

This booklet presents guidelines for extension staff on the use of fertilizers. It explains the need for mineral fertilizers for agricultural development in support of food security and the maintenance of soil productivity. The booklet addresses the role of fertilization in plants in relation to soil characteristics. It provides general fertilizer recommendations for selected crops and contains information on soil and plant tissue testing. Practical suggestions are also offered regarding the design of fertilizer use demonstrations and extension techniques in general.

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Fertilizers and their use

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FERTILIZERS AND THEIR USE



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FERTILIZERS AND THEIR USE

A pocket guide for extension officers

Fourth edition

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
INTERNATIONAL FERTILIZER INDUSTRY ASSOCIATION

ROME, 2000

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Preface

This handbook was prepared originally for use by extension officers working for the FAO Fertilizer Programme. The first edition was published in 1965, third edition was published in 1978, reprinted in 1986.

For this new, 2000 edition, much of the 1978 text has been completely revised. Information on new technical developments and knowledge has been incorporated. The handbook explains the need for mineral fertilizers, their role in plants and the soil characteristics which are relevant to fertilization. A new section provides general recommendations for selected crops.

The chapter on “How to determine fertilizer needs” includes information on deficiency symptoms and on soil and plant tissue testing. A chapter is devoted to explaining and giving advice on laying out fertilizer demonstrations and on extension techniques in general.

The recommendations for selected crops are based largely on IFA’s “World Fertilizer Use Manual”, 1992. More detailed information is given in the Manual, which is available from IFA, Paris.* Even the much more complete information given in the Manual will often require modification by the user to take account of official fertilizer recommendations for local crops and soils.

* “World Fertilizer Use Manual”, 1992, IFA, Paris, 632 p. Web site, <http://www.fertilizer.org>, also available in CD version.

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1. Introduction

As an extension officer you are a leader in your village or community. Farmers look to you for answers and better ways of farming. The more correct your answers are the more confidence the farmers will have in you. This publication will give you the necessary information to teach farmers the proper use of fertilizers. The intention also is to show how fertilizer use should be part of an integrated programme of good agricultural practices in order to improve crop production and thus farmer's income.

Fertilizers supply nutrients needed by crops. With fertilizers you can produce more food and cash crops of better quality. With fertilizers you can improve the low fertility of soils which have been over-exploited. All this will improve the well-being of your village, community and nation.

2. Rationale for the need of fertilizers (increase of production and increase of farm income)

According to the population projections of the World Bank, the world's population will increase from 6 billion people in 1999 to 7 billion people in 2020. Perhaps, you are living in one of the countries in Africa or South Asia with the highest growth rates or a high absolute increase in the number of people. Then the consequences of the population's increase will well be known to you: all these people will also have to be housed, dressed and, above all, to be fed. Up to 90 percent of this necessary increase in food production will have to come from fields already under cultivation. The FAO estimates that during the period 1995 to 1997 about 790 million people in the developing world did not have enough to eat. The number has been falling in recent years at an average of around 8 million people per year. If the pace is not stepped up, there will still be 600 million people going hungry in 2015.

The majority of farmers active in the food crop sector of developing countries are small-scale farmers who form part of the rural poor. The issue of introducing agricultural systems and improved technologies is particularly important for them since improved productivity provides not only more food but also an income.

To summarize, farming activities have two main aims:

1. to supply the growing population of your country (or also that of other countries) with increasing quantities of food and fiber necessary; and
2. to provide a satisfactory income for the farmer and his family.

It is difficult to estimate exactly the contribution of mineral fertilizers to the increase in agricultural production, because of the interaction of many other important factors. Nonetheless, fertilizers will continue to play a decisive role, and this irrespective of which new technologies may yet emerge. It is estimated that, globally, roughly 40% (37% to 43%) of the world's dietary protein supply in the mid-1990s originated in synthetic nitrogen produced by the Haber-Bosch process for the synthesis of ammonia¹.

FERTILIZERS INCREASE CROP YIELDS

The nutrients needed by plants are taken from the air and from the soil. This publication deals only with the nutrients taken from the soil. If the supply of nutrients in the soil is ample, crops will be more likely to grow well and produce high yields. If, however, even only one of the nutrients needed is in short supply, plant growth is limited and crop yields are reduced. Therefore, in order to obtain high yields, fertilizers are needed to supply the crops with the nutrients the soil is lacking. With fertilizers, crop yields can often be doubled or even tripled. The results of many thousands of demonstrations and trials carried out on farmers' fields under the former FAO Fertilizer Programme over a period of 25 years in 40 countries showed that the weighted average increase from the best fertilizer treatment for wheat tested was about 60 percent. The yield increase varied, of course, according to region (for example due to lack of moisture), crop and country.

The efficiency of fertilizers and the yield response on a particular soil can easily be tested by adding different amounts of fertilizer to adjacent plots, and then measuring and comparing the crop yields (see Chapter 12). Such tests will also show another very important effect of fertilizer use, namely that fertilizers ensure the most effective use of land, and particularly of water. These are very important considerations where rainfall is low or crops have to be irrigated, in which case the yield per unit of water used may be more than doubled. Rooting depth of the crop may be increased (Figure 2).

¹ Smil, V. 1999. Long-range Perspectives in Inorganic Fertilizers in Global Agriculture. 1999 Travis P. Hignett Lecture, IFD, Alabama, USA.

Figure 1. Crop yields in the USA, 1930 to 1998

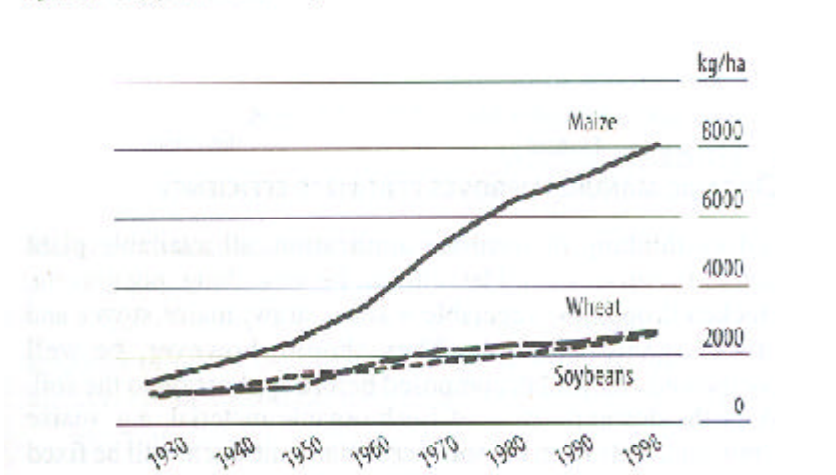
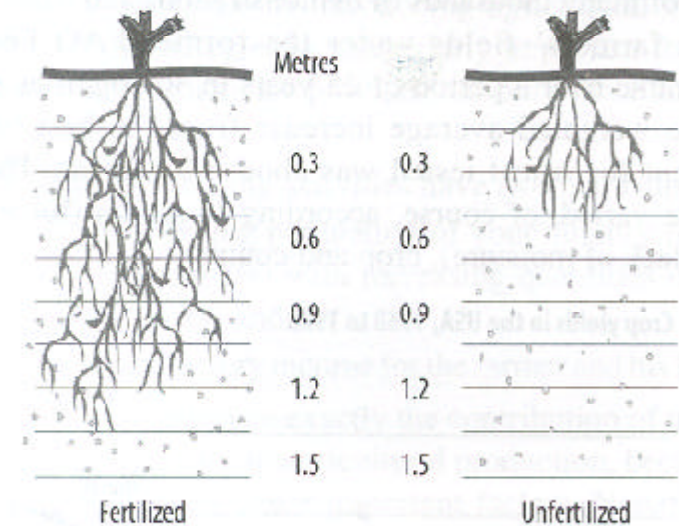


Figure 2. Rooting depth of plants under fertilized and unfertilized conditions

In low fertility soils, fertilizers will increase the depth to which roots grow.



ORGANIC MANURE IMPROVES FERTILIZER EFFICIENCY

Before thinking of fertilizer application, all available plant nutrient sources should be utilized: i.e. cow-dung, pig excreta, chicken droppings, vegetable wastes, straw, maize stover and other organic materials. They should, however, be well composted and well decomposed before application to the soil. With the decomposition of fresh organic material, e.g. maize straw, nutrients from the soil, particularly nitrogen, will be fixed temporarily; thus not being available for the subsequent crop.

Even though the nutrient content of organic manure is low and variable, organic manure is very valuable because it improves soil condition generally. The organic matter improves the soil structure, reduces soil erosion, has a regulating effect on soil temperature and helps the soil to store more moisture, thus significantly improving soil fertility. In addition organic matter is a necessary food for the soil organisms.

Organic manure often creates the basis for the successful use of mineral fertilizers. The combination of organic manure/organic matter and mineral fertilizers (*Integrated Plant Nutrition Systems, IPNS*) provides the ideal environmental conditions for the crop, as the organic manure/organic matter improves soil properties and mineral fertilizers supply the plant nutrients needed.

However, organic manure/organic matter alone is not sufficient (and often not available in large quantities) for the level of crop production the farmer is aiming at. Mineral fertilizers have to be applied in addition. Even in countries where a high proportion of organic wastes is utilized as manure and to supply organic matter, mineral fertilizer consumption has risen steadily.

3. Nutrients - their role for the plant and their sources

NUTRIENTS NEEDED FOR PLANT GROWTH

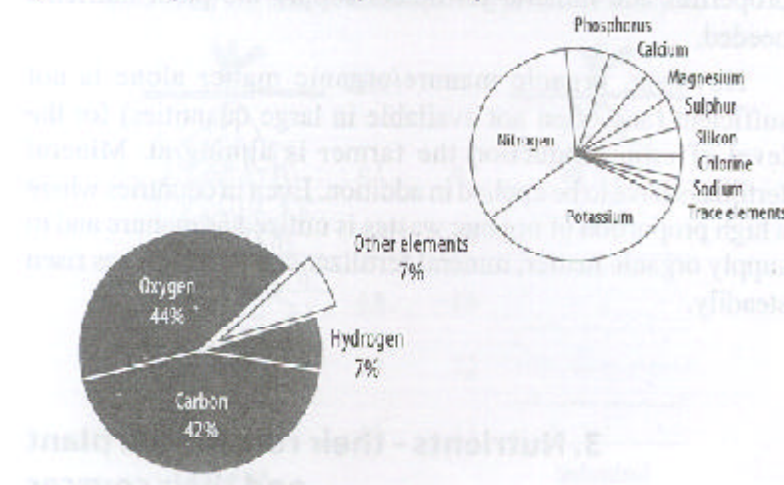
Sixteen elements are essential for the growth of a great majority of plants and these are derived from the surrounding air and soil. In the soil the transport medium is the soil solution.

The following elements are derived:

- from the air: carbon (C) as CO_2 (carbon dioxide);
- from the water: hydrogen (H) and oxygen (O) as H_2O (water);
- from the soil, fertilizer and animal manure: nitrogen (N) - leguminous plants obtain the nitrogen from the air with the help of bacteria living in the root nodules (see Chapter 4, *Rhizobium/biological N-fixation/green manuring/mycorrhizae*) - phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo) and chlorine (Cl).

These nutrients and their average percentage in the dry matter of the plant are shown in Figure 3.

Figure 3. Average elemental composition of plants



Other chemical elements are also taken up. These may be beneficial nutrients for some plants, but they are not essential to growth for all.

Fertilizers, manure or crop residues applied to the soil increase the nutrient supply of the plant. The amounts of primary nutrients needed by the principal crops are detailed in Chapter 10.

THE FUNCTIONS OF NUTRIENTS

Apart from carbon (C), which will be discussed under the heading "Photosynthesis", the plant takes up all nutrients from the soil solution. They are divided into two categories (quantitative classification):

- a) *macronutrients*, divided into ‘*primary and secondary nutrients*’; and
 b) *micronutrients or trace elements*.

Macronutrients are needed in large amounts, and large quantities have to be applied if the soil is deficient in one or more of them. Soils may be naturally low in nutrients, or may become deficient due to nutrient removal by crops over the years, or when high-yielding varieties (HYV) are grown which are more demanding in nutrient requirements than local varieties.

In contrast with macronutrients, *micronutrients or trace elements* are required in only minute amounts for correct plant growth and have to be added in very small quantities when they cannot be provided by the soil.

Within the group of *macronutrients*, which are needed for plant growth in larger amounts, the **primary nutrients** are: *nitrogen, phosphorus* and *potassium*.

Nitrogen (N) is the motor of plant growth. It makes up 1 to 4 percent of dry matter of the plant. It is taken up from the soil in the form of nitrate (NO_3^-) or ammonium (NH_4^+). In the plant it combines with compounds produced by carbohydrate metabolism to form amino acids and proteins. Being the essential constituent of proteins, it is involved in all the major processes of plant development and yield formation. A good supply of nitrogen for the plant is important also for the uptake of the other nutrients.

Phosphorus (P), which makes up 0.1 to 0.4 percent of the dry matter of the plant, plays a key role in the transfer of energy. Thus it is essential for photosynthesis and other chemico-physiological processes in the plant. It is indispensable for cell differentiation and for the development of the tissues, which form the growing points of the plant. Phosphorus is deficient in most natural or agricultural soils or where fixation limits its availability.

Potassium (K), which makes up 1 to 4 percent of the dry matter of the plant, has many functions. It activates more than 60 enzymes (chemical substances which govern life). Thus it plays a vital part in carbohydrate and protein synthesis. K improves the water regime of the plant and increases its tolerance to drought, frost and salinity. Plants well supplied with K are also less affected by disease.

The **secondary nutrients** are *magnesium, sulphur* and *calcium*. Plants also take them up in considerable amounts.

Magnesium (Mg) is the central constituent of chlorophyll, the green pigment of the leaves which functions as an acceptor of the energy supplied

by the sun: thus 15 to 20 percent of the magnesium contained in the plant is found in the green parts. Mg is also involved in enzyme reactions related to the energy transfer of the plant.

Sulphur (S) is an essential constituent of protein and also involved in the formation of chlorophyll. In most plants it makes up 0.2 to 0.3 (0.05 to 0.5) percent of dry matter. Thus, it is as important in plant growth as phosphorus and magnesium; but its role is often underestimated.

Calcium (Ca) is essential for root growth and as a constituent of cell wall materials. Though most soils contain sufficient plant-available Ca, deficiency may occur on strongly Ca-depleted tropical soils. However, the aim of Ca application is usually that of liming, i.e. to reduce soil acidity.

The **micronutrients or trace elements** are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), chlorine (Cl) and boron (B). They are part of the key substances in plant growth and are comparable with the vitamins in human nutrition. Being taken up in minute amounts, their range of optimal supply is very small. Their plant availability depends primarily on the soil reaction. Oversupply with boron can have an adverse effect on the succeeding crop.

Some *beneficial nutrients* important for some plants are *sodium (Na)* e.g. for sugar beets, and *silicon (Si)* e.g. for cereals, strengthening cereal stems to resist lodging. *Cobalt (Co)* is important in the process of N-fixation of legumes.

Some microelements can be toxic for plants at levels only somewhat higher than normal. In the majority of the cases this happens when the pH is low to very low. Aluminium and manganese toxicity are the most frequent ones, in direct relation with acid soils.

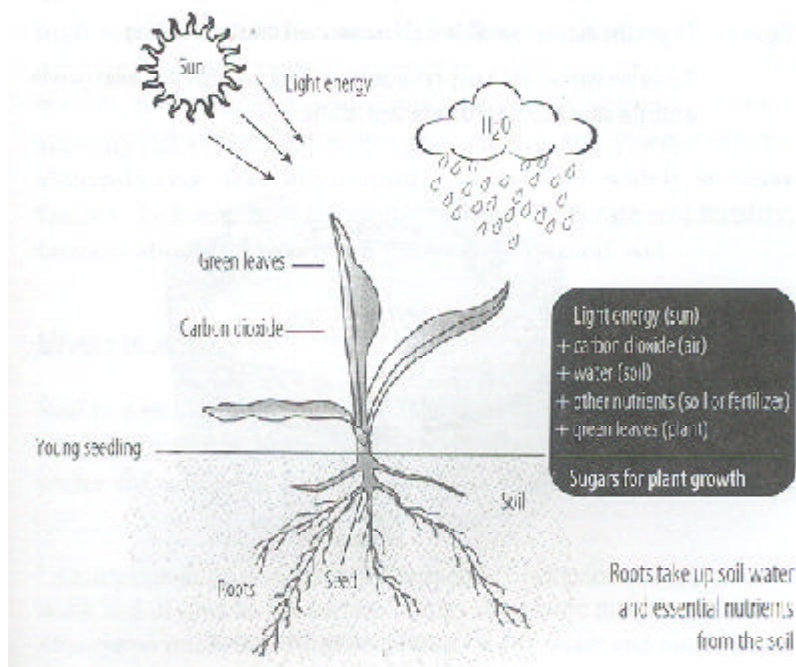
It is important to know that all plant nutrients, whether required in large or minute amounts, fulfill a specific role in plant growth and food production and that *one nutrient cannot be substituted for another*.

PHOTOSYNTHESIS

Through evaporation of large amounts of water during the day, the nutrients taken up from the soil are carried to the leaves of the plant.

It is in the green leaves that the important action takes place. This is called *photosynthesis*. This is nature’s way of transforming the inorganic elements taken up by the plant from the air and the soil into organic matter,

Figure 4. Plants make sugar from sunlight, air, water and soil nutrients



with the help of the light energy of the sun: light energy is transformed into chemical energy (Figure 4).

The fundamental importance of photosynthesis is due to the fact that carbon dioxide and water, which are energetically without value, are converted into carbohydrates (sugar), which are the basic materials for the synthesis of all other organic substances produced by the plant. Without photosynthesis there would be no life on earth.

A sufficient supply of nutrients is important for a correct functioning of this process. This is due to the fact that if one of the nutrients from the soil is not present, photosynthesis is retarded. If the nutrient is present, but insufficient in quantity, the plant develops hunger signs (deficiency symptoms), just as we do, when we do not get the right food. The growth of a plant depends on a sufficient supply of each nutrient, and the yield is limited by the nutrients which are in short supply (yield-limiting minimum factor). In agricultural practice, this is the case for nitrogen, phosphorus, potassium,

Figure 5. To get the highest possible yield no nutrient must be limiting

The factors interact and a crop can make best use of the factor that limits growth when the other factors are close to their optima.



magnesium and sulphur. Therefore, these nutrients have to be applied in the form of mineral fertilizers in order to obtain satisfactory yields.

4. Soils

The best response to fertilizer use is obtained if the soil has a high fertility level. The main factors determining soil fertility are: soil organic matter (including microbial biomass), soil texture, soil structure, soil depth, content of nutrients, storage capacity (adsorption capacity²), soil reaction and absence of toxic elements (e.g. free aluminium). Soils differ widely in these factors.

² *Adsorption* in soils refers to the attraction/adhesion of molecules of water and of ions on the surface of clay or organic matter particles. *Absorption* refers to surface penetration when water and nutrients are taken up by plant roots.

To know how to improve low or moderate soil fertility, farmers should have a basic knowledge of their soil.

WHAT IS A SOIL?

Soil is a remarkable material. It is the uppermost surface of the earth, which has been transformed slowly by decomposition under the action of weather, vegetation and man. The parent material from which a soil is formed can be the underlying rock or deposits from rivers and seas (alluvial soils) or from the wind (aeolian soils, such as loess) or volcanic ash soils.

The soil gives support to the plants by providing a permeable layer for the roots and is a kind of storehouse for plant nutrients and water. Depending on the soil composition, soils differ in their ability to supply the various plant nutrients. Contrary to frequent belief, the colour of the soil reveals very little about the soil fertility.

SOIL CONSTITUENTS, TEXTURE AND STRUCTURE

The soil is composed of mineral particles of different size, weathering products of the parent material, and organic matter, (e.g. residues from plants and animals), as well as variable amounts of water and air.

The *solid particles* are classified by size into: gravel and stones (more than 2 mm in diameter), sand (2.0 to 0.02 mm), silt (0.02 to 0.002 mm) and clay (less than 0.002 mm).

Soil texture refers to the relative proportions of sand, silt and clay contained in a soil. Depending on their texture, soils are described as sands, sandy loams, loams, clay loams, clays, etc. Soils can also be referred to as “light” (e.g. sands and sandy loams), “medium” (e.g. loams) or “heavy” (e.g. clay loams and clay) based on the workability of the soil.

Soil structure refers to the aggregation of the finer soil particles into crumbs or larger units. A well-structured moist soil contains about 50 percent of solid material by volume and 25 percent each of air and water.

Soil texture and soil structure are of special importance for soil fertility and thus for plant growth. Coarse-textured (or sandy) soils do not retain water and nutrients well. Special care has to be taken when applying fertilizers to avoid leaching of nutrients (nitrogen and potassium). Clay soils, on the other hand, can store moisture and nutrients, but may have inadequate

drainage and aeration. Breaking up these soils through liming or supplying them with organic matter will improve their structure.

Cultivation helps to increase the *soil depth* (the volume of soil accessible to the root system), but also tends to break down the soil structure. Organic matter, on the other hand, tends to build up and stabilize the soil structure, as well as the storage capacity.

In the temperate zone, where the climate is cool and humid and the decomposition of plant residues is slow, soils may become very rich in organic matter (more than 5 percent). In subtropical regions characterized by a hot, arid climate, soils are normally low in organic matter content (sometimes as little as 0.1 percent), but are often of excellent structure due to an abundance of calcium. Many soils in the tropics, where organic matter quickly disappears from the soil under the influence of climate and microbiological activity, owe their stable structure to iron and aluminium oxides.

HOW THE SOIL HOLDS NUTRIENTS AND RELEASES THEM

Decomposing rock material forms soils and releases plant nutrients. The original mineral content of the rock material and the nature and intensity of the decomposition process determine the kind and amount of nutrients that are released. Clay (clay minerals) and organic matter (to a lesser extent also iron hydroxides) retain nutrients in a plant available form, i.e. the nutrients are attached to these soil constituents (*adsorption complex*). The ability of a soil to retain a certain amount of nutrients (*storage or adsorption capacity*) determines the natural fertility of a soil.

Nutrients are carrying positive charges (+) (cations) or negative charges (-) (anions). According to these charges they are attracted by the clay minerals and the organic matter like iron pellets attracted to a magnet.

The soil water containing the nutrients in dissolved plant-available form is called the *soil solution*. The plant root can take up nutrients only in dissolved form. Therefore, they have to be released from the adsorption complex into the soil solution to be effectively plant-available.

In the soil there exists an equilibrium (balance) between the nutrients adsorbed on the soil particles and the nutrients released into the soil solution. If this equilibrium is disturbed, e.g. by nutrient uptake through the plant roots, nutrients are released from the adsorption complex to establish a new equilibrium. In this process the cations are replaced by Ca^{2+} , Mg^{2+} from the

solid pool (not dissolved nutrients) or by H^+ ions, while the anions are replaced by OH^- ($H^+ + OH^- = \text{water}$). The released nutrients move from the higher concentrated solution in the vicinity of the adsorption complex to the lower concentrated solution in the vicinity of the roots. This process of nutrient transport from the adsorption complex to the root is called *diffusion*.

In soils left uncropped for some time (fallow) the nutrients released into the soil solution accumulate. This happens in particular with nitrogen derived from the decomposition of organic matter. This can have a negative environmental effect, since in light textured soils, and under humid conditions, the major part of the accumulated nitrogen will be leached (washed out) to the ground water (or be lost due to denitrification³); accumulated potassium may also be lost by leaching.

Under semi-arid conditions nutrients (e.g. chlorides and sulphates of sodium, calcium and magnesium) may move with the evaporation water to the surface and cause salt damage to the crop grown after the fallow period. However, old, weathered soils, which have lost most of the cations, have a large surplus of negative charges. Such soils will retain applied nutrient cations carrying positive charges.

The strength of attraction by the adsorption complex differs with different nutrients (cations and anions). With cations it is primarily influenced by hydration and by the charge they carry. Aluminium (Al^{3+}) is most strongly held by the adsorption complex, followed by metallic microelements (such as iron, manganese and zinc) and potassium (K^+), ammonium (NH_4^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). With the anions, phosphate (PO_4^{3-}), which is highly immobile, is strongly held by the positively charged positions of certain clay minerals and soil constituents like calcium, iron and aluminium. To the contrary, chlorine (Cl^-) and nitrate (NO_3^-) tend to stay in the soil solution, remain mobile and move along with the soil water to the roots (mass flow) when the plants take up water, or they are washed out. Sulphate (SO_4^{2-}), like nitrate remains relatively mobile and is also liable to leaching.

When organic manure, compost and fertilizers are applied on a soil which cannot supply the nutrients necessary for optimal plant growth from their own natural content, the added fertilizers decompose and dissolve and their cations and anions behave as described above.

³ Loss of nitrogen from the soil by its conversion by bacteria under anaerobic conditions to nitrogen oxides and gaseous nitrogen; particularly in flooded, waterlogged soils: $NO_3^- \rightarrow NO_2^- \rightarrow N_2O \rightarrow N_2$

The process of nutrient adsorption and release into the soil solution is very important. In particular the difference in adsorption strength of cations and anions has an important influence on how and when to apply fertilizers (in particular nitrogen fertilizers) in order to receive the highest efficiency and to avoid pollution by leaching.

Organic matter is able to adsorb more nutrients than the comparable amount of clay. Therefore, it is important to build up organic matter especially in degraded tropical soils with less adsorbing power of the mineral component (e.g. kaolinitic soils).

SOIL ORGANISMS

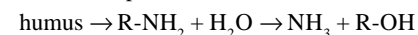
The activities of soil organisms are indispensable for high soil fertility and good crop production. Most of their activities are beneficial for the farmer, since they decompose organic matter to give humus, aggregate soil particles to give a better structure, protect roots from diseases and parasites, retain nitrogen and other nutrients, produce hormones that help plants grow and can convert pollutants that find their way into the soil.

After being mixed into the soil and ingested by earthworms, the insoluble forms of nitrogen (N), phosphate (P) and sulphur (S) contained in the particles of organic matter are converted into plant-available forms through the activities of bacteria. In addition to mobilization of plant nutrients, they play an essential role in the nitrogen cycle in the soil, e.g. ammonification⁴, nitrification⁵, denitrification and N-fixation⁶.

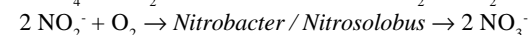
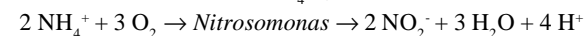
Most soil fauna and flora live aerobically, i.e. they need oxygen from the air. However, some species live anaerobically (see denitrification, footnote 3).

The all-important element for the great majority of soil organisms is carbon - (C) (carbon dioxide is derived from the carbonic acid in the organic matter

⁴ For example, ammonia from amino acids:



⁵ Bacterial conversion of NH_4^+ (from ammonification or from fertilizers) into NO_3^- :



It is assumed that during the process of nitrification considerable losses of nitrogen also occur in form of environmentally important gases, such as N_2O and NO .

⁶ See Rhizobium / biological N-fixation.

of the soil). The level of carbon dioxide present in a soil is a measure of the activity of soil organisms.

Adequate humidity and a soil pH approximately between 5 and 6 (as well as a temperature between 15 and 35°C) and sufficient organic matter (as source of carbon and energy) give optimum conditions for soil organisms.

The farmer can support their beneficial activities through:

- maintaining good aeration, a satisfactory water storage capacity and good drainage;
- trying to keep the soil pH at an optimum level (pH 5 to 6), through the use of lime in moderate quantities and by avoiding extreme changes of pH;
- providing an abundant supply of organic matter to the soil;
- providing a soil cover of plants or mulch to reduce erosion and conserve moisture; and
- avoiding indiscriminate use of chemicals which may damage the equilibrium in the soil and result in crop damage.

RHIZOBIUM / BIOLOGICAL N-FIXATION / GREEN MANURING / MYCORRHIZAE

Leguminous crops (e.g. pulses, peas, soybeans, clovers, alfalfa, and vetches) are an important source of nitrogen. Living in symbiosis with *Rhizobium* bacteria, they fix the nitrogen from the air (N₂) in the nodules of the plants' roots.

The leguminous plants supply the necessary energy, water and nutrients to the microorganisms and receive in return the nitrogen the microorganisms produce. Under favourable conditions the quantities of nitrogen fixed through *Rhizobium* bacteria vary between 15 to 20 kg/ha N on average, with a maximum up to 200 kg/ha N. An average level of 15 to 20 kg N/ha is very low but may be of interest to small-scale farmers who cannot afford to buy the necessary quantities of nitrogen fertilizer or who lack credit facilities.

Leguminous plants prefer calcareous soils and will not grow satisfactorily on acid soils. In the case of acid soils, liming is necessary before planting a leguminous crop. The soil should also be well supplied with plant-available phosphorus and potassium.

Legumes are deep rooting plants; they improve the soil structure and bring up nutrients from deeper soil layers.

When a leguminous crop is planted for the first time in a field, or when it had not been grown for several years on the field, the inoculation of the legumes' seed with the correct *Rhizobium* type is a necessity for satisfactory N-fixation. Since a specific crop needs a specific type of *Rhizobium* bacteria, the local experimental station should be asked for detailed information. In these cases a moderate nitrogen dressing will support their development.

After harvesting or cutting, and even more so when the crop is used as *green manure*, i.e. a green crop which is ploughed undecomposed into the soil, a large part of the fixed nitrogen will stay with the decomposing root mass in the soil. Under such circumstances, the farmer is strongly advised to plant a succeeding crop as soon as possible, to make use of the remaining N released into the soil solution and hence to avoid leaching of nitrogen to the groundwater or emission to the air (see Chapter 4 *How the soil holds nutrients and releases them*). Non-leguminous crops can also, of course, be used as green manures.

Crops which grow rapidly even on poor soils and produce an abundant mass of green leaves and tops can be used as a green manure or cover crop. Cover crops differ from green manures in that they are not ploughed into the soil, but are used as mulch. Cover crops are appropriate for regions with low rainfall, because the crop planted as a cover crop provides organic matter to the soil. Cover crops may also be attractive for farmers with only a small area of land.

The roots of most cultivated crops are infected with another type of soil organisms, the mycorrhizal fungi. They form a network of mycelium threads on the roots and thus extend the surface area of the roots. The beneficial effect of mycorrhizae for the plant is noticeable in increased nutrient uptake, especially phosphorus, and protection against attacks from soil pests and diseases.

In fields planted with flooded rice, the aquatic fern *azolla* (*Anabaena azolla*), which lives in association with nitrogen fixing blue-green algae, is used as an efficient source of nitrogen. Under favourable conditions one third to one half of the recommended rate of nitrogen can be saved through this kind of green manuring.

SOIL REACTION AND LIMING

Soil reaction is another important factor in soil productivity/fertility and plant growth. pH units indicate soil reaction. A pH of 7 means that the soil is

chemically neutral; lower values mean that the soil is acidic (with an excess concentration of hydrogen ions (H^+) at the adsorption complex); and higher values indicate alkalinity (a predominance of calcium (Ca^{2+}) and/or sodium (Na^+) cations).

The pH value of normal, productive soils ranges between 4 and 8 and has to be regarded as a specific characteristic of the soil. Its optimum is determined by the stage of development of the soil and should not be altered excessively.

In the humid tropics, soil pH tends to be rather low, i.e. acidic, because of the leaching effect of heavy rainfall. In the dry subtropics, soil reaction may be higher than 7, i.e. alkaline due to the accumulation of alkaline elements such as calcium and sodium.

Acid soils are brought toward a less acid or neutral reaction through liming. The lime requirements of a soil can be estimated by pH soil tests. To correct soil acidity ground limestone ($CaCO_3$) is one of the most effective and least costly materials. Dolomitic limestone ($CaCO_3 \cdot MgCO_3$) also supplies magnesium where it is needed. Other materials to correct soil acidity are, marl ($CaCO_3$), wood ashes and bone meal ($Ca_3(PO_4)_2$). On acid soils, the use of nitrogen and phosphorus fertilizers containing Ca^{2+} as cations should be given preference. Liming has the positive effect of precipitating the free aluminium, thus controlling Al toxicity. A negative effect can be that liming to pH 7 can cause micronutrient deficiency (except molybdenum, Mo) in tropical soils. Whenever possible, lime and fertilizers (with macro- or micronutrients) should not be applied at the same time, but at certain intervals.

In soils with a high pH (alkaline soils), acid-forming fertilizers such as sulphate of ammonia, ammonium sulphate-nitrate, ammonium nitrate or urea should preferably be used in order to correct alkalinity. On saline/sodic soils gypsum is a useful soil amendment for the removal of sodium (Na).

SOIL AND GOOD AGRICULTURAL PRACTICES

For efficient soil management a farmer must improve the desirable soil characteristics by means of good agricultural practices. These practices should be technically sound, economically attractive, environmentally safe, feasible in practice and socially acceptable, in order to ensure sustainable and high agricultural productivity. The important components of good agricultural practices are:

- selection of quality seed of a high yielding variety;

- choosing the best time and an appropriate method of sowing, with optimum seed rate and plant population;
- an appropriate choice of fertilizers, with balanced rates, method and time of application;
- replenishment of organic matter;
- maintenance of an appropriate soil reaction (pH);
- appropriate measures against possible insect pests and diseases;
- weed and soil erosion control;
- provision of irrigation and drainage; and
- adoption of appropriate management practices.

5. Fertilizer recommendations for selected crops according to their needs

Different crops need different amounts of nutrients. Furthermore, the quantity of nutrients needed depends largely on the crop yield obtained (or expected). The different amounts of nutrients removed by medium and good yields of some of the world's crops are given in Table 1.

Different varieties of a crop will also differ in their nutrient requirements and their response to fertilizers. A local crop variety will not respond so well to fertilizers as an improved variety; e.g. hybrid maize will often give a much better response to fertilizers and produce much higher yields than local varieties.

Although the figures given in Table 1 are a good first indication of the plant nutrient needs at the respective yield level, other factors have to be taken into account in order to determine the real fertilizer requirement: e.g. the soil nutrient reserves as well as a possible unavailability of the applied nutrients to the plant roots due to fixation, leaching or other losses. Therefore, the nutrient requirements are in general higher than the nutrient removal by crops.

Table 1. Nutrient removal by crops¹⁾ in kilograms per hectare

	Yield kg/ha	Nitrogen N	Phosphorus P ₂ O ₅	P P	Potassium K ₂ O	K	Ca	Mg	S
Rice (paddy)	3 000	50	26	11	80	65	-	-	-
	6 000	100	50	22	160	131	19	12	10
Wheat	3 000	72	27	12	65	54	-	-	-
	5 000	140	60	26	130	108	24	14	21
Maize	3 000	72	36	16	54	45	-	-	5
	6 000	120	50	22	120	100	24	25	15
Potatoes	20 000	140	39	17	190	158	2	4	6
	40 000	175	80	35	310	257	-	23	16
Sweet potatoes	15 000	70	20	9	110	91	-	-	-
	40 000	190	75	33	390	324	28	9	-
Cassava	25 000	161	39	17	136	113	44	16	-
	40 000	210	70	31	350	291	57	-	-
Sugar cane	50 000	60	50	22	150	125	-	-	-
	100 000	110	90	39	340	282	-	50	36
Onions	35 000	120	50	22	160	133	-	-	21
Tomatoes	40 000	110	30	13	150	125	-	17	54
Cucumber	35 000	60	45	20	100	83	-	36	-
Alfalfa (hay)	7 000	215 ²⁾	60	26	130	108	164	19	15
Soybeans	1 000	160 ²⁾	35	15	80	66	-	-	-
	2 400	224 ²⁾	44	19	97	81	-	18	-
Beans	2 400	155 ²⁾	50	22	120	100	-	-	-
Groundnuts	1 500	110 ²⁾	15	7	42	35	19	11	12
Cotton (-seed + -lint)	1 700	73	28	12	56	46	6	4	5
	5 000	180	63	27	126	105	-	35	30
Tobacco (dry leaf)	1 700	90	22	10	129	107	48	6	4

- Data not available

1) Plant nutrients contained in the above-ground plant part and the below-ground harvested portion where appropriate at the indicated yields. Note that these are not the same as fertilizer requirements.

2) Leguminous crops can get most of their nitrogen from the air.

Source: Fertilizer Industry Advisory Committee, IFA.

Below, some fertilizer recommendations are given according to the crop needs, based on the experience of selected countries and published internationally⁷.

Rice

Lowland rice in the Philippines, recommended rates of nutrients: 80 to 100 kg/ha N, 30 to 50 kg/ha P₂O₅ and 30 kg/ha K₂O.

Lowland rice, high yielding, improved variety in India: 125 kg/N, 30 kg/ha P₂O₅ and 50 kg/ha K₂O. The nitrogen fertilizer should be applied in two, or even better three, split applications: 1/3 basal, 1/3 at tillering, 1/3 at panicle initiation.

Wheat

Irrigated wheat crop in India: 80 to 120 kg/ha N, depending on the previous crop, 40 to 60 kg/ha P₂O₅ and K₂O based on soil test data (where not available 40 kg/ha K₂O are recommended). With limited irrigation: 60 kg/ha N, 30 kg/ha P₂O₅ and K₂O based on soil test data (where not available 20 to 30 kg/ha K₂O is recommended).

Half the nitrogen and all the P₂O₅ and K₂O before sowing; the remaining half of N top-dressed at first irrigation.

Maize

Hybrid varieties in Indonesia: 120 to 180 kg/ha N, 45 to 60 kg/ha P₂O₅ and 30 to 60 kg/ha K₂O. Local varieties: 45 to 90 kg/ha N, 30 to 45 kg/ha P₂O₅ and up to 30 kg/ha K₂O.

N in two or three split applications, all the P₂O₅ and K₂O with the first N application at sowing.

Sorghum and Millets

Under wet, medium yield conditions: 20 to 60 kg/ha N, 20 to 40 kg/ha P₂O₅ and 20 to 50 kg/ha K₂O. Under irrigated, high yield conditions: 50 to 100 kg/ha N, 40 to 60 kg/ha P₂O₅ and 50 to 100 kg/ha K₂O.

About half of the N and all the P₂O₅ and K₂O applied at sowing, the remainder of the N in one or two split applications at shooting or beginning of flowering.

⁷ Most of the data given here are adapted from the 'IFA World Fertilizer Use Manual', IFA, Paris 1992.

Potato

Recommendations given in Columbia: 85 kg/ha N, 175 kg/ha P₂O₅ and 40 kg/ha K₂O; in the Dominican Republic: 95 kg/ha N, 95 kg/ha P₂O₅ and 95 kg/ha K₂O; and in Mauritius: 78 kg/ha N, 78 kg/ha P₂O₅ and 120 kg/ha K₂O. All the N, P₂O₅ and K₂O - preferably as band placement (but no contact with tubers) - before planting.

On light soils only, half of the N on the seedbed and half at tuber initiation. Depending on soil conditions, instead of muriate of potash, potassium sulphate or potassium magnesium sulphate may give some benefit.

Cassava

Recommendation given in Thailand: 90 kg/ha N, 45 kg/ha P₂O₅ and 95 kg/ha K₂O. Generally given as a basal NPK dressing in short bands near the planting stake and as one or two top-dressings of N and K₂O two to four months after planting.

Field beans

Improved varieties on medium and heavy soils in Egypt: 36 kg/ha N, 72 kg/ha P₂O₅ and two top-dressings after sowing, each of 57 kg/ha K₂O. The N is applied to the seedbed to aid establishment. However, where *Rhizobium leguminisarum* is present in the soil, no N is necessary. Where *R. leguminisarum* is not present, seeds should be inoculated before sowing.

Cucumbers

On light sandy soils, semi-arid area in Senegal: in addition to organic manure, 130 kg/ha N, 95 kg/ha P₂O₅ and 200 kg/ha K₂O. One third of the N and K₂O and all the P₂O₅ is applied before planting, one third at 30 days and one third at 50 days after planting for both N and K₂O.

Onions

On acid acrisols in Nigeria at least two weeks before transplanting 2 t/ha CaO are applied. 20 days after transplanting 75 kg/ha N, 70 kg/ha P₂O₅ and 180 kg/ha K₂O are applied; and about 35 days after transplanting another 75 kg/ha of N.

Sugar cane

Recommendations given for the subtropical region in India: 100 to 250 kg/ha N (three split applications per year after planting), 60 kg/ha P₂O₅ (as per requirement) and 80 kg/ha K₂O.

Banana

For good average yields in Côte d'Ivoire (acid soils) the recommendations, in addition to liming, are 300 to 500 kg/ha N, 30 to 100 kg/ha P₂O₅ and 600 to 1200 kg/ha K₂O. Usually hand-spread within a circle of 1.0 to 1.5 m diameter around the pseudo-stem in several split applications.

Cotton

For the provinces in the Nile Delta of Egypt, in addition to organic manure, the recommendations are 145 to 180 kg/ha N, 35 to 70 kg/ha P₂O₅ and where needed 55 to 60 kg/ha K₂O. N is given in 2 split applications at thinning one month after planting, and one month later. P₂O₅ and K₂O are applied at pre-planting or together with one half of the N also at thinning.

Cotton plants are sensitive to soil acidity, therefore liming should be carried out some months before planting (preferably as dolomitic limestone, which also supplies needed magnesia, Mg).

For more detailed recommendations on how to apply mineral fertilizers see Chapter 9.

The fertilizer recommendations given above demonstrate the importance of respecting regional growing conditions, i.e. soil type, climate, rainfall, irrigation, crop varieties etc. Optimum mineral fertilizer recommendations for your local region should be determined in cooperation with your local experimental station and with leading farmers. How this can be done is explained in Chapter 10.

6. The importance of balanced fertilization

Nitrogen being '*the motor of plant growth*' will usually show its efficiency soon after application: the plants develop a dark green colour and grow more vigorously. However, unbalanced, excess nitrogen in cereals / rice may result in lodging, greater weed competition and pest attacks, with substantial losses of cereal or paddy production (in other crops it will decrease quality, particularly storage ability). In addition, the nitrogen not taken up by the crop is likely to be lost to the environment.

Where the financial resources of the farmer are limited or no credit facilities are available and if his tenure of the land is insecure, and urea, for example, is offered on the market at a comparatively attractive price per unit of nitrogen, the farmer - expecting an immediate and evident return - will supply his crops exclusively with nitrogen. In the short term this is a logical decision. Consequently, most of the increase in world nitrogen consumption has been accounted for through the use of urea⁸.

Such a one-sided or unbalanced preference may be justified on soils rich in plant-available phosphate, potassium and all other necessary secondary and microelements. However, higher yields will also take up greater amounts of the other nutrients (mainly phosphorus and potassium) from the soil. Thus increased yields through application of nitrogen alone deplete the soils of the other plant nutrients. IRRI research suggests that under intensive rice-rice cropping systems the demand for phosphorus and potassium increases over time. Research showed that, without phosphorus and potassium application, nitrogen efficiency declined, whereas when all nutrients were applied together phosphorus and potassium efficiency increased steadily, thereby indicating interactions between these nutrients⁹. Thus, on all depleted soils, which have been cultivated for a long time, in addition to unavoidable losses¹⁰, unbalanced fertilization in favour of nitrogen is not only contrary to good agricultural practices, it is also a waste of labour and capital, environmentally detrimental and not sustainable.

Therefore, for optimum fertilizer use efficiency, balanced fertilization is necessary. Plants are like people: a balanced diet is needed and it is not

⁸ From 1973/74 to 1997/98 urea consumption has increased from 8.3 million tonnes N to 37.6 million tonnes N, from 22% to 46% of total N consumed. Most of the increase of phosphate consumption has been accounted for by diammonium phosphate. The potash market is dominated by potassium chloride. The preference given to high-concentration straight fertilizers, particularly in the case of nitrogen with urea, has resulted in many developing countries in unbalanced fertilizer use in favour of nitrogen, especially in Asia: the global average ratio N:P₂O₅:K₂O fell from 1:0.6:0.5 in 1973/74 to 1:0.4:0.3 in 1998/99 (Source: IFA, 1999).

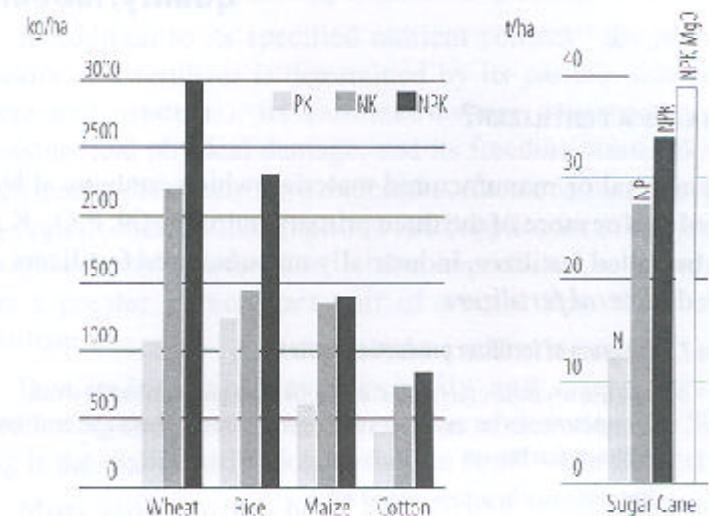
⁹ S.K. De Datta, 'Sustainable rice production: challenges and opportunities'. In: International Rice Commission Newsletter, Progress assessment and orientation in the 1990s, FAO, Rome 1994.

¹⁰ In addition to removal through the crops, nutrients are further lost through leaching, erosion, soil fixation, etc. Nutrient losses caused by denitrification, volatilization and naturally occurring leaching are unavoidable, even with the best agricultural practices.

enough to eat a surplus of one kind of food. If the diet is unbalanced, living beings eventually fall ill. The same happens to plants. Moreover, plants cannot move around to find the nutrients they lack. Therefore, conditions must be made as favourable as possible in the immediate surroundings where they grow. An effort should be made to keep the soil pH at an optimum level by liming or application of gypsum (on alkaline soils), and to supply organic matter, water and a balanced fertilization.

It has been demonstrated that primary, secondary or micronutrients which are the most deficient in the soil limit the yield and/or affect the quality; they cannot be substituted by any other nutrient. Therefore, for good agricultural practices, balanced fertilization primarily means a supply of nitrogen, phosphorus and potassium in line with soil reserves, the requirements and expected yield of the crop, with the addition of magnesium, sulphur and microelements where necessary. Figure 6 clearly demonstrates the effect of balanced fertilization on results from Pakistan.

Figure 6. Effect of balanced fertilization on crop yields - Pakistan



Note

The present overall average ratio between the nutrients applied in Pakistan, N : P₂O₅ : K₂O is 1 : 0.26 : 0.02.

Source: M.I. Bajwa and A. Qidwai, 1985. IFA Regional Agricultural Meeting, New Delhi.

Furthermore, fertilizer use integrated into good agricultural practices should provide the needed plant nutrients in sufficient quantities, in balanced proportions, in available form and at the time when the plants require them¹¹. The easiest way to achieve this is through the use of NPK complex fertilizers containing the guaranteed grade/formula of primary nutrients in each granule. These fertilizers also permit an even application due to their stable granule quality and their consistent granule size¹².

NPK complex fertilizers are usually more expensive than mixtures/blends. However, under practical farm conditions, the loss in crop yield and quality can easily be much higher than that of the savings obtained through buying and applying products of lower quality. The farmer should be aware of these consequences, because the most persuasive argument for farmers in developing as well as in developed countries is still the return the farmer will receive through the application of fertilizer to his crop during the season of application. Therefore, in any promotion of balanced plant nutrition, the challenge is to demonstrate the economic benefits of balanced fertilization to the farmer.

7. Fertilizers, their appearance, quality, labeling

WHAT IS A FERTILIZER?

Any natural or manufactured material, which contains at least 5% of one or more of the three primary nutrients (N, P₂O₅, K₂O) can be called fertilizer. Industrially manufactured fertilizers are called *mineral fertilizers*.

The appearance of mineral fertilizers is very varied. Depending on the process of manufacture, the particles of mineral fertilizers can be of many different sizes and shapes: granules, pellets, 'prills', crystals or coarse/

¹¹ This, of course, also depends on an economical and efficient fertilizer marketing and delivery system, including regional warehousing and/or local buffer stocks!

¹² Uneven fertilizer spreading means over-supply on some parts of the field (=pollution) and under-supply on other parts of the field (=reduction in yield).

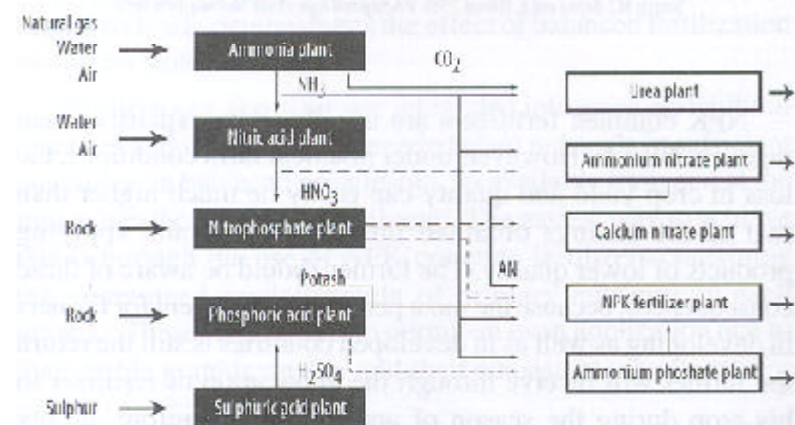
Figure 7. Diagram of fertilizer production routes

Ammonia is synthesized from hydrocarbons (mostly natural gas but also naphtha or coal), atmospheric nitrogen and steam. Carbon dioxide resulting from this conversion can be combined with ammonia to form urea.

Nitric acid is made by oxidizing ammonia with air.

Sulphuric acid is produced by burning sulphur in air. It is reacted with rock to produce phosphoric acid.

Potash salts from natural deposits are the source of K.



compacted or fine powder (dust). Most fertilizer is supplied as solids. Liquid and suspension fertilizers are important mostly in North America.

In addition to its specified nutrient content¹³ the *physical quality* of a fertilizer is determined by its particle size range (screened products), its hardness/density, its resistance to moisture and physical damage, and its freedom from caking - high quality fertilizers have a special surface treatment/coating. As regards transport, storage and field application, the specific weight/density of a fertilizer is also important. Urea normally has a greater volume per unit of weight than most other fertilizers.

¹³ Usually the nutrient content is guaranteed. Tolerance limits from the guaranteed content are normally permitted, due to large scale production and possible errors when taking samples.

Due to its simplicity, flexibility and safety (against weathering and greater losses as well as adulteration) the 50-kg bag is the main distribution method to small-scale farmers¹⁴.

Most governments have established strict regulations through the Ministry of Agriculture or other authorities, on the type of fertilizer bags (or containers) in which mineral fertilizers are delivered to the farmer and how they have to be labeled. The information on the label comprises the nutrient (primary and/or secondary and/or micronutrients), the contents of the fertilizer (in most cases also the nutrient forms) and indicating the analysis or grade.

The primary nutrients are commonly expressed as percent N-P₂O₅-K₂O (sometimes with the addition of Mg-S-trace elements). They are always given in this sequence. Thus, in an 17-17-17 formula, the first number is the percentage of N, the second number the percentage of P₂O₅¹⁵ and the third number the percentage of K₂O¹⁵.

The label also indicates the weight of the bag, often gives recommendations for correct handling and storage, and the name of the producer or dealer of the fertilizer¹⁶. Most fertilizers also have a brand name, which will be printed on the fertilizer bag.

For example, two 50-kg bags of fertilizer of a 17-17-17 *grade* contain 17 kg N, 17 kg P₂O₅ and 17 kg K₂O. In contrast to the term *grade*, the *nutrient ratio* refers to the relative proportions of the nutrients to each other: a 17-17-17 *grade* would have a 1:1:1 ratio of N-P₂O₅-K₂O, while a 12-24-12 *grade* would have a 1:2:1 ratio.

It is important to know the fertilizer analysis or grade to calculate the correct amount of fertilizer for the necessary rate of nutrients to be applied per hectare. For example, a farmer needs eight 50-kg bags (400 kg) of the *grade* 15-15-15 to apply a rate of 60-60-60 per hectare.

¹⁴ The costs of the bag and bagging are saved with bulk delivery. However, bulk delivery calls for a minimum tonnage of fertilizer, and has to be well managed to avoid possible high losses in transport and storage.

¹⁵ The terms 'P₂O₅' and 'K₂O' are conventionally used to express the fertilizer nutrients 'phosphate' or 'phosphorus' and 'potash' or 'potassium'. They are the oxides of the elements P and K. (see Annex: Conversion factors)

¹⁶ In the case of ammonium nitrate (33-34.5% N) the degree of hazard has also to be indicated.

FERTILIZER GRADES

Fertilizers that contain only one primary nutrient are referred to as *straight fertilizers*. Those containing two or three primary nutrients are called *multinutrient fertilizers*, sometimes also binary (two-nutrient) or ternary (three-nutrient) fertilizers.

Straight fertilizers

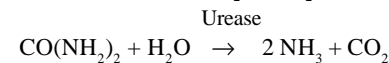
Some of the most important (as well as the regionally important) straight fertilizers are as follows:

Urea, with 46 percent N, is the world's major source of nitrogen due to its high concentration and its usually attractive price per unit of N. However, its application requires exceptionally good agricultural practices to avoid, in particular, evaporation losses of ammonia to the air. Urea should be applied only when it is possible either to incorporate it into the soil immediately after spreading or when rain is expected within the few hours following the application¹⁷.

Ammonium sulphate (AS) with 21 percent of N (in the form of ammonia) is not as concentrated as urea. However, it contains, in addition to N, 23 percent sulphur, a plant nutrient that is of growing importance. It is used by preference on irrigated crops and where sulphur has to be applied. The same holds true for *ammonium sulphate nitrate* (ASN) with 26 percent of N (about 2/3 in the form of ammonia and 1/3 in the form of nitrate) and 13 to 15 percent of sulphur.

Calcium ammonium nitrate (CAN) with up to 27 percent of N (equal parts of ammonia and nitrate nitrogen) is a fertilizer of preference on crops in semi-arid regions of the subtropics.

¹⁷ The amide-N (the form of nitrogen in urea) is transformed (hydrolyzed) relatively rapidly through the activity of the enzyme urease, which is ubiquitous in surface soils, to ammonia, CO₂ and H₂O:



Even at relatively low temperatures the transformation of amide-N to ammonium-N is completed within one to three days, under tropical and subtropical conditions within few hours. Where urea is not incorporated into the soil, but left on the soil surface, substantial evaporation losses of ammonia will occur, particularly on alkaline soils (soils with a high pH value). Where it is incorporated - and a superficial incorporation is sufficient - the ammonia is attracted (adsorbed) as NH₄⁺ on the clay and organic matter particles of the soil and thus protected against evaporation losses.

Table 2. Some important fertilizers

Common names (formulae)	N	Grade or analysis in percent			S
		P ₂ O ₅	K ₂ O	Mg	
Nitrogen fertilizers					
Ammonium sulphate (NH ₄) ₂ SO ₄	21	0	0	-	23
Ammonium nitrate NH ₄ NO ₃	33-34.5	0	0	-	-
Ammonium nitrate-limestone NH ₄ NO ₃ +CaCO ₃ (calcium ammonium nitrate)	20.5-26	0	0	-	-
Urea CO(NH ₂) ₂	45-46	0	0	-	-
Ammonium sulphate-nitrate NH ₄ NO ₃ ·(NH ₄) ₂ SO ₄	26	0	0	-	15
Phosphate fertilizers					
Single superphosphate CaH ₂ (PO ₄) ₂ + CaSO ₄	0	16-20	0	-	12
Triple or concentrated superphosphate CaH ₂ (PO ₄) ₂	0	46	0	-	-
Ground rock phosphate (mineral phosphate)	0	20-40	0	-	-
Potash fertilizers					
Muriate or chloride of potash KCl	0	0	60	-	-
Sulphate of potash K ₂ SO ₄	0	0	50	-	18
Sulphate of potash-magnesia K ₂ SO ₄ ·2MgSO ₄	0	0	26-30	5-7	16-22
Magnesium fertilizers					
Kieserite MgSO ₄ ·7H ₂ O	-	-	-	16	22
Calcined kieserite MgSO ₄ ·H ₂ O	-	-	-	20	27
Sulphur fertilizers					
All fertilizers containing S as anion	-	-	-	-	according to formal.
Gypsum CaSO ₄ ·2H ₂ O	-	-	-	-	16-18
Some fertilizers with regional importance					
Sodium nitrate NaNO ₃	16	0	0	-	-
D1-calcium phosphate Ca ₃ (PO ₄) ₂	0	35-42	0	-	-
Basic slag	0	16-20	0	1-3	-

Single superphosphate with 16 to 20 percent of P₂O₅ contains in addition 12 percent of sulphur and more than 20 percent calcium (CaO).

Triple superphosphate with a concentration of 46 percent P₂O₅ contains no sulphur and less calcium. Both types of P-fertilizers contain the phosphate in water-soluble, plant-available form.

A substantial amount of phosphate is applied in form of NP- (nitro-, monoammonium- (MAP) and diammonium (DAP) phosphate) and NPK-fertilizers.

Muriate of potash with up to 60 percent of K₂O is the leading straight potassium fertilizer used on most crops. On crops sensitive to chlorine or where sulphur is needed, *potassium sulphate* with 50 percent of K₂O and 18 percent of sulphur is used. However, as with phosphate fertilizers, a major part of K₂O is applied in form of NPK-and PK-fertilizers.

Secondary nutrients

In the past secondary nutrients, particularly sulphur, were not always listed on the bag or container. This has now changed.

In addition to the straight fertilizers containing magnesium, sulphur and/or calcium listed above, sulphur is also contained in gypsum (16-18 percent S). Potassium magnesium sulphate or sulphate of potash magnesia provide readily available supplies of both (magnesium, 6 percent Mg) and sulphur (16-22 percent S).

For calcium requirements, see also Chapter 4 'Soil reaction and liming'.

Multinutrient fertilizers

A large number of multinutrient fertilizers are offered on the world market. Table 3 gives the possible range of nutrient contents of NP, NPK and PK fertilizers.

The most noteworthy advantages of multinutrient fertilizers to the farmer are:

- ease of handling, transport and storage;
- ease of application;
- high nutrient content;
- even distribution of nutrients in the field;
- balanced fertilization, i.e. nitrogen, phosphate and potassium available together from the start and in accordance with plant requirements; and

Table 3. Multinutrient fertilizers - range of nutrient contents

Fertilizer type		% N	% P ₂ O ₅	% K ₂ O
NPK fertilizers		5-26	5-35	5-26
Ammonium Phosphates	DAP	16-18	42-48	-
	MAP	11	52	-
Nitrophosphates	NP	20-26	6-34	-
PK fertilizers	PK	-	6-30	6-30

- high fertilizer efficiency.

In general, there are three distinct types of multinutrient fertilizers¹⁸:

- *complex fertilizers*: manufactured through processes involving a chemical reaction between the constituents containing the primary plant nutrients (each granule contains the declared ratio of nutrients);
- *compound fertilizers*: granulated straight fertilizers or intermediates, the granules containing the nutrients in varying ratios;
- *mixed fertilizers* or *blends*: simple mechanical mixtures of straight fertilizers (the mixture may not be homogeneous if care is not taken).

Typical NPK- and NP-grades of multinutrient fertilizers are:

1. NPK complex / compound fertilizers:
22-22-11, 19-19-19, 17-17-17, 14-35-14, 14-28-14, 15-15-15, 13-13-21, 12-24-12, 12-12-17, 11-22-22, 10-26-26.
2. NP complex / compound fertilizers:
28-28-0, 26-14-0, 24-24-0, 23-23-0, 20-20-0, 18-46-0, 16-20-0.

In addition to the primary nutrients nitrogen, phosphorus and potassium, a number of grades also contain secondary nutrients such as magnesium, sulphur and calcium. Some also contain micronutrients such as iron, copper, zinc, manganese, boron and molybdenum. Thus, in choosing the right grade, the farmer has the possibility of applying all the needed nutrients in one single fertilizer.

¹⁸ Adapted from FAO 'Fertilizer and plant nutrition guide', Bulletin 9, Rome, 1984.

Micronutrients

Micronutrients require special attention and care because there is a narrow margin between excess and deficiency in the microelement needs of the plants.

Micronutrients are needed only in small amounts. If too much of a given microelement (e.g. boron) is applied, it may have a harmful effect on the crop and/or the succeeding crop. Special compound fertilizers can be prepared containing micronutrients along with the NPK grades for soils and crops where deficiencies are known to exist.

In many cases microelement deficiencies are caused through a soil pH which is too low (acid), or more often, through a soil pH which is too high (neutral to alkaline), thus a change in soil pH may make microelements plant-available.

Whenever micronutrient fertilizers are needed a fertilizer specialist at the local experimental station should be consulted.

A more exact rate of application and usually also a greater efficiency are made possible through the use of spray or seed treatments with micronutrients (formulated as powders or liquids). Types of microelement fertilizers used are on the next page.

Complex organic compounds of iron, zinc, manganese and copper - chelates¹⁹ - will significantly increase the efficiency of the applied micronutrients, particularly that of iron, which is hardly taken up in non-chelated form.

SLOW RELEASE FERTILIZERS / NITRIFICATION AND UREASE INHIBITORS

Slow or controlled-release fertilizers²⁰ contain a plant nutrient (usually nitrogen) in a form, which - after application - delays its availability for plant uptake significantly longer than a common fertilizer. This effect is obtained either by coating a common (nitrogen or NPK) fertilizer with sulphur or with a (semipermeable) polymer material or by special chemical nitrogen

¹⁹ Chelating agents form complex organic molecules protecting the microelements against fixing and facilitating a better uptake through the plant.

²⁰ There is no official differentiation between slow release and controlled-release fertilizers. However, commonly the micro-biologically decomposed N products, such as urea-formaldehydes, are referred to as slow release fertilizers and coated or encapsulated products as controlled-release fertilizers.

Table 4. Some important micronutrient fertilizers

Micronutrient carrier	(formula)	Micronutrient
Ferrous sulphate	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	Iron (Fe)
Coppersulphate	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	Copper (Cu)
Zinc sulphate	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	Zinc (Zn)
Manganese sulphate	$\text{MnSO}_4 \cdot 7\text{H}_2\text{O}$	Manganese (Mn)
Borax	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	Boron (B)
Sodium molybdate	$\text{Na}_2\text{MoO}_4 \cdot 10\text{H}_2\text{O}$	Molybdenum (Mo)

compound formulations. Because the release of nitrogen from slow or controlled-release fertilizers generally also depends on the soil temperature and humidity, nitrogen will be made available according to the growth of the plant.

The main advantages are labour saving (instead of several split applications only one for the whole growing period), reduced toxicity to seedlings even with high application rates and saving of fertilizer material by a better efficiency of the nitrogen (with 15 to 20 percent less nitrogen applied, the same yield has been obtained as with common nitrogen fertilizers).

Although these benefits have mainly been proved in rice, a disadvantage for general agriculture is that the cost per nutrient unit is considerably higher than that in common fertilizers. Therefore such slow and controlled-release fertilizers are used practically exclusively on high value crops, such as vegetables.

Nitrification and urease inhibitors are more economic for use in general agriculture. Nitrification inhibitors are compounds which, when added to nitrogen fertilizers containing the nitrogen in form of ammonia, delay the transformation of the ammonium-ion (NH_4^+) held by the adsorption complex into nitrite and further to nitrate (NO_3^-) through the activities of soil bacteria, thus preventing leaching of nitrate not taken up immediately by the crop.

Urease inhibitors depress the transformation of the amide-N in urea into ammonium for about 10 to 12 days; thus preventing, or reducing, evaporation losses of ammonia to the air when the weather stays dry or the urea cannot be incorporated into the soil immediately after application.

Both nitrification and urease inhibitors are thoroughly mixed with the nitrogen fertilizers before spreading and then spread together in the mixture.

Depending on the amount of ammonium or amide nitrogen contained in the nitrogen fertilizer, the application rate is a few kilograms or litres per hectare.

The use of nitrification and urease inhibitors gives higher yields or maintains the same yield level with reduced rates of nitrogen (as compared to nitrogen fertilizers without amendment with nitrification or urease inhibitors) due to reduced losses of nitrate or ammonium.

8. Calculation of fertilizer rates

The amount of fertilizer to be applied per hectare or on a given field is determined through the amount of nutrients needed and the types and grades of fertilizers available. Usually mineral fertilizers are delivered in 50-kg bags. Therefore, the farmer has to know the quantity of nutrients contained in a 50-kg bag. The easiest way to calculate the weight of nutrients in a 50-kg bag is to divide the number printed on the bag by 2.

Example: How many bags of ammonium sulphate (AS) (with 21% N and 24% S) are needed to supply 60 kg/ha of N? 21 divided by 2 gives 10.5. Thus approximately six bags of AS are needed to give (a little more than) 60 kg/ha N. In addition, six bags of AS will supply 72 kg/ha of sulphur.

If the area of the field is only 500 m² (square metres), the required amount of fertilizer would be one twentieth of that for one hectare: 1 hectare: 10 000 m² divided by 500 m² = 20, i.e. for an area of 500 m² 300/20=15 kg of ammonium sulphate are necessary to apply the amount of nitrogen corresponding to 60 kg/ha N.

If the recommendation is 60-60-60, the easiest option for the farmer is to buy a multinutrient fertilizer grade 15-15-15. One 50-kg bag contains 7.5-7.5-7.5. 60 divided by 7.5 gives 8. Thus eight 50-kg bags of 15-15-15 are needed to apply the recommended rate of 60 kg/ha N, 60 kg/ha P₂O₅ and 60 kg/ha K₂O.

When the recommendation per hectare is 60-30-30, with eight 50-kg bags of a 15-15-15 grade the farmer would apply double the amount of phosphate and potassium needed. In this case he should apply only four 50-kg bags per hectare, giving half of the recommended rate of nitrogen and the full rate of phosphate and potassium as basal dressing. The remaining 30 kg/ha N should be applied in the form of a straight nitrogen fertilizer as one or two top-dressings in line with good agricultural practices.

The situation is more complicated if the recommendation per hectare is 60 kg N, 30 kg P₂O₅ and 50 kg K₂O and there is no grade with the required ratio of 2:1:1.7 available (or 1:1:1.7 plus straight N). In this situation the farmer has three possibilities:

1. He can try to combine available multinutrient grades with straight (primarily nitrogen) fertilizers, splitting the nitrogen fertilizer rate recommended.
2. He makes a fertilizer use plan to cover the whole crop rotation, applying nitrogen every year exactly at the recommended rate for the individual crop, and phosphate and potash independently of the individual crop. However the P₂O₅ and K₂O should be applied in such amounts that finally the total quantity recommended for all crops in the crop rotation is given.
3. He can apply straight fertilizers separately, or he can mix straight fertilizers to produce his own multinutrient fertilizer mixture or blend according to the necessary nutrient ratio.

The recommended rate of 60-30-50 could be a mix of ammonium sulphate (21% N), where also sulphur is necessary, or of urea (45% N), triple superphosphate (46% P₂O₅) or diammonium phosphate (18% N and 46% P₂O₅) and muriate of potash (60% K₂O).

To obtain the corresponding mixture/blend the following quantities of fertilizer material are needed:

$$\begin{aligned} \text{Urea} & \quad \frac{60 \text{ kg/ha} \times 100}{45} = 133 \text{ kg/ha} \\ \text{Triple superphosphate} & \quad \frac{30 \text{ kg/ha} \times 100}{46} = 65 \text{ kg/ha} \\ \text{Muriate of potash} & \quad \frac{50 \text{ kg/ha} \times 100}{60} = 83 \text{ kg/ha} \end{aligned}$$

The resulting mixture of urea, triple superphosphate and muriate of potash should be spread on the field as soon as possible after mixing.

When ammonium sulphate is used instead of urea, the farmer needs the following quantity of ammonium sulphate:

$$\text{Ammonium sulphate} \quad \frac{60 \text{ kg/ha} \times 100}{21} = 286 \text{ kg/ha}$$

In addition to 60 kg N, 30 kg P₂O₅ and 50 kg K₂O this blend would also contain 69 kg/ha sulphur.

If diammonium phosphate is used instead of triple superphosphate the quantity necessary should be based on the recommended rate for phosphate:

$$\text{Diammonium phosphate} \quad \frac{30 \text{ kg/ha} \times 100}{46} = 65 \text{ kg/ha}$$

This would also supply 12 kg/ha²¹ of N. The remaining 48 kg/ha of N might be incorporated into the mixture or directly applied in one or two split applications in the form of a straight nitrogen fertilizer.

However, not all fertilizers can be mixed together. Fertilizers, which are mixed together must be compatible both chemically and physically.

They have to be chemically compatible to avoid caking due to increased hygroscopicity or gaseous losses of ammonia. When fertilizers containing ammonia are mixed with basic slag, rock phosphate or lime, evaporation losses of ammonia will occur.

Similarly, water soluble phosphate fertilizers (single and triple superphosphate, ammonium- and nitro-phosphates) should not be mixed with fertilizers containing calcium (e.g. calcium nitrate), since the calcium will revert the water soluble phosphate into insoluble form.

Mixtures of urea and superphosphates or ammonium phosphates and superphosphates should also be avoided.

To prevent an increase in hygroscopicity, as a general rule mixtures or blends should always be spread as soon as possible after mixing.

Fertilizers that are to be mixed should also be *physically* compatible, i.e. they should be of similar granule size and possibly also of similar density to prevent segregation during handling, storing and spreading. This is of particular importance when centrifugal spreading equipment is used. However, segregation is also possible when the mixture is broadcasted by hand.

To avoid mixing errors when preparing the necessary mixture on the farm, the farmer may avail himself of the services of his regional fertilizer retailer with a mixing unit (the investment for a mixing or bulk blending²² installation is usually relatively low).

²¹ Rounded up/down figures.

²² Bulk blending = mixed fertilizer prepared without chemical reaction through mixing of dry, granular fertilizers or fertilizer materials. Usually prepared shortly before use and delivered to the farm in bulk.

The retailer can prepare individual blends with nutrient ratios tailored to the needs of the farmer's soils and crops. He will know which types of fertilizers can be mixed with each other and which cannot. However, because the farmer is normally unable to check the nutrient content and quality, particularly with fertilizer mixtures or blends, the retailer preparing the blend should be known as trustworthy and reliable.

9. How to apply fertilizers

The method of application of fertilizers (organic manure or mineral fertilizers) is an essential component of good agricultural practices. The amount and timing of nutrient uptake depends on various factors, such as crop variety, planting date, crop rotation, soil and weather conditions. For good agricultural practices, the farmer chooses the timing and the quantity in such a way that as much as possible of the nutrients is used by the plants. For optimum crop use efficiency and minimum potential for environmental pollution, he must apply the nutrients as near to the time the crop needs them as is practical. This is of particular importance for mobile nutrients such as nitrogen, which can easily be leached out of the soil profile, if they are not taken up by the plant roots.

In the cases of urea and diammonium phosphate application, losses may occur through emission of ammonia to the air. Both these fertilizers must be incorporated into the soil immediately after application, if there is no immediate rainfall or irrigation to wash it into the soil. This is of particular importance on alkaline (calcareous) soils.

All primary and secondary nutrients should be incorporated immediately after application in regions where intense rainfall is expected, to avoid losses due to run-off and erosion.

When fertilizer is applied by hand, extreme care should be taken to distribute nutrients uniformly and at the exact rates. Where fertilizer application equipment is used, it should be adjusted to ensure uniform spreading and correct rates. The equipment should be well maintained.

BROADCASTING

The broadcasting of fertilizer (i.e. applying it to the surface of a field) is used mostly on dense crops not planted in rows or in dense rows (small grains)

and on grassland. It is also used when fertilizers should be incorporated into the soil after application to be effective (phosphate fertilizers), or to avoid evaporation losses of nitrogen (urea, diammonium phosphate). Incorporation through tilling or ploughing-in is also recommended to increase the fertility level of the entire plough layer. Whether the fertilizer is broadcast by hand or with fertilizer spreading equipment, the spreading should be as uniform as possible.

ROW OR BAND PLACEMENT

When localized fertilizer placement (putting the fertilizer only in selected places in the field) is used, the fertilizer is concentrated in specified parts of the soil during planting, which may be either in bands or strips under the surface of the soil or to the side of, and below, the seed. This can be done either by hand or by special planting and/or fertilizer drilling equipment (*seed-cum-fertilizer drill*). It is preferably used for row crops, which have relatively large spaces between rows (maize, cotton, and sugar cane); or on soils with a tendency to phosphate and potassium fixation; or where relatively small amounts of fertilizer are used on soils with a low fertility level.

Where crops are cultivated by hand and planted in hills, the recommended number of grams of fertilizer are placed in the row or planting hole (preferably measured out in an appropriate tin or pot), under, or beside the seed, and covered with soil. Great care has to be taken that no fertilizer is placed either too close to the seed or to the germinating plant to avoid toxicity, i.e. salt damage to the seedling (burning of the roots).

TOP-DRESSING

Top-dressing (broadcasting the fertilizer on a standing crop) is mainly used for small and large grain crops and for crops such as forage. Top-dressing is normal practice where there is a need for additional nitrogen on soils and with crops where a single application of the total nitrogen amount needed at sowing might lead to losses through leaching, or where the crops show a special need for nitrogen at certain stages of growth. The mobile nitrate moves downwards in the soil and can be taken up there by the plant roots.

Top-dressing of potassium, which does not move in the soil to the same extent as nitrogen, might be recommended on light soils, i.e. applying the total amount divided into a basal dressing and top-dressing.

Phosphate hardly moves in the soil at all. Hence, it is usually applied before or at sowing or planting time (basal application), preferably in com-

mination with potassium and part of the nitrogen. The remaining nitrogen should then be applied as a top-dressing in one or more split applications.

SIDE-DRESSING

Applying fertilizer as side-dressing is the practice of putting it to the side of widely spaced plants grown in rows such as maize, cotton and sugar cane. Trees or other perennial crops also are normally side-dressed.

FOLIAR APPLICATION

Foliar application is the most efficient method of supplying micronutrients (but under a stress situation for the crop also N or NPK) which are needed only in small quantities and may become unavailable if applied to the soil. To minimize the risk of leaf scorch, the recommended concentration has to be respected and spraying should preferably be done on cloudy days and in the early morning or late afternoon (to avoid an immediate drying of the droplets).

10. How to determine fertilizer needs

To determine fertilizer needs for crops and soils in your region, you must know two things:

1. Which nutrients are needed in the fertilizer?
2. How much of each nutrient is needed to get the highest or most profitable (optimum) yield?

There are several approaches to finding the answers to these questions. The use as a first good indication of the plant nutrient removal figures at respective yield levels has been discussed in Chapter 7 '*Fertilizer recommendations for selected crops*'. Other approaches are listed and discussed below:

1. Nutrient hunger signs on growing crops (deficiency symptoms).
2. Soils tests or analyses to determine the fertilizer nutrients and amounts needed.
3. Plant and/or plant tissue tests in the field.
4. Fertilizer field trials.

HUNGER SIGNS IN PLANTS

If plants do not get enough of a particular nutrient they need, the symptoms show in the general appearance as well as in the colour of the plant. Very typical symptoms are: the nutrient-deficient plants are stunted (small), the leaves have a pale green colour or a very dark bluish green colour, are yellowish or have reddish spotting or striping. At harvest, yields are reduced, sometimes severely.

Identification of nutrient deficiency (hunger signs) is easy in some cases, but difficult in others. The reason for this is that deficiency symptoms of two different nutrients can be nearly identical or that the deficiency of one nutrient is masking (hiding) the symptoms of another deficiency. The hunger signs may also appear or disappear as the weather changes (change between humidity and drought). It may also be the case that plants are suffering from not yet visible latent deficiency ("hidden hunger"). Furthermore, care should be taken not to confuse hunger signs with virus or fungus disease symptoms or damage caused by insects/animal pests.

Clear symptoms will occur only in cases of extreme deficiency of one nutrient. Indicated hunger signs of a deficient nutrient should be verified by soil tests, plant analysis, field tissue tests and/or field trials (pot experiments in the local experimental station).

General hunger signs for some crops are specified below.

Nitrogen deficiency

- Stunted plants (common to all deficiencies), poor plant health and small plants.
- Loss of green colour (common to all deficiencies), yellow discoloration of leaves from tip backward (tip chlorosis²³), older leaves brown.
- Lower leaves may die prematurely while the top of the plant remains green (sometimes mistaken for lack of moisture).

Phosphorus deficiency

- Stunted growth.

²³ *Chlorosis*, i.e. a yellowish discoloration of leaves, indicates an affected formation of chlorophyll; chlorosis is *reversible* by application of the needed nutrient.

Necrosis, i.e. brownish discoloration of leaves or parts of leaves, indicates dead tissue. It is *irreversible*, i.e. it cannot be cured through nutrient application.

- Leaves dark bluish green, purpling and browning from tip backward (often also at stems).
- Plants slow to ripen, remaining green.
- Fruits may be misshapen, grain is poorly filled.

Potassium deficiency

- Stunted growth.
- Leaves show discoloration along outer margin from tip to base.
- Outer edges of leaves yellow or reddish, becoming brownish or scorched and dead (edge necrosis); leaves wilted.
- Lodging.
- Tree leaves are yellowish, reddish, pinched, cupped or curved.
- Fruit is small, may have lesions or injured spots, poor storage and keeping quality.

Magnesium deficiency

- Yellowish discoloration between green leaf veins (typical stripe chlorosis; Mg is part of the green plant pigment, chlorophyll, needed for photosynthesis), finally followed by blotching and necrosis (death of tissues), starting at lower old leaves.

Sulphur deficiency

- Whole plant is yellow (often mistaken as N deficiency).
- Yellowing of upper leaves, even on newest growth.
- Delayed crop maturity.

Calcium deficiency

- Young leaves yellowish to black and curved or cupped (brown spots).
- Plants appear to wilt.
- Fruits may appear rotten (tomato).
- Roots are malformed.

Boron deficiency

- Leaves frequently misshapen and crinkled, thick and brittle, white, irregular spots between veins.
- Growing tips of buds die, with bushy growth near tips, extension growth inhibited with shortened internodes.

- Water-soaked, necrotic spots or cavities in beet and other root crops and in the pith of stems.
- Fruit small and poorly formed, often with corky nodules and lesions.
- Low seed production due to incomplete fertilization.

Zinc deficiency

- Stunted growth of leaves.
- Fruit trees with typical shortened bushy shoots.
- Chlorotic stripes (white bleached bands) between the leaf veins in lower part of leaf.
- In some cases leaves have an olive green or grayish green colour (very similar to P deficiency).

Iron deficiency

- Young leaves with typical chlorosis between green veins, along the entire length of leaves (usually on calcareous soils).

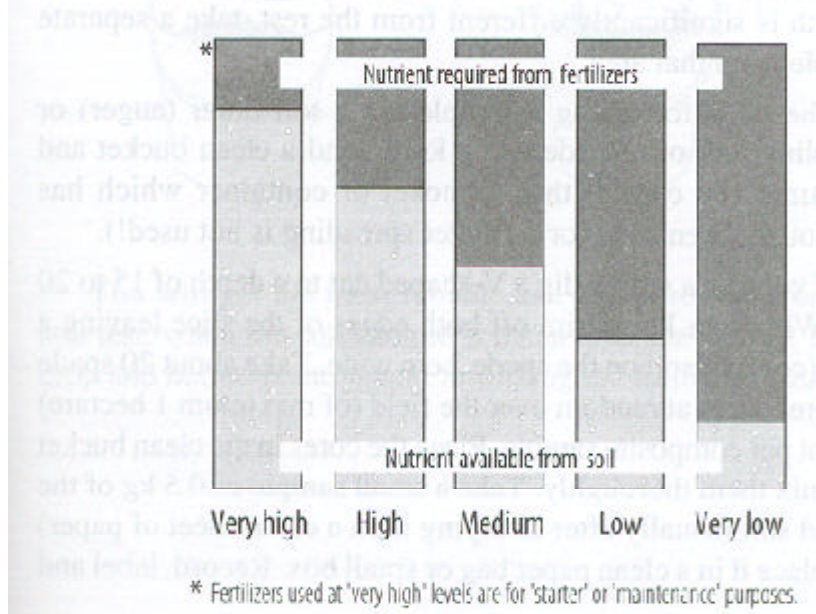
Though hunger signs are useful in signaling nutritional disorders to the farmer, even when these clearly visible hunger signs are quickly corrected through applying adequate nutrient supply, generally speaking the yield at harvest will still be lower in comparison to crops which are well nourished from planting to harvesting. Therefore, good agricultural practices would avoid all nutrient deficiencies for a crop throughout the growing season. To reach this aim the most helpful methods are soil tests, plant analysis, field tissue tests and field trials.

SOIL TESTS

Soil testing is used to find out how much of a nutrient will be plant-available from the soil, and how much should be additionally applied in the form of a mineral fertilizer to reach an expected crop yield. For a given nutrient and different soil-test levels Figure 8 presents a simple interpretation.

The higher the level of a soil test in plant nutrient, the less is the amount needed from fertilizers. Even at high test levels some nutrients should come from fertilizers in order to maintain soil fertility and productivity. There are different kinds of soil tests. However, the main problem is to relate suitable nutrient extraction methods for a given soil with the corresponding yields (calibration).

Figure 8. Relative sources of nutrients at different soil test levels



If your experimental station has conducted soil analyses and field experiments and has related (calibrated) the soil tests to crop responses to fertilizers, you should take your soil samples there. They will then be able to give a correct interpretation of the soil test result and the corresponding fertilizer recommendation.

How the soil test works

A soil test by a nutrient extraction method chemically extracts and measures the amount of nutrients available to crops from a small sample of soil that is taken to the depth of the arable layer (ploughed depth). The results found are related to fertilizer crop response data from corresponding field experiments.

Based on such calibrated data the soil test result can be interpreted and fertilizer recommendations can be given (of course, also taking into account data from previous cropping/crop rotation, fertilizer use and weather conditions).

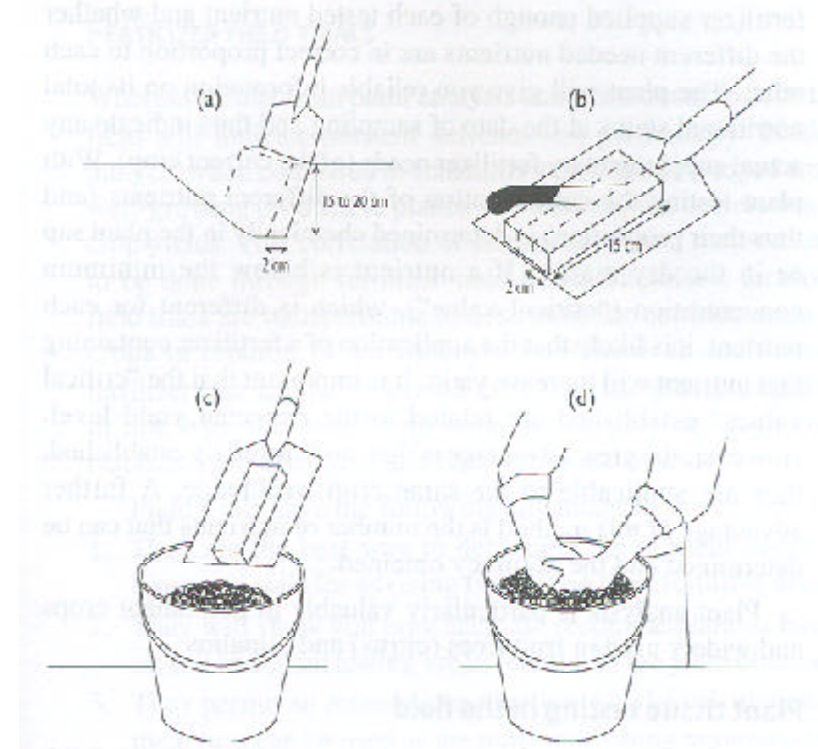
How to take a soil sample

A soil test cannot be better than the sample that is tested. Therefore, careful sampling is a "must". Of great importance is selecting the area to be sampled. Do not mix different kinds of soil. If any area of soil in a field appears different, or if crop growth is significantly different from the rest, take a separate sample from that area.

The tools for taking a sample are a soil borer (auger) or sampling tool or a spade and a knife, and a clean bucket and container (be careful that a bucket or container which has previously been used for fertilizer spreading is not used!).

If you use a spade, dig a V-shaped cut to a depth of 15 to 20 cm. With your knife trim off both edges of the slice leaving a strip (core) of soil on the spade 2 cm wide. Take about 20 spade or borer cores at random over the

Figure 9. Soil sampling



field (of maximum 1 hectare) or plot per composite sample. Place the cores in the clean bucket and mix them thoroughly. Take a small sample of 0.5 kg of the mixed soil (usually after airdrying it on a clean sheet of paper) and place it in a clean paper bag or small box. Record, label and date the sample properly and make a diagram of the area for a particular sample, so that you can relate the soil test results correctly to the field.

You will get the most reliable and useful results from the soil test, when the soil sample is taken after the harvest of the crop and before planting and fertilizing the following crop.

PLANT TESTING

Plant analysis

With plant testing you are “asking the plant” if the soil and fertilizer supplied enough of each tested nutrient and whether the different needed nutrients are in correct proportion to each other. The plant will give you reliable information on its total nutritional status at the date of sampling and thus indicate any actual supplementary fertilizer needs (of the current crop). With plant testing the concentration of the different nutrients (and thus their proportion) is determined chemically in the plant sap or in the dry matter. If a nutrient is below the minimum concentration (“critical value”), which is different for each nutrient, it is likely that the application of a fertilizer containing that nutrient will increase yield. It is important that the “critical values” established are related to the expected yield level. However, the great advantage is that, once properly established, they are applicable to the same crop worldwide. A further advantage of this method is the number of nutrients that can be determined and the accuracy obtained.

Plant analysis is particularly valuable in permanent crops and widely used in fruit trees (citrus) and oilpalms.

Plant tissue testing in the field

Plant tissue tests are made on green/growing plants in the field. The selected part of the plant, usually the (young, actively functioning) leaves or leaf stalks (petioles), is either cut up and shaken in an extractant, or sap is squeezed onto a test paper and treated with appropriate chemicals (spot tests with extracts). The colours which develop, can be compared against known concentrations of nutrients or of healthy productive and well established plants.

Plant tissue tests in the field are valuable for verifying deficiency symptoms. Moreover, they help to discover “hidden hunger” which is not indicated by deficiency symptoms. They have the advantage that they can be made rapidly and directly on the growing crop, that they are inexpensive and that tests of plants or treatments can be compared directly in the field.

FERTILIZER FIELD TRIALS

Whereas results from plant analysis and plant tissue tests in the field will indicate nutrient deficiencies, particularly ‘hidden hunger’ when compared to standards which are developed from well-growing productive plants, soil tests require correlation to crop yields. This correlation or calibration of test methods has to be done through fertilizer field trials. Therefore, fertilizer field trials are indispensable to determine the nutrient needs of crops in relation to the final yield obtained. In such trials, fertilizers are applied at known rates of plant nutrients (and/or in line with the data found with soil or plant testing), crop responses are observed, and final yields are measured.

Field trials have the following advantages:

1. They are the best way to determine the nutrient needs of crops and soils for advising farmers on their fertilizer needs.
2. They will show you how accurate recommendations based on soil and plant testing are in relation to the yield obtained.
3. They permit an economic evaluation, i.e. the calculation of the return can be used as the most motivating argument to a farmer to use fertilizers.
4. The growing crops can be photographed. The pictures can be used in publicity and demonstrations for many years.
5. Demonstrations or simple trials show the benefits of fertilizers to farmers and agricultural workers.

The way to conduct demonstration (or a simple trial) is discussed in Chapter 12.

LONG-TERM FIELD EXPERIMENTS

General recommendations for a region are available when enough fertilizer trials have been carried out. Examples for your region may be inserted at the end of this booklet.

However, nutrient needs for a crop on a given soil cannot be determined once and for all, because conditions change rapidly. When only one nutrient is applied (unbalanced fertilization), another may become limiting. Not enough - or too much - of one nutrient may reduce yield or lower the profitability of fertilizer use to the farmer. Unbalanced nutrient supply may also result in increased susceptibility to disease, lodging or late maturity.

Therefore, continuing studies are necessary, i.e. long-term field experiments should be conducted to find out the amounts and ratio of nutrients required.

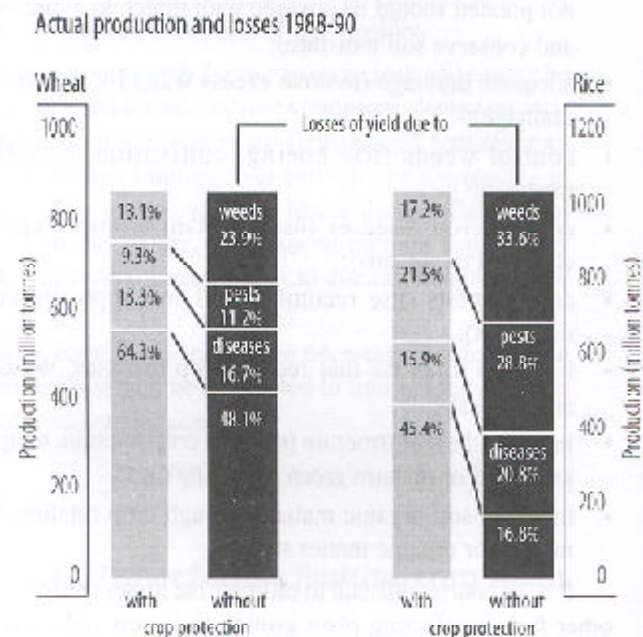
11. Other factors limiting crop yields

Fertilizer use is one of the most important factors which contributes to increased productivity and sustainable agriculture. But it will not solve all the problems of crop production.

In the foregoing chapters of this booklet several other factors or practices have already been mentioned which can limit and affect crop yields and reduce fertilizer use efficiency. In applying good agricultural practices the farmer should pay particular attention to:

- proper and timely preparation of the seed bed;
- crop varieties (preferably select high yielding varieties (HYV));
- correct seeding rate:
 - a) plants per hectare
 - b) spacing between plants or rows
- optimal seeding time;
- sufficient moisture (use irrigation where available, a field not planted should be covered with mulch to avoid erosion and conserve soil moisture);
- adequate drainage (remove excess water by surface or tile drainage);
- control weeds (use hoeing, cultivation or chemical treatments);
- control crop diseases (use resistant crops or approved chemical treatments);
- control pests (use recommended and approved control measures);
- use crop rotations that reduce crop diseases, weeds and animal pests;

Figure 10. **Importance of crop protection**
The response to fertilizers is reduced if there are other factors holding down crop yields.



Source: Adapted from F. C. Geake, European Crop Protection Association, Brussels 1992.

- improve the soil structure (through crop rotation, temporary grassland or manure/green manuring); and
- maintain soil organic matter (through crop rotation, bulky manure or organic matter supply).

It is, of course, difficult to estimate the losses caused through other factors affecting plant growth and crop yield precisely. Some calculations have been made for weed control and crop protection. Figure 10 illustrates the importance of weed control and crop protection by showing the losses in wheat and rice, which are caused through the competition of weeds, through crop diseases and the attack of pests. The theoretically attainable yield is contrasted with the actual recorded production. In wheat without crop protection more than half of the theoretical attainable yield would be lost through weeds, animal pests and diseases; with crop protection approximately two

thirds have been harvested. The situation is worse for rice: without crop protection, less than one fifth would be harvested, and even with crop protection only less than half of the theoretical attainable yield has been harvested.

12. Fertilizer extension work

As an extension agent, it is your obligation, but also the opportunity to help farmers. Thus you will demonstrate to them through conversation, articles, fieldwork and meetings how fertilizers will lead to higher yields of their crops. Furthermore, you will show them the benefits of improved farm management practices leading to better farm income and protection of the environment, and thus to sustainable agriculture. Consequently, your work with fertilizers is not only very important for the farming community in your region, but also for your country.

When introducing fertilizers to the local farmers you have to know what your objective is. Therefore, you need to prepare yourself clearly and well. First you have to find out where you can get fertilizers, i.e. who are the fertilizer retailers in your region, what grades of fertilizers are available in stock and what is the time required to order them. Secondly, you will contact your experimental station, agricultural school or agricultural university for appropriate fertilizer recommendations. Recommended amounts of fertilizers to be applied to the crops of your country may be inserted as an appendix to this booklet. Start your field demonstrations on the basis of these recommendations and adapt them to the results you will get in your region. Thirdly, you will invite the farmers to the demonstration plots, to see and discuss with them the effects of fertilizers on growth and yield of their crops. This should be integrated in a programme of good agricultural practices. Finally, you will hold field days or start a farmers' field school and you will demonstrate the economic benefit from improved yields through fertilizer use.

CONDUCTING A FERTILIZER DEMONSTRATION

Before starting a fertilizer demonstration you should set up a plan and a layout: What do I want to demonstrate to the farmer? With which crop will the demonstration be most convincing (most valuable or most grown in your

area or most needed for food)? With which farmers will I cooperate? What will be the best situated place or field for the demonstration? What fertilizer do I have available for use on the selected crop? When and how do I have to apply the fertilizer? What other measures do I need to take into account?

Therefore, in order to carry out a fertilizer demonstration you need to prepare and have ready the following:

1. A plan for the demonstration (two or more plots²⁴, where and with which crop, size of each plot, demonstration on one field only or on several fields).
2. A notebook for the demonstration plan, for plot records (amount of nutrients applied, date of application), location of plots, growth observations, weed and pest control during crop growth and the final yields.
3. One or more interested farmers who will work with you and help you to conduct the demonstration in his/their fields.
4. Fertilizer of the right grade or grades at the right time and a dry place to store the fertilizers before use.
5. A scale or balance to weigh out the fertilizer quantity for each plot.
6. Have ready paper bags, preferably multilayered, in which you put the fertilizer for the different treatments clearly marked.
7. A measuring tape or device to determine the plot size/length and shape; stakes and strings to mark the plot boundaries, particularly the corners.
8. Harvesting equipment, including cutting tools, and scale or balance for measuring crop yields.
9. Information on actual fertilizer and agricultural produce prices, and possibly a pocket calculator to calculate the economic outcome of the demonstration (value/cost-ratio VCR and/or the net profit).

As a general rule: Keep your fertilizer demonstrations simple!

- a) Identify the fertilizer effect against a non-fertilized plot, with all other factors remaining equal. The simple design would be: no fertilizer - recommended fertilizer.

²⁴ Usually you will start with two plots, i.e. one treated plot and one control plot or farmers practice plot. Thus you will work without replications. However, if you implement the demonstration plots on fields of several farmers, the different locations may be considered as replications of the demonstration and may be evaluated. However, this should be verified with the statistician at your local experimental station.

b) If you want to convince farmers to use a higher rate of N and/or P_2O_5 and/or K_2O you have to adapt the design to compare two rates of nutrients.

The design then would be: no fertilizer - lower rate of nutrient (e.g. 30 kg/ha N) - higher rate of nutrient (e.g. 60 kg/ha N). The same design is used for P_2O_5 and K_2O . The demonstration while testing a higher rate of one nutrient, should always be done in the presence of the other two nutrients (balanced fertilization).

c) If you want to demonstrate to the farmers the importance of balanced fertilization you will have to use a three or four plot-design: no fertilizer - plot only with nitrogen (N) - plot with nitrogen and phosphate (NP) - plot with nitrogen, phosphate and potassium (NPK).

Variations of this design with three plots are:

no fertilizer - NP -NPK

or no fertilizer - P - NP

or no fertilizer - N - NP

or no fertilizer - N - NPK.

d) In addition to proving the benefits of fertilizer use you may also want to demonstrate the benefits of improved agricultural practices, particularly the system of integrated plant nutrition. Then you need a four plot design:

1. plot: no fertilizer with farmer's practice.
2. plot: recommended fertilizer with farmer's practice.
3. plot: no fertilizer with recommended improved practices (conservation tillage, organic matter supply, manure, green manure, improved seed variety, date and method of planting, weed and disease control, etc.).
4. plot: recommended fertilizer with recommended improved practices (conservation tillage, organic matter supply, manure, green manure, improved seed variety, date and method of planting, weed and disease control, etc.).

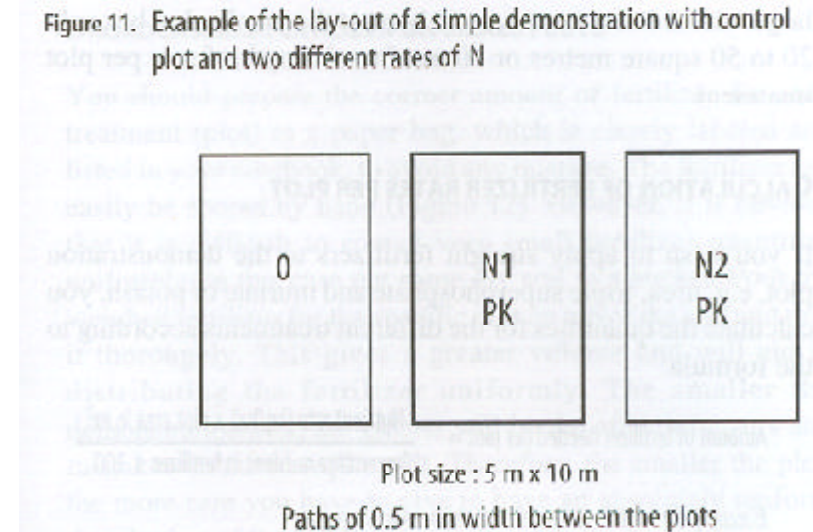
Because of the gradual inclusion of "other" improved practices, and not only fertilizer use, this last design calls for special emphasis. Therefore, it is recommended to work primarily with simple demonstrations as described under a) and b), and to implement the other demonstrations or simple trials

as under c) and d) or with still more, i.e. six to ten treatments²⁵ in cooperation with your local experimental station.

DETERMINATION OF PLOT SIZE

The size of demonstration plots will depend on the field size of farms. Since farms and fields may often be small in your region, the demonstration plots also have to be small. However, they should be large enough to make convincing demonstrations and to get accurate yield data to determine the effect of the treatments. Thus, the size of plots or strips may vary between 50 to 400 square metres (5 m x 10 m up to 10 m x 40 m).

In general, the plots used for the demonstration should be rectangular and laid out side by side. Paths of 0.5 to 1 m in width should be left between the plots and around the site of the demonstration (see Figure 11). Keep in mind the topography of the field so that all plots look in the same direction.



²⁵ The former FAO Fertilizer Programme worked with an 8-plot design for simple trials: Control plot = 000, PK plot = 011, NK plot = 101, NP plot = 110, NPK plot = 111, 2N + PK plot = 211, 2P + NK plot = 121 and 2K + NP plot = 112.

The FAO database on the results of trials and demonstrations is scheduled for publication on the internet in 2001.

It is recommended that the order of treatments should be at random for the trials, not systematic. However, when you are running a demonstration with only three plots the order 0-1N-2N (or other nutrients) should be used. To avoid any confusion to the farmers regarding the plots, this should also be done if you lay out the same demonstration on several farmers' fields²⁶.

For row crops you have to adjust the width of the plot so as to include an exact number of rows: ten rows each spaced 1 m apart require a plot 10 m wide, but nine rows 1.20 m apart will need a plot which is 10.80 m wide. If the treated plots are of the larger size it is not necessary to harvest the whole plot, but only 20 to 50 square metres or 10 m of total length of row per plot treatment.

CALCULATION OF FERTILIZER RATES PER PLOT

If you wish to apply straight fertilizers to the demonstration plot, e.g. urea, triple superphosphate and muriate of potash, you calculate the quantities for the different treatments according to the formula:

$$\text{Amount of fertilizer needed per plot} = \frac{\text{Nutrient rate (kg/ha)} \times \text{plot area (m}^2\text{)}}{\text{Percentage nutrient in fertilizer} \times 100}$$

Example: the demonstration design is

Plot treatment (kg/ha)	N	and/or P ₂ O ₅	and/or K ₂ O
a)	0	0	0
b)	30	30	30
c)	60	60	60

Please note that high fertilizer application rates should only be used for irrigated crops or in areas with high rainfall. With a nutrient rate of 30 kg/ha N, a plot area of 50 square metres and urea with 45% N as nitrogen fertilizer the calculation is as follows:

$$\text{Amount of urea needed per plot} = \frac{30 \times 50}{45 \times 100} = 0.33 \text{ kg of urea needed per plot}$$

²⁶A randomized lay-out is normally used when a trial is carried out with e.g. six different treatments and three replications. The following is an example of the order of treatments for such a trial:

Replication a: (treatments) 6 - 3 - 5 - 2 - 4 - 1

Replication b: (treatments) 2 - 4 - 6 - 1 - 3 - 5

Replication c: (treatments) 1 - 2 - 3 - 4 - 5 - 6

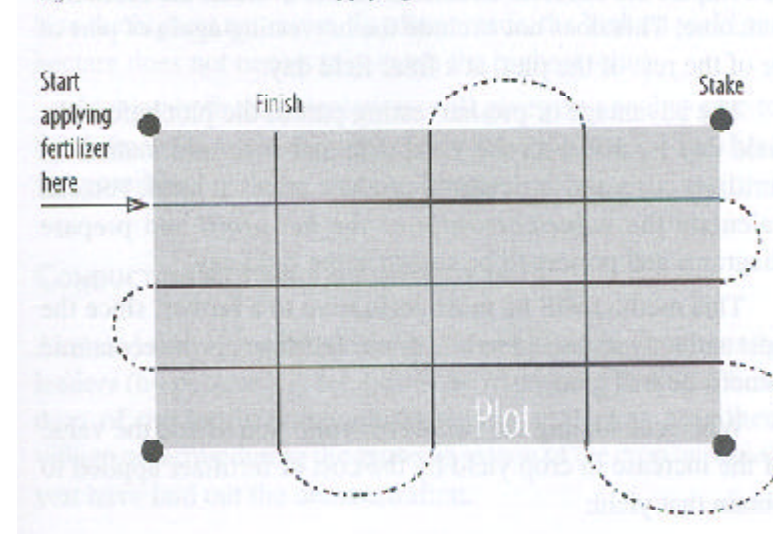
Therefore, you would have to weigh out 0.33 kg of urea per plot for treatment b) and 0.66 kg for treatment c). For a plot size of 400 square metres the necessary quantity of urea would be 2.64 kg and 5.28 kg, respectively. Rates in pounds and acres can be calculated in a similar way (see Annex).

BROADCASTING FERTILIZER ON SMALL PLOTS

You should prepare the correct amount of fertilizer for each treatment (plot) in a paper bag, which is clearly labeled and listed in your notebook, to avoid any mistake. The fertilizer can easily be spread by hand (Figure 12). However, it is obvious that it is difficult to spread very small fertilizer quantities uniformly, in this case put some dry soil in a bucket. Pour the weighed fertilizer for the specific plot on top of the soil and mix it thoroughly. This gives a greater volume and will aid in distributing the fertilizer uniformly. The smaller the demonstration plot, the greater will be the effect of errors and mistakes on the overall result. Therefore, the smaller the plot, the more care you have to give to have an absolutely uniform distribution of the fertilizer over the plot.

With small handfuls of fertilizer/fertilizer soil mixture, use a spreading or sowing movement to broadcast the fertilizer as you walk over the plot.

Figure 12. Correct method of applying broadcast fertilizer on a small plot



This method can be used for basal dressing (before planting) and for top-dressing (on a standing crop) and is applicable to a great number of crops. However, for crops planted in rows such as maize, yams, and groundnuts or for tree crops, side dressing or single plant treatment is recommended. Small amounts (some grams) of fertilizer may be dropped in holes or furrows beside the seed and covered with soil (see also Chapter 10).

EVALUATION OF FERTILIZER DEMONSTRATIONS

The demonstration sites must be regularly visited throughout the season, wherever possible with the owner of the field. Data on growth development as well as on rainfall/irrigation, weed and disease control, etc. should be written down in your notebook.

The harvesting and weighing of the yield can be done in the course of a field day. However, if you have had field days during the growing season to demonstrate the difference in growth development, it may be useful to harvest approximately 20 m² of the crop a few days before the field day, to weigh the yield, to compare the different treatments and to evaluate the economic outcome. This does not exclude the harvesting again of part of or of the rest of the plot, at a final field day.

The advantage of pre-harvesting part of the plot before the field day is, that with the yield data and with information on fertilizer costs and agricultural produce prices at hand, you can calculate the *value/cost-ratio* or the *net profit* and prepare diagrams and posters to be shown at the field day.

This method will be most persuasive to a farmer, since the best and only argument to him to use fertilizers is the economic benefit he will gain.

When calculating the *value/cost-ratio* you divide the value of the increase in crop yield by the cost of fertilizer applied to obtain that yield:

$$\frac{\text{Value of yield increase (in terms of money)}}{\text{Fertilizer cost (in terms of money)}} = \text{Value/cost-ratio}$$

A value/cost-ratio of more than 1 indicates that the fertilizer has been profitable. A VCR of 2 indicates a return of 100 percent: i.e. it means that, e.g. every US\$ 1 spent on fertilizers gives a return in additional crop yield of US\$ 2. Furthermore, the farmer generally receives this return already after a short period of investment, i.e. usually after a few months. However, the value/cost-ratio should be higher than 2 to secure a profitable return to the farmer.

The net return indicates the income increase in absolute amount of money. It is calculated by subtracting the cost of fertilizer used from the value of the increase in the crop produced through the use of fertilizer:

$$\text{Value of yield increase (in terms of money)} - \text{Fertilizer cost (in terms of money)} = \text{Net return}$$

A positive net return means that the fertilizer application was profitable. Net return and value/cost-ratio serve different purposes. Depending on the cost of the fertilizer applied, it may be the case that the highest value/cost-ratio is not always giving also the highest net return. In other words, the highest yield per hectare does not necessarily mean the highest return.

Making both the calculations will give you a tool to give to the farmer the most economic recommendation for fertilizer use possible.

CONDUCTING MEETINGS ON FERTILIZERS

As stated above, you should invite farmers and other community leaders (by postcard, letter, poster, newspaper or radio) to field days of the fertilizer demonstrations or trial plots near their village or farms, during the growing season of the crop on which you have laid out the demonstration.

Your invitation should include the following information:

- *Purpose of the meeting:* to see and to discuss a fertilizer demonstration on... crop.
- *Who is invited:* local farmers (with their wives), friends, community leaders, representatives of rural banks, fertilizer retailers, etc.
- *Place of the meeting:* clear directions where the meeting will take place and how to get there.
- *Time of the meeting:* month, day and hour.

For the field day you should have samples of fertilizers prepared to show them to the farmers. Demonstrate to them how the fertilizer had been applied. The host farmer should show and explain the growth and yield observations made on the different plots. If possible, harvest part of the plots with the participants and encourage them to estimate the expected yields of the plots treated as well as the plots untreated, and also estimate the resulting economic benefit through the application of fertilizers. Recommend to the farmers to carry out demonstrations on their own farms and fields.

In addition to those special field days, invite together with farmers (and their wives), retailers and village leaders to more general meetings to dis-

cuss and inform about fertilizers. Make these meetings a village affair by generating enthusiasm. These meetings work best if you can present photographs, coloured slides, posters or wall charts of trial and demonstration results. These should preferably have been obtained in your region. Make wall charts to explain the nutrient needs of plants and the role that fertilizers play in fulfilling those needs. Diagrams from this booklet may be helpful. Get the village chiefs to sponsor such meetings.

As stated before, because conditions change rapidly, the recommendation given for this year may not necessarily also be the optimal 'recipe' for the next year. Not only weather conditions change, but also rainfall, soil fertility and crop varieties planted are all subject to changes.

Considering farming in a wide general sense, one notes that farming is changing constantly. Therefore it is recommended that farmers, in addition to making proper use of fertilizers, should also aim at gaining the knowledge of all the underlying principles and processes, to enable them to cope with new situations or new and different problems. Farmers are forced to change their farming system or management practices when technical, economic or social conditions change.

Programmes for '*Integrated soil and nutrient management*' (ISNM), in a broad sense are sometimes implemented in '*Farmer Field Schools*'. Contact your governmental agencies to find out whether such '*Farmer Field Schools*' already exist in your country and/or whether they could be implemented in your region.

13. Conclusions

Fertilizers are one of the most important tools for agricultural development in support of food security and for maintaining soil productivity. Through your efforts, interest and enthusiasm, you can bring about a real change through introducing and expanding fertilizer use. It is your responsibility and a challenge for you to help to improve the living conditions in your region, and to help to maintain sustainable agriculture.

Annex: Conversion factors

Area and distance	
1 hectare	= 10 000 sq. metres = 2.471 acres
1 metre	= 1.0936 yards = 3.2808 feet = 39.37 inches
1 acre	= 4.840 sq. yards = 0.4047 hectare
1 yard	= 3 feet = 0.9144 metre
1 foot	= 12 inches = 0.3048 metre
Weight	
1 kilogram	= 1 000 grams = 2.2046 pounds
1 kg/ha	= 0.8922 lb/acre
1 metric ton	= 2 204.6 pounds = 1.1023 short tons = 0.9842 long ton
1 pound	= 0.4536 kilogram
1 lb/acre	= 1.1208 kg/ha
1 short ton	= 2 000 pounds = 0.9072 metric ton
1 long ton	= 2 240 pounds = 1.016 metric ton
Fertilizers	
Phosphorus	
To change P_2O_5 (phosphate) to P	multiply P_2O_5 by 0.4364
To change P to P_2O_5	multiply P by 2.2914
Potassium	
To change K_2O (potash) to K	multiply K_2O by 0.8302
To change K to K_2O	multiply K by 1.2046