together. Until they are firmly established and working properly, the adoption of fertilisers will inevitably be delayed. (It is true that in some countries, these services have been largely developed by commercial undertakings interested in selling fertilisers or in growing export crops. But in general, most developing countries prefer to have such services under their own control.) But although investment in research is essential, especially in the early stages of agricultural development, it seems to be inevitable that sooner or later, research outruns extension. The scientists, in fact, can solve their problems quicker than the farmers can be persuaded to act on their findings. This is true of even the most advanced countries, with a well educated farm population. In the developing countries, the gap between research and its application is usually very much wider.

For this reason, in most of the developing countries, the greatest need is for very many more, and much more experienced, agricultural extension workers. This is made clear, and its importance stressed, by all authorities when the increased use of fertilisers is discussed. Thus, Dr. H. L. Richardson, pointing out in 'Outlook on Agriculture'* that it should be possible to double the yield of paddy rice to the acre in India, writes 'The figure appears to be one that could be realised within a generation. The chief problem will be that of extension and advisory work: persuading the Indian cultivators to adopt the new methods'.

Value of Trials and Demonstrations

Part of the value of extension services lies in the fact that they enable a broad picture of improved agriculture to be put before

* "Increasing World Food Supplies Through Greater Crop Production", Outlook on Agriculture, Vol. III No. 1

the farmer: improved methods of irrigation, of cultivation, of pest control and crop storage can all be discussed and often demonstrated at the same time as the need for more and better use of fertilisers. But in so far as fertilisers are concerned, the work of the extension officer must depend, to some extent at least, on that already done at experimental stations, as well as on more fundamental information on such things as soils, rainfall, and on meteorological data generally.

Experimental work on fertilisers, as conducted at research stations, may provide information on the reactions of crop plants to varying proportions and quantities of the essential nutrients. But this is done under strictly controlled conditions, on soil that is probably in good condition, and where efficient cultural practices are used as a matter of course. These very facts tend to limit the usefulness of such work when it comes to applying the results in the broader context of peasant farming, where, as P. H. Nye has pointed out, 'the responses to be expected from fertilisers are greatly influenced by the natural vegatation and the cropping history of the land'. Nye's work was carried out in 1951/52 in Ghana, and was based on previous experiments (in 1948 and 1949) at experimental stations, which had given a broad picture of results that might be expected from fertilising the main annual food crops. To expand the usefulness of this information it was decided to survey the effects of applying fertilisers to these crops, in a number of areas representative of farming conditions in the country as a whole. 'The general plan for the survey was to select at random thirty sites on native farms for each crop-mixture under trial in each area.'

This work showed that very considerable increases in yield could be obtained with the principal crops concerned: cereals, yams and groundnuts. Yet seven years later, it was considered that the total consumption of nitrogen fertiliser in Ghana was still only 'around the 100-ton (per year) mark'. Even widespread field experiments, carried out on cultivators' own fields, therefore, may not of themselves produce the desired results. On the other hand, the practice of carrying out field trials in this way, certainly does bring the results and the demonstration of fertiliser use more closely to the attention of the farmer. In India, where several hundreds of thousands of demonstrations and cultivators' trials have now been carried out on farmers' own land, the effect has certainly been remarkable. But it is most important that the success of such demonstrations should be as nearly as possible guaranteed by previous work on experimental farms, before demonstrations to farmers are put in hand. An unsuccessful demonstration can do real damage and set the whole programme back in any area in which it takes place.

However, essential as research and experiment are, the findings of the research workers, especially where the economics of fertiliser use are concerned, cannot always provide the final answer. In one area of Nigeria, for example, experimental results seemed to cast doubts on the profitability of using fertilisers on rice. The farmers themselves, however, having used the fertiliser on a small scale, became so enthusiastic that the local extension officers were scouring the country for more supplies. The fact that some farmers found it profitable to fertilise their rice crop counted for more with their neighbours than did the doubts of the scientists. Certainly, the best of all advertisements for fertilisers is the fact that one member of a community has used them with success and has made more money as a result.

Importance of Improving Education

The prime responsibility for spreading information about fertilisers certainly among the farming community, and for ensuring that full advantage is taken of it, rests with the extension services. But the success which they may have itself depends to some extent on the ability of the farmers to understand and take advantage of the information when they get it – in other words, upon their general level of education. This is considered to be one of the problems in introducing fertilisers into tropical Africa in particular, where the low level of education of the farming communities is a major difficulty.

Thus, during the period 1947/48 to 1957/58, a group of 28 developing countries which had initially a fertiliser nitrogen consumption of less than 1,000 tons per annum each, increased their consumption nine-fold. But the tropical African countries concerned increased theirs only four-fold in spite of the fact that when the original consumption is very small, a rapid rate of increase is easy in the early years of a fertiliser adoption campaign. As an indication of the small amounts of fertiliser being used, as late as 1955, Dr. Galley quotes reports that 'no commercial fertilisers were sold (in Ghana) by commercial firms in 1955 but "encouraging progress" was made in the Northern Territories'. Among the quantities mentioned in this connection were 53 cwts of superphosphate sold by the Department of Agriculture and commercial firms in one area and 27 cwts of superphosphate and 9 cwts of sulphate of ammonia supplied free of charge elsewhere. 'It is staggering to think', Dr Galley comments, 'that trivial quantities like these should even be mentioned'.

Social and Other Problems

All experience goes to show that the chain of information, research and experimental work – field trials – demonstrations on farmers' own plots – extension – must be properly established if a fertiliser programme is to succeed. But sometimes, success or failure may depend on more subtle factors than these, which can often only be identified after the programme has failed to go ahead as expected. The incident already quoted, in which a peasant was interested in fertiliser only in as much as it enabled him to grow in a single row all the maize he needed for the year, and thus saved him work, is a case in point. In Africa, again, difficulties have arisen when the crops for which fertiliser has been recommended happen to be those with low prestige value, grown perhaps by the women. Encouragement given to them may be looked on with disfavour by the men of a village, who will claim any additional income, which may thus be put to no really useful purpose.

The problems raised by having to handle increased crops may also have to be taken into account. Heavier yields require more labour at harvest time, more storage capacity, and possibly, if the farming is above subsistence level, more facilities for disposing of the crop. Where there is no price control and insufficient storage, it may be that the grower has to sell his increased crop on a market that is already flooded. If the returns from the increased crop show little profit, there will be no further incentive to use fertilisers the following season. On the other hand, if fertilisers have been accepted and farmers are eager to obtain them, any shortage, for whatever reason, will possibly undo the good that has been done, and even cause ill-feeling between those who have been able to obtain supplies, and those who have not.

There are, of course, many other aspects of agricultural improvement that have to be considered and in respect of which action must be taken, if productivity is to be successfully raised. Land tenure systems, for example to which reference has already been made and which are further discussed later, may need to be drastically revised if it is going to be worth the peasants' while to produce more. There must be greatly improved crop protection services and these must extend to the protection of the harvested crop as well as to the growing plants. Insects attacking stored products, birds, and rodents perhaps most of all, may have to be dealt with; where rodents form an appreciable part of the peasants' intake of animal protein, their destruction may have to be balanced, from a nutritional and sociological as well as an economic point of view, against the damage they do.

All of these things, however, may be considered in one way or another as part of extension, and no apology is made for stressing once more how essential these services are. Dr. Richardson, again, has made this clear with reference to Mexico, where the quantity of fertiliser used increased dramatically, between 1947/48 and 1957/58, from 4,500 tons to 138,300 tons of nitrogen alone.

Writing of the Mexican development programme for wheat, Richardson notes that 'the first ten years of the development programme were largely devoted to field experiments and had little impact on the farmers; it was only with the subsequent growth of the extension services that the wheat farmers began to appreciate what fertilisers could do, and since then further development has been very rapid. By 1957 farmers who a few years before, had never used fertiliser were already applying up to 120 lb. fertiliser nitrogen per acre to their wheat crop and were benefiting accordingly'. In fact, farmers were harvesting five or six times as much wheat per acre, once the results that fertilisers could achieve had been shown to them by the extension service.

Wider Effects of Fertiliser Use

But the value of these services is not only in persuading farmers to use fertilisers and other modern aids to productivity in the first place. When the first applications of fertilisers have been made, crop yields rise steeply; but later, more fertiliser does not bring a proportionately greater increase in the harvest. It is then that other factors – such as improved crop hygiene, better storage, the use of varieties that can take advantage of the added soil nutrients – become more important. If fertiliser use is to have a continued effect, and yields are to go on increasing, extension work must continue. Most authorities reckon that if the yield of a crop can be increased 50% by the use of fertilisers, the other new practices that are taught and adopted at the same time may add a further 50%. Though fertilisers may play the part of a 'booster' to break through the barrier of low productivity, they are only one of many essential advances that extension services, above all, can bring to the farmers' notice.

There is one further way in which the often dramatic effect of fertilisers can cause a real revolution in the thinking of an agricultural community, especially when this is at a very low level of subsistence farming. The members of such a community may be largely influenced by a fatalistic approach; never having had larger crops, they may tend to accept this situation and take it for granted that things cannot be otherwise. But if a dramatic improvement can be made, and made on their own farms, it may open their minds to the many other things that can be done to increase the yield of their land, and thus eventually to raise their standard of living.

This sort of break-through can also, of course be obtained in other ways, as for example by irrigation (which is often essential if fertilisers are to be used to full advantage). But the effects of even quite a small quantity of additional nutrients can be so surprising, and so evident to the farmer who may not appreciate the results of a more subtle approach, that the funds spent on bringing these effects to the farmers' notice will repay themselves many times over.

This approach has been admirably summed up by the team responsible for FAO's survey* to which reference has already been made: 'Increased fertiliser use', says this report, 'can act as a vehicle for the introduction of general improvements in methods of cultivation. Appropriate programmes of fertiliser use can yield tangible results for most crops produced in the Region. These may encourage the cultivator to adopt new farming practices. This could act in turn as a catalyst for the introduction of further improvements, such as water control, certified seed, pest and disease control, modern farm practices. These are essential, in any case, for the attainment of maximum benefits from commercial fertilisers, and they must often be applied, side by side with fertilisers, if setbacks are to be avoided'.

* See page 17.

4 Long Term Problems and Ultimate Gains

National Fertiliser Committees

Although fertilisers are probably the quickest means of attaining increased agricultural production, other than by breaking in new land, their introduction, as should already be clear, must be considered as an integral part of agricultural development, and planned as such. It is for this reason that FAO so consistently advocates the setting up of National Fertiliser Committees (or some such bodies) in the less developed countries, 'with representatives from the Government, research institutes, extension services, agricultural leaders, and the fertiliser trade, to co-ordinate policy and activities in the supply, marketing, distribution and use of fertilisers'.

Such a Committee can be particularly effective in helping to anticipate some of the long-term problems that need to be tackled before the widespread use of fertilisers can be effective. For example, it is generally considered that a minimum of five years is necessary for the education of the farming community as a whole, to the proper use of additional plant nutrients and water supplies. As already pointed out, extension services play the key role during this period. But even before this, it may be necessary to educate the extension staff, who may be almost as ignorant of the use of fertilisers as are the peasant farmers themselves. The same may apply to rural agricultural merchants. The latter may know nothing at all about the materials they are handling; yet in the absence of a complete extension service (which is likely to last for a good many years to come in many of these countries) they may be able to play a useful part if this deficiency can be rectified.

Fertilisers and Irrigation Development

At no place in the development of agriculture is the need for joint planning better shown than in the relationship of fertiliser policies with irrigation. The better use and control of water has long been recognised as one of the essential requirements in most of the less developed countries. But for the full benefits to be reaped, it must be combined with the introduction and proper use of fertilisers; the two, in fact, are closely complementary. This is a particularly good example of the way in which extension services can work in the long term. As FAO has noted with reference to Asia, 'Most countries are trying to educate the farmers on the newly irrigated lands, but in general the effort is insufficient. It was estimated in Thailand that about five years are required before the farmer will learn reasonably good management, including proper use of water and fertilisers. Irrigation alone, without fertilisers, will often result at first in a striking improvement in yields. But unless the supplies of nutrients is soon increased, yields are liable to fall back, as the hitherto unused reserves of nutrients in the soil are exhausted by the increased crops made possible by irrigation'.

Credit Facilities and Land Tenure Problems

There are two other requirements which, like education and extension, need to be met in virtually all the less developed countries. These are, the need for more equitable and efficient systems of rural credit, and the revision of land tenure arrangements. It is noticeable that in FAO's report on the introduction of fertilisers into the Far East, these are the impediments to fertiliser use most frequently mentioned in a number of countries. In this respect, what goes for the Far East is true for the less developed lands of other regions, especially those that either do not yet have, or have not yet implemented, a fundamental land reform programme.

Detailed discussion of these essentially political problems is far outside the scope of this book, for they usually require legislation. Where the provision of credit is concerned, however, it is possible sometimes to take *ad hoc* measures especially designed to help purchases of fertilisers. Such measures, in fact, have had to be taken in many of the most highly developed countries, although they usually take the form of subsidies rather than credit schemes. Countries having as different economies as Australia, India, Japan, El Salvador, Norway, the United States and Britain all have subsidies of one sort or another, and this by no means exhausts the list. In India, the use of green manures has been encouraged by a subsidy on green manure seed distributed to rice growers; in Ecuador, on the other hand, fertilisers are bought in bulk by the central organisation marketing bananas, and distributed by them to the growers. In the Philippines, a bag of fertilisers is given free for every four bags purchased, and in Ceylon and certain other countries, fertilisers are made available through co-operatives against repayment in kind (with paddy).

The subsidising of fertilisers is sometimes criticised on the grounds that it lowers the value of such materials in the eyes of a peasant farmer. But where such farmers are living at the lowest income levels, it is often the only way to induce them to use these materials at all. In Nigeria, for example, a group of farmers were asked when they had first heard of fertilisers and when and why they had started to use them. One man had heard of them some ten years previously, at a time when they were being given away free; he had never used any because he did not believe in them. A second, more educated farmer, had heard of them first five years previously, when they were being sold to farmers and the extension services were explaining their use. But he had not bought any until the year before he was questioned. That year, a fertiliser subsidy was introduced. The farmer had bought one bag, and, he said, he would buy two during the current year 'because it is obvious I shall make more money if I do'. In general, while the free distribution of fertilisers appears to be ineffective, a reasonable subsidy seems accepted as a good way of introducing them to farmers.

Unfavourable conditions of rural credit and land tenure exist in probably a majority of less developed countries. One further difficulty, fortunately much less common, occurs when the official farm price policy itself acts as a deterrent to higher productivity. In one rice producing country, for example, the export of rice by the government is regarded as a principal source of revenue. Prices paid to farmers are so low as to provide little beyond subsistence, so that they have neither the money to buy fertilisers nor the incentive to use them. Conditions such as these can be as great an impediment to fertiliser use as the grip of moneylenders on the peasants of other countries, or the not infrequent situation where 50% of the crop is paid as rent to the landlord.

Need for Surveys

Reference has already been made (in Chapter I) to a number of subjects on which information is required before a national fertiliser policy can be put into operation. The lack of information about what goes on, and is produced, within a country is itself a long-term problem, and one that can only be solved by surveys of various types. The need for soil surveys is one, but no fertiliser programme can wait until these, which take many years in even the most advanced countries, have been completed. Socio-economic surveys, which aim to find out what the peasant population really does, and what it would like to be able to do, are also of considerable value. For example, they can help to provide clear and accurate information about the amount of land under various crops, especially when these are grown for subsistence (with cash or export crops, the situation is usually clearer). Only when this information is available can the increase in production due to fertiliser use be properly estimated, and the other necessary facilities – for transport, marketing, storage, etc. – be calculated.

The planning of distribution and storage facilities will also be affected by the type of farmer who is being encouraged to use fertilisers. If they are being introduced for use by small peasant farmers, a much larger number of small storage units may be required than if the effort is first directed to obtaining their adoption by the owners of larger farms. Often the latter may be a better way in which to increase production. Concentration on the more advanced farms is likely to raise yields quicker and to mean less effort in education (and more encouragement for the extension officers) and demonstration, since every convert to the new system will apply the new knowledge over a comparatively larger area. But while this may mean a more rapid rise in production, it may be politically undesirable to encourage only a small sample of the rural population, and those the most prosperous already. This, of course, is likely to be a political rather than a purely economic problem, but it is one that may have to be faced. Even where it may not be economically worthwhile at first to import expensive fertilisers for subsistence farmers, a great deal can be done, by encouraging their better use of local nutrient materials, animal manures, plant residues, wood ash and lime.

Need for Careful Planning

Absence of planning can lead to other anomalies, such as that apparent from part of the FAO team's report on India. Referring to the unsatisfied demand for fertilisers during the three years 1957–59, the report notes that 'the actual supplies of nitrogen fertilisers available are reported to have fallen short of demand by about 50%. 'Yet', the report states, 'unusually large stocks appear to have accumulated in some states; whilst this may be no more than evidence of rapid growth in an untried market, it would seem important to pay regular attention to the movement of stocks as one of the indicators of development.' This again speaks of the need for information, all of which implies additional costs, even if such information comes from some service which is being set up as part of the development of agriculture as a whole. What is equally significant is that this situation has arisen in a country which is already using a very considerable amount of fertiliser, and where a good deal of attention has in fact been paid to the channels for distributing it to the peasant population, and for ensuring that supplies are available for the crops of which increased production is most urgently required.

On the other hand, a decision to go ahead and manufacture fertilisers in a country, perhaps for the sake of prestige or as a part of an unrealistic plan for industrialisation, can lead to problems of a different sort. This has been seen in Pakistan where, referring to the potential production of two new factories that were being set up, the report referred to above says: 'Indeed, even if the demand rises faster than would be required by the estimate (an estimate well above the present rate of increase), it seems highly probable that for some time after both the new factories are in operation, only part of their capacity could be absorbed in Pakistan. Output in excess of this domestic demand would have to compete with other foreign supplies on the export market and might have to be sold below the cost of production.' This seems to be a clear instance of the dangers of pressing ahead with fertiliser production before the extension services have had a chance to ensure that there is a large enough market.

Returns from the Use of Fertilisers

As we have seen, a broad picture can be drawn, with at least a certain amount of detail, to show that the use of fertilisers does normally give worthwhile increases in yield from the food production point of view. Whether or not these increases are worthwhile from the farmers' point of view, is another and much more complicated matter, depending on the solution of socio-economic rather than agricultural or technical problems. However, before looking at some actual examples of the sort of increases in yield that may be expected, it is as well to make clear from the start that some use of additional nutrients is, or will become, essential on a large part of the world's soils if even current levels of production are to be maintained. Modern farming techniques, especially in the advanced countries, remove far more nutrients from the soil than are put back into it by natural means. This is especially the case where monoculture is practised and the dung and other refuse from mixed farming is not available to help return nutrients to the soil. But it is not only a problem of the agriculturally advanced countries. One of the main problems of India is the enormous extent of her run-down soils, which have been deprived of their nutrients by many centuries of ever-increasing pressure on the land – a pressure of livestock as well as human beings, but aggravated in this instance by the fact that the dung is not returned to the soil but used as fuel by the human population.

A very large amount of fertiliser, then, is and will be increasingly needed to maintain current levels of production. Any yield given over and above this, which is sometimes referred to as 'marginal yield', can be counted as profit from the use of fertilisers in whatever form they are applied. Figures indicating such marginal yields, for various crops grown in different countries and under a wide variety of circumstances, are available in the reports of research and experimental stations. In general, however, they refer either to complicated experiments carried out by agricultural scientists under carefully controlled conditions, or to increases brought about in advanced countries, where a highly sophisticated farming community is being advised by an equally skilled and experienced extension service, or in many cases, by the manufacturers of fertilisers themselves. Actual figures of increases on the holdings of small peasant farmers in the less developed countries are less easy to obtain, while the cash profit that may be made by farmers of this type is even more difficult to identify.

Nonetheless, certain facts have emerged as to the sort of marginal yields that can be expected under average conditions. In calculating as to the advantages to be gained introducing nitrogenous fertilisers to the Indian rice farmers, Prof. Mahalanobis has spoken of from 2 to 2.2 additional units of food-grains for each unit of ammonium sulphate applied. A similar figure is claimed for the rice crop in many other countries, and in general, FAO notes that 'response to nitrogen is almost universal. In many instances, it is not known up to what rates the response is profitable, because high enough rates have not been used in many experiments. Response to phosphorus is almost as general as to nitrogen, although it is often a matter of meeting nitrogen needs first.' Gains from the use of potassium seem to be greatest with cash crops.

These gains, and to some extent the profits resulting therefrom, will be greatest when their use is first introduced, although the effective increase in production may continue to increase as other indirect results take effect – for example better cultural practices, pest control, storage, etc. As FAO has pointed out in 'The Efficient Use of Fertilisers', 'If a farmer were to use constantly increasing doses of fertilisers, a point would be reached beyond which the extra fertilisers would increase his costs more than the added output would increase his income. It is at this point that a farmer is using the most economic quantity of fertiliser.' To some extent, this is an academic argument in so far as the less developed countries are concerned, since except for certain important cash or industrial crops, optimum fertiliser quantities are still very far from being attained, even in some of the countries whose agriculture is most highly developed.

Of the rare accounts of detailed results obtained on cultivators' own fields, that given by P. H. Nye of work done in Ghana is most valuable. While he considered that current market conditions (the experiments were carried out in 1951–52) did not justify the use of sulphate of ammonia on cereals, Nye was able to show that 'the introduction of superphosphate will bring great benefits to the impoverished subsistence farmers of the far north. There are about 47,000 acres under groundnuts every year in this region. If superphosphate at the rate of 120 lb. per acre is spread on this area each year, and the residual effect taken on mixed cereals, the increased output per annum is estimated at 6,500 tons of shelled groundnuts and 3,760 tons of grain, representing a cash return of £180,950 on groundnuts and £64,000 on grain. If, as the general fertility of the farm rises, more groundnuts are grown, the return will increase.'

Despite the lack of detailed records and estimates of cash returns such as that quoted above, there is no real doubt about the value to farmers of fertilisers in giving an increased monetary return, always provided that the agrarian conditions allow it. What is almost equally important, especially in the long term, is the general agreement that, if 50% increased yield can be expected from the use of fertilisers *per se*, a further 50% can result from the improved cultural practices that fertilisers make necessary. Trials on experimental stations, for example, often do not consider the residual effect referred to by Nye above, but which should be regularly obtained on actual farms. Where secondary crops have been undersown, there will also be an additional effect. And, as several authorities have pointed out, if the extra yield means more work at harvest time, a much more vigorous growth of the crop plant may also mean fewer weeds and less weeding.

If against the extra revenue from the effects of fertilisers are offset the extra initial expenses in greater storage facilities, pest control and labour, there will still be enough additional income to justify fertiliser use. Moreover, many of the things that have to be done to make the best use of the extra crop yields should come in any event as part of the general improvement of a country's agriculture. In the long term the country as a whole stands only to benefit from this.

Overall Requirements

Turning finally to the possible overall requirements to provide the food needed for the world's population growth, we are faced more with an absence of precise estimates. Some idea of size of the problem, however, was given by Sir Alexander Fleck in speaking during the symposium on World Food and Population at the meeting of the British Association held in Cardiff in 1960. 'Unpublished estimates', he said, 'point to the probability that an extra 7 million tons (of nitrogen) available to the Far East would achieve a vast improvement in general social conditions as well as straightforward greatly increased food availability. At present, consumption in that area is running at less than 2 million tons per annum.

'For the world as a whole', Sir Alexander continued, 'estimates of the quantity of fertiliser nitrogen likely to be needed to maintain food supplies for the population expected by the end of the present century, ranging from over 30 to nearly 60 million tons a year have been put forward.'

If these figures seem astronomical in the light of present world nitrogen consumption, which is in the region of 11 million tons per annum, it must be pointed out that consumption is running at about 30% below production capacity. Similarly, if phosphate and potash fertilisers also require equivalent, or perhaps, in the immediate future, even faster rates of increase in many areas, there is no sign of shortage in the supply of raw materials for their manufacture. The materials for the world's fertiliser needs are available; what is still lacking is demand. To create that demand, and to satisfy it where it has been created, a firm foundation of expert knowledge, spread among farmers at the peasant level is one essential. Essential, too, are improved facilities in rural credit, transport and marketing, control of pests in the field and during storage. And at the higher levels, adequate finance to make full use of carefully planned fertiliser introduction into the agriculture of the developing countries.

Whether fertilisers are to be imported or manufactured domestically remains a question for individual governments to decide. But unless they are introduced by one means or another, there is little hope of feeding a world whose population is rising at the rate of about 1.8% per annum. Fertilisers provide, it is true, only one of the ways of increasing food production sufficiently to take care of this annual increment. It is an essential one; yet, to quote once more the report of the FAO team who visited the Far East: 'Fertilisers are no panacea for all ills. They can become *fully* effective only in a concerted programme in which the provision and regulation of water supplies, the improvement of seeds, the control of pests and diseases, the betterment of farm management, promotion work, extension services, price stabilisation, marketing and credit facilities have been given their full weight.'

5 Types of Fertilisers and their Uses

More Definitions

Artificial fertilisers are used normally to increase the available quantities of three main nutrients in the soil: nitrogen (N), phosphorus (P) and potassium (K). To these must be added lime, usually referred to as 'soil amendment', and the most important nutrient of all, water.

Each of these plays a different part in the development and growth of the plant, but a balanced diet containing N, P and K (and also quantities usually minute, of certain 'micronutrients') is essential for its complete health. The precise amount of each element required depends on the species of plant, the soil, the climate and other factors. These factors are identified and their relative importance made apparent by the scientists working at research and experimental stations, and in field trials, the importance of which has already been pointed out. The resultant fertiliser requirement or the treatment recommended, is usually expressed in terms of 'N', 'P', and 'K'. Whereas the quantity of nitrogen expressed by the term 'N' usually refers to nitrogen as an element, the figure given for 'P' usually indicates the amount of phosphorous pentoxide (P_2O_5) and that for 'K', of the oxide, K_2O, or 'potash'.

Need for Nitrogen

Nitrogen, in a form which the plant can easily absorb, is essential for optimum growth. But nitrates, the salts in which nitrogen is usually available to the plant, are very soluble and are continuously being washed out of the soil. Since nitrogen also forms a large part of plant tissues, it is also lost when a heavy green crop is taken off the land. So this element has continuously to be replenished; this is done in Nature by the decomposition of vegetable and animal matter. Nitrogen is also 'fixed' by the action of certain bacteria which are present in nodules on the roots of leguminous plants (members of the natural order *Leguminosae*).

Many soils are deficient in nitrogen, especially those which have been heavily cropped for many years; in regions of heavy rainfall; where extensive irrigation is practised, or where there is continuous unrelieved grazing and the dung is removed for fuel.

Non-leguminous forage and fodder crops, grown for their leaves and stems, sugar cane, cereals, tea and many fibre crops are among those that benefit from additional nitrogen. The rich green colour seen in many such crops grown at their best indicates a sufficiency of this element. Partly because their effects are easily visible, in greater growth and evident good health, nitrogenous fertilisers are usually the first to be introduced.

In the fertilisers of this group, nitrogen is usually made available in the form of ammonia, or as urea (another chemical containing a high percentage of this element), or as calcium or sodium nitrate.

World consumption of nitrogenous fertiliser increased more than 2½ times in the decade 1947–48 to 1957–58, and was then twenty-five times greater than at the turn of the century. The total available in 1960–61 representing about 11 million tons of nitrogen per annum, was none the less about 30% below the world's potential production capacity. As consumption and production are rising by about 10% per annum, there should be no danger of shortages of nitrogenous fertiliser for the time being.

Phosphorus for Root Development

Phosphorus plays a particularly important part in root development especially in the early stages of growth. Root crops, therefore, benefit greatly from the fertilisers of this group; so do certain legumes. Phosphorus is also important in seed production. Phosphates are firmly held in most soils, although soluble superphosphates may be leached out in areas of heavy rainfall.

Although crushed or calcined bones have been used as a source of phosphorus in Greek or Roman times, the principal modern source of phosphorus is in rocks containing various phosphates.

Phosphate production keeps pace with world demand, and although this has not increased so rapidly as the demand for nitrogen, the annual world production of phosphates as fertiliser is about 9 million tons P_2O_5. The effects of phosphatic fertilisers are less obviously spectacular than those of additional nitrogen, which perhaps accounts for the fact that they are even more slowly adopted by farmers in many of the less developed countries. But in general, countries that use a great deal of nitrogen use an equivalent amount of phosphorus in their agriculture; there are, however, certain large areas of soils deficient in phosphorus in which fertilisers of this group are of the first importance.

Use of Potassium

The precise part played by potassium in the plant is not yet completely worked out. It might be said to increase the efficiency with which the plant functions, for example, in raising the rate of starch and sugar production. Potassic fertilisers can increase the quality and weight of seeds and fruit; their use improves the general vigour of the plant, as is shown by increased resistance to disease. In many ways, potassium is complementary to nitrogen. For example, the latter can so increase the growth of cereals that the stems collapse, or 'lodge'; potassium can strengthen the stems, preventing or reducing lodging. Like phosphate, potash is retained in most soils in a form available to plants.

Potassium has a comparatively short history as a commercial fertiliser, having been little used before the middle of the nineteenth century. In part this is because traditional agricultural systems tended to conserve potassium returning it to the soil in animal manure or when straw and other vegetable refuse were ploughed in. The use of wood-ash (potash) and the burning of forest and bush country are also traditional ways of returning this element to the soil, still practised where peasant, subsistence agriculture is the rule. But in the more advanced countries especially, modern, highly extractive farming has changed this, root crops such as potatoes and sugar-beet especially removing large quantities of potassium. Thus, whereas old farming systems are calculated to have removed 7 lb. of potassium/acre over a four-year period, some modern systems may remove as much as 435 lb./acre in the same length of time.

Fortunately, there are ample supplies of naturally occurring potassium bearing minerals to provide the world's chief source of this class of fertiliser. Although mined in only a few countries, the deposits now worked easily satisfy the annual world's consumption of some 7.5 million tons (as K_2O).

Micronutrients

Although the micronutrients are present in soils in very small quantities, their absence or excess may have serious effects on crops and also on livestock production. Lack of boron and molybdenum are probably the most frequent examples of micronutrient deficiency, but only very small amounts per acre are needed to remedy the situation. Copper and cobalt are two other micronutrients, the excess or deficiency in which can also seriously affect the use of pastures for grazing in some parts of the world. But in general, micronutrient problems only become apparent when fertiliser use has already begun to be accepted, and are not likely to attract much attention early on. Because of the very small quantities required, micronutrients are usually supplied in mixture with other, major fertiliser materials.

Mixed and Compound Fertilisers

'Mixed' fertilisers, as already explained, are straightforward mixtures of fertiliser materials, each of which contains one of the main single ingredients. The practice of applying commercially mixed materials of this type has spread considerably in recent years, and in any developing countries the first domestic production of fertilisers may well be by mixing imported ingredients.

'Compound' fertilisers may be composed of such substance as ammonium phosphate (which thus contains two nutrient materials) with others containing further nitrogen, and potash. Nitrophosphates are prepared by treating phosphate rock with nitric acid or a mixture of nitric and other acids. Ammonia is then introduced and later, muriate of potash. The final product contains ammonium nitrate, calcium phosphate and potassium chloride. Such a material is more or less homogeneous, each granule containing all the necessary major nutrients.

These and other compound materials have the advantage that they can be, so to speak, designed to have the particular proportions of essential nutrients indicated by a given soil or crop requirement. Besides being easy to handle and saving the labour needed when nutrients are applied separately, they may have a very high proportion (45–60%) of nutrient materials available for the plant. Where transport and application costs are high, this can be an important point in favour of their use, and many of the less developed countries are already beginning to appreciate this point.

With both mixed and compound fertilisers, the normal basic manufacturing costs have to be met, although in some compound manufacturing processes no intermediate products are crystallised out, and the compound fertiliser is itself the end product.

New Ideas for Handling Materials

Besides the increased use of mixtures and compounds, certain other developments have changed the picture of fertiliser application in recent years. Modern techniques for mixing, preparing and handling difficult materials, for example, have made these much easier to use. Ammonium nitrate, for example, was little used in spite of its high nitrogen content because it picked up moisture and became deliquescent, liable to melt away. Now, it is commonly mixed with lime or chalk, and is then 'prilled' or granulated to give a product with good handling qualities and a neutral effect on the soil. 'Prilling' is a process whereby a hygroscopic (water-absolvement) material is protected by a layer of some neutral substance and formed into large granules (prills). This process not only prevents deterioration by deliquescence, but also makes for easy handling by modern mechanical equipment, or for aerial fertiliser application.

Even more recent is the suggestion of coating fertilisers, especially those which are fairly soluble, with a waterproof layer of wax, various resins or even plastic emulsion. The aim of this is to ensure a gradual release of nutrients in the soil. The very opposite effect may be attained by the use of certain nitrogenous materials, such as ammonia, by direct injection with highly specialised equipment. This, however, is a very sophisticated practice, principally confined to the United States, and not likely to be of general importance in any of the less developed countries.

Materials for Various Crops

So greatly do fertiliser requirements depend on soil characteristics, cultural practices, availability of water, etc., that even for a single crop it is almost impossible to generalise as to optimum amounts of nutrient materials required, nor is a booklet of this nature the place to enter into such details. Quite apart from the many studies made in research stations devoted to specific crops, there is a mass of excellent material in the FAO publication, "The Efficient Use of Fertilisers", which has the additional advantage that it is especially designed for those concerned with the broad aspects of fertiliser use in regard to agricultural planning. However, a few examples may give an idea of the variations in quantities and treatments likely to be involved when fertilisers are being applied on the large scale to major crops.

Thus on certain Canadian soils, wheat may receive from 0 to 30 kg. nitrogen per hectare, 0 to 20 kg. phosphorus, and no potash. In Japan, rates may be as high as 135 kg. N, 75 kg. P, and 80 kg. K, per hectare, including in these totals both farmyard manure and commercial fertilisers. Again, all types of nitrogenous materials have been and are, used in one country or the other on rice. But quantities, and results obtained therefrom, vary according to timing and method of application, varieties grown, cultural systems, etc. Moreover, for optimum results, nitrogen must be balanced by such phosphates and potassium as soil and other considerations indicate. In particular, phosphorus is becoming more widely used on this crop.

In general, almost all crops on most soils respond to additional nitrogen; nitrogenous fertilisers are still the most widely used and in many countries they are almost the only ones so far employed. The fact that in the tropics, in which so many of the less developed countries lie, nitrogen has often been considered the most important requirement has resulted in the unbalanced use of fertilisers. In fact, on very many soils, and crops in temperate as well as tropical regions, phosphorus is also needed, and when the requirement for N and P has been satisfied, the necessity for potash often becomes evident—another reminder of the need for properly balanced fertiliser use. Nonetheless, seeing that even in the most advanced countries, quantities of fertilisers used by the great majority of farmers are much below those recommended by agricultural scientists, the amounts of nitrogen available in almost all the tropical countries are very many times below the optimum. Exceptions are perhaps Japan and South Korea, in both of which fertilisers have been used for many years and in which their use has increased very rapidly indeed in the last decade.

Until recently, ammonium sulphate was the form in which nitrogen was most often supplied, but by 1959–60 world production of ammonium nitrate at 30% of the total nitrogen production, equalled that of the sulphate, while ammonia and urea are also being increasingly used.

Root crops and those with high starch content, such as cassava, potatoes and also sugar beet often receive proportionately larger amounts of potash than is the case with, for example, cereals. In the same way, legumes and pulses receive smaller proportions of nitrogen and relatively more phosphorus than most other crops. But besides the actual requirements as indicated by experiments, certain cost elements may influence the actual proportions used. Thus, where transport costs are very high, it may pay better to use concentrated, high-analysis compound fertilisers, and it is noticeable that many authorities recommend ammonium superphosphates or similar materials for rice under tropical conditions.

As to actual methods of application, these will also vary according to materials being used, the nature of the terrain, the crop, and above all, the degree of mechanisation of the farming community. Everything from the direct injection of liquids to the broadcasting of granulated materials from aircraft or the application of very small quantities of fertiliser by hand to each individual plant has its use where fertiliser distribution is concerned. In general, however, the more sophisticated methods will be of use to the developing countries for many years, except perhaps where some extremely valuable crop is being grown for export. Where little or no equipment is available, and seed is sown broadcast, broadcasting of fertiliser by hand will be all that can be expected. But even in some otherwise primitive farming communities, the habit of placing small quantities of fertiliser with individual seeds or plants has been followed for many years. A development of this placement method is the spreading of a band of fertiliser along a seed-row or in the furrows, although under some circumstances this is said to be no more efficient than broadcasting.

While full-scale mechanisation of fertiliser application may still be a long way off, except in plantation or export crops, advantage can certainly be taken of the work now being done, in many of the less developed countries, on the development of improved tools and implements for peasant farmers. Special tool bars for use with draught animals, for example, will make it possible to simplify placement wherever row crops are grown. On a large scale, once fertilisers begin to be used by the bulk of the farmers in any district, co-operative buying and application may make some more advanced form of mechanisation possible. These advances will, however, like other aspects of fertiliser use, depend on good and convincing demonstrations, and on the farmers' conviction that the new methods, as well as the fertilisers themselves, really are worth while.

6 Import or Manufacture?

Reasons for Local Manufacture

The type of fertiliser – N, P, or K, or a combination of these – that is required by any given situation is dictated mainly by the nature of the soil, and the crop which it is desired to fertilise. The precise form in which these nutrients are made available, however, may be governed by a number of other factors, not all of which are under the control of the agriculturist or even of his immediate advisers. For example, the initial stages of any deliberate campaign for the wider use of fertilisers in a developing country will almost certainly have to be based on imported materials. What is actually used, therefore, will depend on what is available or what can best be afforded within the means of the country's finances.

Sooner or later, however, Government may wish to set up, or at least to encourage, a domestic fertiliser industry. This may at first consist only of a simple plant for local production of mixed fertilisers, but eventually the question of actual manufacture will probably arise. The decision to start manufacture may be a political one; it may be based on a desire to save foreign exchange; or it may be due to the availability of raw materials.

These factors operate in a variety of different ways. The lower limits of consumption of fertiliser nitrogen, for economic home manufacture, for example, is put at around 30,000 tons per annum, a figure reached by few of the really under-developed countries. But this figure may be much lower if there are ample local supplies of cheap raw materials or energy. Anticipated development in other fields, again may need to be considered. A rapidly expanding steel industry may make coke-oven gas or basic slag available; the sudden discovery of petroleum or natural gas, or the establishment of a large refinery, may make raw materials available. These may also be decisive factors in indicating which type of plant can be most economically built, and what it shall produce. Here again, a very long term view has to be taken. For example, it is now apparent that for many years there has been undue emphasis on fertiliser nitrogen in a number of countries. If a balanced programme is to be evolved, either plant for phosphorus and potash production must be set up, or these materials must be bought abroad. The setting up of a domestic nitrogen plant may, therefore, result in little if any savings in foreign exchange, if adequate quantities of other materials must be purchased, especially since there is in most countries already a considerable lag, as between nitrogen and other essential nutrients.

Question of Cost

For whatever reason the manufacture of fertilisers is being considered, the key question is the same; What will it cost? To this must be added an equally important supplementary question; How much is the fertiliser we hope to make, going to cost the individual farmer who wishes to use it?

We are not at the moment concerned with this second question, but it must be pointed out right away that unless home-manufactured fertiliser can be absorbed by the home market, it may not be worth a developing country's while to go into this business. The reason is that any excess production will have to be sold in the very highly competitive world market, against the competition of the large manufacturing countries. Some of the pre-requisites to ensure that there is a good domestic market have already been discussed, and we shall here concentrate on the costs likely to be entailed, once it is decided that conditions at least justify domestic manufacture.

The possible ultimate gains from setting up a domestic nitrogen industry to produce fertiliser for food grain crops have been analysed by Professor Mahalanobis, with reference to the problem dealing with the increase of India's population at the rate of more than five million a year. He pointed out that over a five-year period, importing fertiliser to raise domestic production would cost about one-third as much in foreign exchange, as importing the food grains themselves. Only one-third as much foreign exchange (one-ninth of the cost of actual grains from abroad) would be spent if the fertiliser were home produced from a series of new factories within India itself. To establish a heavy manufacturing industry and make the actual plant for such factories would cost the same amount, but the foreign exchange component would be very much less.

But whatever solution is sought, many factors other than simply those concerned with the cost of manufacture have to be borne in mind, and at an early stage in planning. Moreover, where economic development as a whole is being considered, it must be appreciated that once the factory is built, fertiliser manufacture is labour-intensive, and can do little to alleviate the question of under-employment with which many developing countries are, or are likely to be, faced.

Factors affecting Cost

Because so many and such variable factors have to be taken into account, it is not possible accurately to forecast the capital costs of fertiliser manufacture, nor the actual production costs. The list below, which is not necessarily complete gives some idea of what the factors are, and an indication of the complexity of the whole problem.

(a) *General factors affecting any type of plant*

Climatic conditions, particularly maximum temperature

Water supply

Power supply

Local (or national) facilities for fabrication or structural steelwork and simple plant items such as tanks, low and medium pressure vessels, pipelines, etc.

Availability of skilled and semi-skilled labour for erection

Availability of managerial staff and skilled and semi-skilled labour for operation and maintenance

If local skills and experience not available, will overseas training be necessary?

Will customs charges be levied on imported plant and materials, etc.?

(b) *Factors affecting any given type of plant*

End product to be manufactured

Availability of raw materials

Water and power supply (for manufacturing, as distinct from constructional requirements)

(c) *Factors affecting choice of site*

Foundation conditions at site; whether piling for heavy plant loads will be necessary or not?

Drainage conditions. Will treatment of effluents before disposal be necessary?

State of development of immediate area of site. Will housing have to be provided for construction workers? Must provision be made for amenities, such as hospitals, schools, markets, etc.?

State of communications for (i) materials to and from site; (ii) personnel

Location of site in relation to markets

Transportation facilities for raw materials to and from site

Location of source of supply of main plant items in relation to site for the purpose of estimating sea freight and insurance, etc.

Importance of Size and Site

At this point it is necessary to point out that, with fertiliser factories in general, and with factories based on ammonia synthesis in particular, the size of the factory affects very profoundly both capital cost per ton of installed capacity, and also production costs. Comparing a factory for the production of, say, 100,000 tons of nitrogen per annum with one of 20,000 tons, the capital cost per ton of installed capacity of the smaller factory could well be double that of the larger. There would also be a variation in production costs, but not of the same magnitude. It is indeed doubtful whether the smaller factory could produce at prices competitive with world prices for imported fertilisers from large factories, not withstanding the sea freight and possibly customs charges on imported fertilisers. Where small plants are built and profitably operated, as in certain parts of the USA it is almost always due to the presence of ample sources of raw materials and energy (as for example, natural gas), together with good communications and sites that are close to a steady market and do not need excessive development. It is extremely unlikely that such a combination of favourable circumstances will pertain in a country which remains underdeveloped.

In any industrially underdeveloped country, costs for construction and for site development will almost certainly be a great deal higher than for plant of similar type and size in a country such as Britain. Unit construction costs, in fact, may be 20–50% higher, and unless a very convenient easily developed site is available, the overall cost may be 50–100% higher than in the UK.

Cost varies with Product

Since the type of end product may be the most important of all cost factors, it may be as well here to see what the principal modern fertilisers are, and the complexity of the processes involved in their manufacture. This applies especially to nitrogenous materials, since it is in this group that manufacturing costs are especially high. Whereas phosphorus and potash manufacture consist largely in processing mineral raw materials, nitrogen fertilisers are usually based on ammonia, made by synthesis of hydrogen and nitrogen in a complex and costly plant and requiring very large amounts of energy.

Making Nitrogenous Fertilisers

Until the end of the 19th century, the natural nitrate deposits of Chile (chiefly sodium nitrate) were much the most important source of nitrogenous fertilisers, the only other important source being 'by-product' nitrogen from ammonia produced as a by-product in gas works. Once the possibilities of fixing the nitrogen in the air and combining it with hydrogen to form ammonia synthetically, had been fully developed, the picture changed dramatically. Accounting for only 1% of the world's fertiliser nitrogen in 1909, synthetic processes had come to supply some 93% fifty years later, the amounts from natural and by-product sources having fallen to 3% and 4% respectively.

The principle synthetic nitrogenous fertilisers in use today include, in order of their percentage of output:

	%N *Available*
Ammonium sulphate	20.5
Ammonium nitrate	33.5
Ammonia, anhydrous	82
Ammonia, aqueous solution	20–25
Urea	45
Calcium nitrate	15.5
Calcium cyanamide	35

Of these materials, those with high percentages of nitrogen have become more popular in recent years, although the use of ammonia itself is largely confined to the United States. Urea and ammonium nitrate are frequently made up in 'prilled' form, and the former especially is gaining in popularity in spite of being rather more expensive to manufacture. The manufacture of calcium nitrate and cyanamide is more or less confined to areas where electrical energy is very cheap.

Except for natural nitrates, ammonia is required for the manufacture of virtually all these materials, and its synthesis accounts for the greater part of their cost. Indeed, the decision, whether to manufacture nitrogenous fertiliser or not, will depend largely on the viability of the ammonia manufacturing sector of the proposed project. Because of the importance of this, and in order to make the various processes more clear, the manufacture of nitrogenous fertilisers is more fully discribed in Appendix I.

Phosphatic Fertilisers

The most important sources of phosphorus for fertilisers are basic slag and phosphatic rock, although countries having deposits of guano will continue to use them. Phosphorus fertiliser, mainly from bones, is also a by-product of the large meat-packing industries of some countries.

Basic slag is a by-product of one type of steel-making process; besides phosphorus it contains large amounts of lime and also micronutrients and is especially useful on acid soils. But its value largely depends on the phosphorus content of the original iron ore, which may be the deciding factor in its use.

Phosphatic rocks of various types provide by far the greater part fo the world's phosphate fertilisers. Known reserves run into billions of tons, the principal being in USA, USSR, and N. Africa. These materials vary considerably in the amount of available phosphate, and in their reaction to the treatment necessary for fertiliser manufacture; only exceptionally can the finely ground rock be applied direct to the soil.

Normally, rock phosphates are treated with acid, the process varying according to the final product required. The most usual end product is that known as 'normal' 'single' superphosphate, which contains 16–21% of phosphorus (P_2O_5). It is made usually by treating finely ground phosphate rock with sulphuric acid, but in countries where sulphur is in short supply, nitric acid or a mixture of the two is used. The resultant product is a generally useful fertiliser, suitable for a wide range of crops and soils and used either by itself or in mixture with other fertiliser materials. Its low phosphorus content, however, means that transport costs play a relatively large part when the cost per unit of phosphorus on the ground is being calculated. Where nitric acid is used, the final product is nitrophosphate (see p. 46).

'Double' or 'triple' superphosphates are also made by treating the finely ground rock with sulphuric acid, which first produces phosphoric acid, gypsum (calcium sulphate) being a waste product. Further rock is then treated with the phosphoric acid, a concentrated superphosphate containing up to 48% P_2O_5 being obtained. The capital costs of plant for this process and the production costs are higher than for single superphosphate, but it has the advantage, especially as compared with nitrogen plants, that it can be installed in comparatively small sizes. This, and the high phosphate concentration makes it more suitable for remote areas, where transport costs will also be relatively lower.

Potassic Fertilisers

There are two main sources of potassium for fertiliser use, of which one, mineral ores containing very high proportions of potassium salts, is very much the most important. The other source is the potassium in solution (again as salts) in certain inland lakes, of which the Dead Sea on the Israel/Jordan border is the best-known example. More or less pure potassium salts are extracted and refined on the spot, when available in this fashion.

By far the greater part of the world's fertiliser potash, however, comes from vast underground deposits which exist in a number of countries and which are sufficient for all foreseeable future needs. The most important are those at Stassfurt in Germany, exploitation of which began just one hundred years ago, together with their continuation across the frontier in France. There are also big deposits in E Germany, Spain, USSR, and USA but as in the case of phosphate rock, more deposits are being and will continue to be discovered as geological exploration spreads to other parts of the world. As the demand, of which over 60% is at present concentrated in Western Europe and N America, also expands, exploitation of newly found deposits should make these materials more cheaply and easily available

The principle constituents of the deposits is usually potassium chloride, known as muriate of potash, with which are a number of impurities, such as salts of magnesium and sodium. These last are valuable for fertilising certain crops, but usually the ore, having been mined by normal methods, is crushed, ground and then refined to produce material with a higher percentage of potassium. Ground but not refined, the ore makes a product marketed in some countries as 'manure salt', containing up to 20% of potash, as compared with the 50–60% in the salts from inland lakes.

Factors affecting Manufacturing Costs

The list of factors given above as affecting forecasts of capital expenditure includes also a number that affect manufacturing costs. In this connection, the type as well as the actual nature of the raw materials may also be important. Thus, if ammonium sulphate is the end product, and sulphur or gypsum are available in the country, it may, other things being equal, be worthwhile siting the plant close to the sources of these. Being bulky and containing a large proportion of unwanted material, sulphur-bearing ores and gypsum can be extremely costly to transport, in terms of end product, and materially affect the final cost of the product. Again, the type of feedstock will have a similar effect; coal and coke are much more bulky and expensive to transport than liquid feedstock, and the latter is more expensive again than gas, especially if this last is available by pipe-line. Those developing countries that have their own sources of petroleum will thus find themselves in an increasingly favourable position, as their nitrogen consumption approaches the minimum at which domestic fertiliser production is considered worthwhile.

One other factor that has to be considered is whether the factory is being built and financed by the State, or is to be constructed by private enterprise. If the latter, the manufacturing costs will reflect depreciation of the plant, insurance and other overheads, to an extent that may not be the case with a State enterprise. The State may be able to consider much longer-term financing, especially in view of the fact that a large fertiliser plant will almost inevitably be only one unit in the industrialisation of a district, and the facilities created for it will be an addition to the national capital usable for other purposes. On the other hand, a privately constructed plant will certainly sooner or later be managed and maintained by nationals of the country in which it is situated, and their training and experience is ultimately a national asset.

Some Idea of National Capital Costs

To determine the effects of all the factors detailed above on both capital and production costs would require a detailed survey after the site of the proposed factory and the type and amount of output have been fixed. In the light of these factors, the following figures may be taken as a rough approximate guide to the capital cost of a factory to produce 50,000 tons of fertiliser nitrogen (N) per year, erected in UK. It is also assumed that (a) production of the synthesis gas will be based on petroleum products, and (b) all prerequisities listed earlier in this chapter are exclusive to the forecast cost.

	Capital cost per ton/year of N (£)
Ammonium Nitrate	
(1) Ammonia synthesis plant	80
(2) Nitric acid plant	10
(3) Ammonium nitrate plant	10
	100
Ammonium Sulphate by direct reaction of ammonia with sulphuric acid	
(1) Ammonia synthesis plant	80
(2) Ammonia/sulphuric acid plant including plant for making sulphuric acid by the contact process	5
	85
Ammonium Sulphate by ammonium carbonate/anhydrite or gypsum reaction	
(1) Ammonia synthesis plant	80
(2) Ammonium carbonate/anhydrite or gypsum reaction plant	6
	86
Nitro-limestone	
(1) Ammonium nitrate production as above	100
(2) Nitro-limestone plant	2.5
	102.5

Thus, with ammonium nitrate as the end product, 50,000 tons N/year x £100/ton will give a capital cost of £5 million.

When considering these figures, however, it must be borne in mind that whereas ammonium sulphate and nitro-limestone both have 20.5% of fertiliser nitrogen, ammonium nitrate has 33.5%. Moreover, urea, which is becoming more popular in many countries, has 45% nitrogen; on the other hand, it costs considerably more to produce, the energy requirement alone being 25–45% higher, since a second high-temperature process is involved (*see* Appendix I).

Given above figures, worked out for a highly industrialised country, it is of interest to examine some from less developed countries in which nitrogenous fertiliser plant has been built within the last decade. According to the FAO report on the situation in Asia, already referred to, 'the total investment for a nitrogen plant with an annual capacity of 50,000 to 70,000 tons per annum will amount to approximately 30–50 million US dollars' (say £11–18 million), of which it is suggested the foreign currency element will amount to US $20–30 million. Referring in greater detail to the situations in various countries, it is pointed out that the operating costs of nitrogen plants in India and Pakistan are high because of the small size of the plants or, as in India, because of the freight costs of raw materials. The big ammonium sulphate plant at Sindri, the first of India's expansion programme in this field, for example, relies for its sulphur components on gypsum brought overland from 1,000 miles away. 'The investments for plants in three countries, in US $ per ton N installed capacity, are: India $500; Pakistan $1600; the Philippines $900'.

Where raw materials are hydrocarbons (coal, oil, gas) the energy element is included in calculations of manufacturing costs, but if hydro-electric power is used for the energy supply this will have to be added to the manufacturing cost. Some 12,000 kilowatts are required for every ton of ammonia produced, and costs per kilowatt may vary from .1d in a country such as Norway to .3–.5d in India. Except where very small plants are concerned, which are usually built where conditions are particularly favourable on account of some unusual circumstance, a good rough rule is that if the size of the plant is doubled, the capital costs increase as $\sqrt{2}$.

Although phosphatic fertilisers, which do not depend on the expensive synthesis of ammonia, require comparatively much lower capital investment, the minimum convenient size of plant is still considered to be in the neighbourhood of 30,000 tons of single super-phosphate per annum. Such a plant, reckoned at around £10/ton/year capital, will cost £300,000–£350,000. But costs for phosphate plants, again, depend on the availability of raw materials and on the system for financing the sulphuric acid supplies.

An example of the opposite situation, in which the high value of the *agricultural* product may make a large expenditure worth while, may be quoted from Southern Rhodesia, where some 24,000 tons of fertiliser are *imported* every year for virtually exclusive use on the tobacco crop.

Finally, it must be emphasised once again that there is in theory no limit within reason to the 'smallness' of a fertiliser plant. Ammonia synthesis plants with as low an output, as 20 tons/day have been built. However, it must be kept in mind that the smaller the output, the higher the capital cost per ton of installed capacity and the higher the production cost. Eventually, a point is reached where the cost of the end product is entirely non-competitive.

Appendix 1 Nitrogen Fertiliser Manufacture

Ammonia forms the basis for the manufacture of virtually all nitrogenous fertilisers, except where natural nitrates are available. The vastly greater proportion of ammonia is produced synthetically (some 4% comes as by-product ammonia from gas works), and this takes up two of the three stages in nitrogenous fertiliser manufacture, other than where 'ready-made' by-product ammonia is used. These stages are:

1 The production of hydrogen and nitrogen, from which in turn is produced 'synthesis gas', a mixture of one volume of nitrogen with three of hydrogen.

2 Ammonia formation by the synthesis of the two gases under conditions of high pressure and temperature.

3 Reaction of the ammonia with whatever other materials are required to make the particular fertiliser required.

1 'Synthesis Gas' for Ammonia Production

A number of different methods are in use today for the production of synthesis gas. The choice of which to employ is basic to the whole planning of a nitrogenous fertiliser production project. It may depend on any one of a number of factors, which include the availability of cheap electric power; an assured supply of cheap and convenient fuel; a source of cheap hydrogen, as, for example, from refinery gases; and, most usually, whichever of a number of hydrocarbons is most conveniently available for hydrogen production; coke, coal, liquid petroleum products, natural or other gases. A source of steam is also essential.

The following are the main processes for hydrogen and nitrogen production for fertiliser manufacture.

(*a*) The production of hydrogen by the *electrolysis of water*, and the production of nitrogen by the liquefaction and fractional distillation of air.

In both of these processes oxygen is a by-product for which a use is generally found later in the fertiliser manufacturing process. Under modern practice, electrolytic hydrogen production can be ruled out unless there is large electrical generating capacity which cannot otherwise be usefully employed. The capital cost of installations using this process are also twice as high as those for the reforming or gasification of petroleum products.

(*b*) There are a number of processes based on the use of coal, lignite or coke. The most important of these is that known as the *semi-water gas process* for the gasification of coke. This is normally done by blowing steam and air alternately through a bed of red-hot coke. Both hydrogen and nitrogen are produced and after a complex series of purification and other processes have been carried out a mixture in the correct proportions for synthesis results.

This process has been widely used in the past, but is now giving way to those based on petroleum products, except where the latter are not within easy reach and coal is readily available. Besides the high capital cost of the massive coke-ovens and ancillary handling equipment required for the conversion of coal to coke, the coke-gasification process is more expensive to run than are those based on petroleum. Another point is that the plans for steel-production in many emerging countries require the use of caking coal to provide the coke needed for blast furnaces.

The *direct gasification* of coal or lignite has so far been mainly employed where there are ample supplies of suitable materials. New direct gasification processes for a wider range of coals are now being evolved and this system may become much more widely used. In general it follows the semi-water gas process except in the gasification stage.

Surplus *coke-oven gas* from steelworks is also used for hydrogen production. It can be liquefied and distilled to take out the hydrogen, the balance of the gas being used either as fuel in the works or processed for other purposes. A second method is to reform the coke-oven gas with steam.

(*c*) A rather different process is that in which hydrogen is produced by passing steam over red-hot, specially treated iron. This can be done with coal or coke as fuel and also, where there are large forests capable of recuperation, and no suitable alternative material, even using wood as fuel. Whatever fuel is used, the nitrogen for the final gas mixture is produced by the 'air separation' method, as under (*a*) above.

(*d*) Much the most important current source of hydrogen for synthesis gas is from petroleum products of one sort or other. This is also the most economical process in both capital cost per ton of installed capacity and production cost per ton of end product.

The term 'petroleum products' used in this connection includes natural gas, refinery gas, heavy fuel, oil residues and various other liquid petroleum fractions. The conversion process used, and also the costs, vary considerably according to which of these is used as the source of hydrogen. This is because as we pass from a solid such as coal to natural gas the proportion of the (useful) hydrogen as compared with the (useless) carbon becomes higher. Other things being equal, therefore, the costs of production decrease from heavy fuel oils (10 of carbon to 1 of hydrogen) through the lighter fractions (6:1), to methane, the principal constituent of natural gas (3:1), which provides the lowest production cost figures.

This is especially significant when one realises that in the Middle East alone not less than 300,000 million cu. ft. of natural gas from the oil fields is discharged annually into the atmosphere and uselessly burnt. This is equivalent to some 5 million tons of fertiliser nitrogen. As the oil resources of the Middle East develop, this potential will increase further, to say nothing of the enormous reserves still being discovered in North Africa, and in Latin America.

The precise process followed for the 're-forming' of petroleum products depends on the raw material or 'feedstock' as it is usually called. In general, the process depends on the reaction of the raw material with steam and oxygen, which produces a mixture of gases containing mostly hydrogen, carbon dioxide and nitrogen in various proportions. This mixture is cleaned and purified to produce 'Synthesis gas' from which ammonia is made.

Much of the capital cost involved in plant for this process is due to the need to employ high temperatures and sometimes high pressures, requiring complex and costly equipment and materials.

2 Ammonia Synthesis

The purified mixture of three parts of hydrogen with one nitrogen is passed to a synthesis chamber. Synthesis is carried out at pressures ranging from 100 to 1,000 atmospheres, and within the temperature range 400–650°C. With modern equipment, about 18% of ammonia is made at each pass of the mixture through the converter. The unconverted gas is recycled through the converter, whilst at the same time make-up gas (unconverted) from the synthesis gas plant is introduced into the system by the main compressors. Synthesis chambers capable of making up to 350 tons of ammonia a day are now in use. The ammonia is stored as a liquid or gas, or can be piped direct to some other part of the plant. In any event, if intended for fertiliser production, it is then used for one or other of materials already mentioned.

3 Making the Final Product

Apart from its direct use, at present confined to a few countries, ammonia provides the nitrogen in four main groups of fertilisers in common use.

(i) *Ammonium sulphate.* Still the most widely used of all nitrogenous fertilisers, this is made usually by one of two methods. The first of these, the direct reaction of ammonia with sulphuric acid, is almost universal where sulphur supply presents no problem. The availability of sulphur is therefore a matter of importance if this process is to be considered. In operating the process, anhydrous ammonia is reacted with sulphuric acid in a reactor vessel under controlled temperature conditions, and a solution of ammonium sulphate is formed. From the reactor, the ammonium sulphate solution flows to a crystalliser, from the bottom of which the crystals are taken off and centrifuged.

The principal sources of supply of sulphur for this process are native sulphur, iron pyrites and other metal sulphide ores, natural gas and various petroleum products. The major countries with deposits of native sulphur are USA,, Italy, Japan, Mexico and according to recent discoveries, Iraq. The other sources of this element are widely distributed throughout the world; France in particular exports sulphur extracted as an impurity from natural gas.

The second process for producing ammonium sulphate is based on reaction of ammonium carbonate with calcium sulphate, which occurs naturally as either anhydrite or gypsum. Anhydrous ammonia is first reacted with carbon dioxide, usually obtained at an earlier stage in the ammonia synthesis process, to form ammonium carbonate. This is piped into the reaction vessel as a liquid, the calcium sulphate being usually added as a finely ground powder. The reaction gives a suspension of calcium carbonate in ammonium sulphate liquor. The calcium carbonate is filtered off and used as the raw material, usually, in a cement plant, which is thus a normal adjunct of a fertiliser plant using this process. The ammonium sulphate is crystallised out, and eventually stored until required for packaging as fertiliser.

An alternative method is to make sulphuric acid by treating anhydrite or gypsum first, and then to proceed with the same reaction as described for the first of the above two processes.

(ii) *Ammonium nitrate.* This is produced by the treatment of anhydrous ammonia with nitric acid. The process has the advantage that no additional raw material is required after the anhydrous ammonia has been produced. Roughly 55% of that produced in the synthesis plant is burnt in an ammonia oxidation plant to produce nitric acid. This acid is used in turn to nitrate the remaining 45% of the ammonia to produce ammonium nitrate.

Ammonium nitrate is an awkward material to handle, since it takes up moisture to become first a paste and then caking into a hard mass, which may be inflammable or even explosive. For this reason the raw ammonium nitrate is often mixed with chalk, to form 'nitro-chalk', which is non-inflammable but which has a much lower nitrogen content. Since the bulk for any given quantity of nitrogen is greater, distribution and transport costs will be higher.

Ammonium nitrate is now sometimes 'prilled', with an outer covering of diatomaceous earth which adds little to the weight, prevents its picking up moisture and also provides a very conveniently handled material. This process, however, again adds to the cost of the final product.

(iii) *Urea.* Urea is produced by reacting anhydrous ammonia with carbon dioxide, which as already indicated, is usually available from the ammonia production process. High pressures and temperatures are needed in this reaction, which produces great heat, of which use is made in evaporating the urea to a solid product.

Urea is produced in crystalline form, or can be made up as 'prills' as in the case of ammonium nitrate. It is becoming increasingly popular, mainly because of its high nitrogen content, and its good storage and handling properties. Its manufacture, however, is more expensive than that of the fertilisers made direct from ammonia, since it entails a second operation involving high temperatures and pressures, the plant for which is also costly. Nonetheless, many of the plants now planned or building, for fertiliser production in the developing countries, have urea as their end product. At high temperatures and humidities, however, it may deliquesce and may then need specially packing in moisture-proof bags.

Calcium Nitrate and Calcium Cyanamide

Both these nitrogenous fertilisers have declined in popularity in recent years, although with new technical developments they may come back into favour somewhat. There are two distinct ways of making calcium nitrate. The first of these is by the neutralisation of nitric acid (made as described in the section above on ammonium nitrate) with limestone. This is done as a continuous process in towers built of acid-resisting brick; a solution of calcium nitrate results, from which solid granular material is produced after further treatment. The Suez fertiliser factory operates on this process.

The second method of producing calcium nitrate works on what is known as the 'flaming arc' system for nitrogen fixation. This was the first process to be used commercially for synthetic nitrogen production; for economic operation under modern conditions, it requires ample supplies of cheap electricity. This last requirement is also characteristic of cyanamide manufacture, which is based on the heating of calcium carbide and carbon together in an electric furnace. Besides its rather costly manufacture, cyanamide has certain other disadvantages, requiring rather different handling and application techniques from most other nitrogenous fertilisers. It is, for example, toxic to plants under certain conditions, and can in fact be used as a weed-killer as well as a fertiliser.

Appendix 2
Raw Materials required for the Production of Chemical Fertilisers

The raw materials listed here are those required for the production of the fertilisers most suitable for, and most likely to be used in the developing countries.

This information is intended to be used in conjunction with that available from economic and other planning units, and especially, in the case of mineral raw materials, from geological surveys. Or it may be taken as an indication of the materials required and for which surveys may need to be put in hand, before the decision to engage in domestic manufacture can finally be made. Requirements are:

I For the Production of Ammonium Sulphate

(*a*) For making ammonia synthesis gas

(i) Cheap electric power, if the hydrogen is to be produced by the electrolysis of water, and for the liquefaction of air for nitrogen production (the 'air separation' method);

OR

(ii) petroleum products, which may be natural gas, refinery gases, stabilised gas, heavy fuel oil or various residues;

OR

(iii) if the semiwater gas process is being employed, caking coal for the necessary coke production;

OR

(iv) where direct gasification is being used, non-caking coal or lignite;

OR

(v) coke-oven gas;

OR

(vi) under very exceptional circumstances, e.g. no other source of material than extensive, easily renewable forests, wood or charcoal may be employed for gas production.

Synthesis of the hydrogen and nitrogen produced by the above means provides anhydrous ammonia as the final source of nitrogen.

(*b*) For the sulphur element, when the end product is being made by the sulphuric acid process

(i) elemental sulphur

OR

(ii) pyrites or other metal sulphide ores,

OR

(iii) natural gas or other petroleum products with a high enough sulphur content;

OR

(iv) gypsum or anhydrite for making sulphuric acid, with cement as an associated product.

(*c*)

(i) Carbon dioxide, normally obtainable from the earlier synthesis-gas making stage, or else made by burning lime-stone;

(ii) Anhydrite. This mineral is the same as gypsum but of slightly different chemical composition, which allows a saving of 20% in transportation (bulk for bulk) and also some saving in processing;

(iii) Gypsum. This mineral is found in various forms, from celinite which is nearly 100% pure crystalline calcium suplhate, through a variety of other forms down to those in which impurities are such that the material ceases to be regarded as gypsum at all. Impurities may include silica, which over 7% renders the material unsuitable for processing. Salt (sodium chloride) as an impurity is objectionable as it causes corrosion. Generally speaking, gypsum for ammonium sulphate production should have purity of 90% with low silica content and not more than a trace of salt.

2 The Production of Ammonium Nitrate

(i) Anhydrous ammonia, made as described in (i) above.

(ii) Nitric acid, made by the burning of anhydrous ammonia in an ammonium oxydation plant.

3 The Production of Urea

(i) Anhydrous ammonia, made as described in (i) above.

(ii) Carbon dioxide, usually obtained from the earlier synthesis gas making stage see (*c*) (i) above.

4 The Production Calcium Nitrate

(i) Nitric acid, made as described in (2) (ii) above.

(ii) Limestone.

5 The Production of Single or Normal Superphosphate or Nitro-phosphate* Fertiliser

(i) Phosphate rock.

(ii) Sulphuric acid.

OR

(iii) Nitric acid*

OR

(iv) A combination of (ii) and (iii).

6 The Production of Triple Superphosphate

(i) Phosphatic rock.

(ii) Phosphoric acid, made by reacting phosphate rock with sulphuric acid.

7 The Production of Potassic Fertiliser

(i) Potassic brines

OR

(ii) Potassic ore.

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ODI Development Pamphlets

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