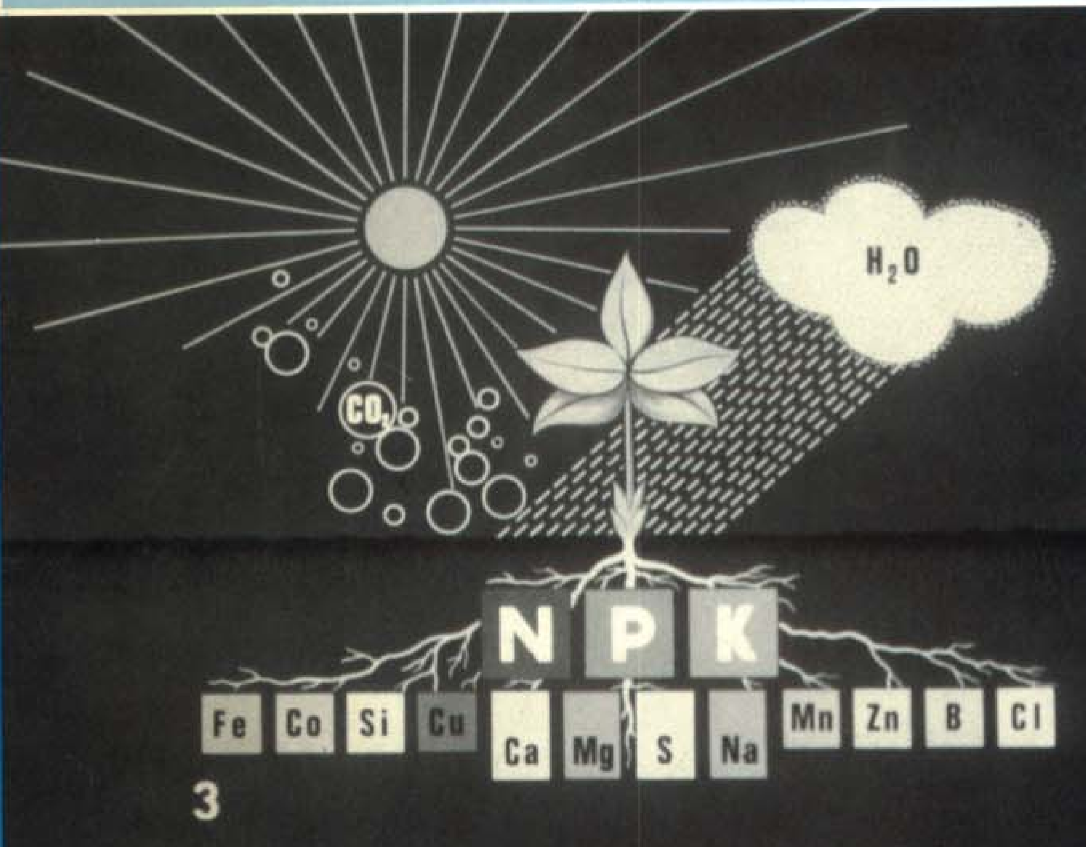
Fertilizer and plant nutrition guide

FAO
FERTILIZER
AND PLANT
NUTRITION
BULLETIN

9



FOOD
AND
AGRICULTURE
ORGANIZATION
OF THE
UNITED NATIONS

Fertilizer and plant nutrition guide

Fertilizer and Plant Nutrition Service
Land and Water Development Division

FAO FERTILIZER AND PLANT NUTRITION BULLETIN
9

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FOREWORD

The need is well-recognized for the efficient and integrated use of mineral fertilizers and other sources of plant nutrients, like organic materials, biologically fixed atmospheric nitrogen, etc., in order to achieve self-sufficiency in food production in developing countries.

FAO, through its Fertilizer Programme, has been deeply engaged in field activities for more than 20 years, in more than 50 economically developing countries. Its aim is to assist in increasing crop production, particularly of food crops grown by small farmers, through the development and application of appropriate fertilizer use and plant nutrition technology. One of FAO's earliest and most well-known publications entitled "Efficient Fertilizer Use" by V. Ignatieff and H.J. Page, first printed in 1950, served as a useful reference for many years. It has now been out of print for some time. Since then many countries have expressed concern at the lack of a single, handy reference source which treated all aspects of plant nutrition and fertilizer use in relatively simple language, to meet the requirements of a wide range of users.

The Fertiliser Association of India (FAI) had published its "Handbook on Fertiliser Usage", a comprehensive source of information which came closest, among all other known works of that nature, to the requirements of FAO in its services to its member countries. FAI reacted positively to the request to prepare a first draft of the Bulletin. This is gratefully acknowledged.

Much valuable guidance and assistance has been received from the members of the FAO/Fertilizer Industry Advisory Committee of Experts (FAO/FIAC) in adapting the content to various agro-ecological and technological conditions.

Mr. M. Holmes, whom FAO retained as a consultant, has assisted in merging suggested additions with the first draft. Final compilation and editing has been done in the Fertilizer and Plant Nutrition Service by Dr. R.N. Roy.

It is hoped that this Bulletin will at least partially fill the need for such a publication. Suggestions for possible improvements and additions for a future version of the Bulletin will be most welcome.

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1. INTRODUCTION

World population has grown from about 3000 million to 4400 million during the two decades between 1961 and 1981 and it is likely to reach 6300 million by the year 2000. To feed this population, it is necessary to double world foodgrain production during the next sixteen years.

Crop production can be increased either by increasing crop yields or by extension of virgin land. Between 1961 and 1981 world arable land and world population increased by 6 and 49 percent respectively. It has been estimated that 28 percent of the food requirements in the year 2000 could come from a further increase in the cultivated area while the remaining 72 percent must come from intensification of agriculture by the use of fertilizers and other inputs.

It is only in Africa and in parts of Latin America that large extension of agriculture onto virgin land is possible. Table 1 gives the area of arable land per person in different countries and shows how important it is to increase crop productivity in those countries with population pressure.

The role of fertilizers in increasing foodgrain production has been very evident, particularly during the last two decades. It is recognized that fertilizers have so far accounted for more than 50 percent of the increase in crop yields. Trials and demonstrations conducted by scientists all over the world clearly indicate the impact of fertilizer use on foodgrain yields per unit of land, and it is also evident that crop yields are higher in countries with higher fertilizer consumption per unit area (Table 2).

Fertilizer consumption expressed as N, P_2O_5 and K_2O increased from 30 million tonnes in 1961 to 115 million tonnes in 1981. It is interesting to note that about 27 percent of this increase took place in developing countries. The statistics also show that the share of developing countries in the expansion of arable land during 1961-81 accounted for 70 percent of the overall 6 percent increase.

To meet the foodgrain requirements of the year 2000, intensification of agriculture in developing countries as a group will require a three- to four-fold increase in fertilizer use coupled with the increased use of better seeds, pest control and improved water management. These global objectives will have to be implemented at national and regional levels, taking account of available resources.

The present world fertilizer strategy is to increase agricultural production through the efficient use of mineral fertilizers and other inputs and through improved farming methods. Fertilizer use efficiency is currently rather low, particularly in developing countries, and there particularly on rice. A vast potential, however, exists for improved efficiency. Increasing the efficiency of nitrogen from 30 to 50 percent in rice in a country which at present is using 2.8 million tonnes of nitrogen on that crop would provide a saving of 0.56 million tonnes of nitrogen, or contribute 6 to 8 million tonnes of additional foodgrains. Apart from increased availability of foodgrains, more efficient fertilizer use would also contribute to conservation of energy. Estimates show that one kilogram of nitrogen fertilizer needs about two kilograms of fossil fuel for its manufacture, packing, transport and application. The corresponding needs for phosphorus (P_2O_5) and potash (K_2O) are 0.33 and 0.21 kg respectively.

FAO has started to implement the concept of integrated plant nutrition systems that increase efficiency of use of all nutrient inputs, from mineral fertilizers, organic manures, and soil sources and biologically fixed atmospheric nitrogen, and optimize all other factors that enhance crop yields. An important objective is to sustain the farmers' economic interest in fertilizer use as a means of increasing agricultural production.

Table 1 ARABLE LAND PER HEAD OF POPULATION IN DIFFERENT COUNTRIES (1982)

Country	Population ('000)	Arable land area ('000 ha)	Land per head of population (ha)[1]
Australia	14 830	46 374	3.12
Bangladesh	93 269	8 916	0.10
Brazil	128 160	63 000	0.49
Canada	24 625	46 100	1.87
China	1 020 670	97 528	0.10
India	711 664	165 600	0.23
Indonesia	153 032	14 280	0.09
Iran	40 549	13 100	0.32
Japan	118 440	4 255	0.04
Kenya	17 864	1 900	0.11
Malaysia	14 765	1 020	0.07
Nepal	14 951	2 318	0.16
Pakistan	92 009	19 960	0.22
Sri Lanka	15 424	1 052	0.07
Thailand	49 200	17 100	0.35
USA	231 980	188 755	0.81

[1] Calculated

Source: FAO Production Yearbook, Vol. 36 (1982) and 37 (1983). FAO, Rome.

Table 2 FERTILIZER CONSUMPTION AND WHEAT YIELD

Country	Fertilizer consumption (kg N + P_2O_5 + K_2O per ha arable land and permanent crops, 1982	Average grain yield 1983 (t/ha)
Germany	435	5.44
France	299	5.13
Italy	161	2.56
China	158	2.83
USA	87	2.65
USSR	87	1.61
Pakistan	62	1.68
Turkey	54	1.86
Canada	44	1.97
India	35	1.84
Australia	24	1.72

Source: FAO Production Yearbook, Vol. 37 (1983) and Fertilizer Yearbook, Vol. 33 (1983). FAO, Rome.

2. PLANTS NEED FOOD

2.1 ESSENTIAL NUTRIENTS

In common with all living beings, plants need food for their growth and development. Man and other animals can only subsist on food in organic form, that is, on food derived from plant or animal products. Plants on the other hand have the ability to build up organic tissues directly from inorganic materials. They live, grow and reproduce by taking up water and mineral substances from the soil, carbon dioxide from the air and energy from the sun to form plant tissues.

Of the large number of elements that have been identified as occurring in plant tissue, only sixteen have been found to be indispensable for their growth, development and reproduction. These essential elements are referred to as "nutrients". To be categorized as essential, an element should meet the following three criteria:

i. A deficiency of the element makes it impossible for the plant to complete the vegetative or reproductive stage of its life.

ii. The deficiency symptoms of the element in question can be prevented or corrected <u>only</u> by supplying the element.

iii. The element is directly involved in the nutrition of the plant quite apart from its possible effect in correcting some microbiological or chemical condition in the soil or culture medium.

The essential elements are carbon, hydrogen and oxygen, which are derived from the air and soil water, and nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, zinc, manganese, copper, boron, molybdenum and chlorine, which are supplied from the reserves in the soil or through application of manures and fertilizers. In addition, certain plant species have been shown to benefit from the presence of cobalt, sodium, silicon and possibly vanadium, but these do not rank as essential nutrients.

Nitrogen, phosphorus and potassium are used in large quantities by plants and are therefore called "major (or primary) nutrients". Calcium, magnesium and sulphur are required in smaller but appreciable quantities and are now classified as "major" rather than "secondary" nutrients. Iron, zinc, manganese, copper, boron, molybdenum and chlorine are required by plants in very small quantities and are therefore referred to as "micronutrients" or "trace elements".

The thirteen mineral nutrients (i.e. excluding carbon, hydrogen and oxygen which are taken up from water and air) and the forms in which they are taken up by plants, are shown in Table 3.

Leguminous plants such as pulses (e.g. peas, beans, gram) and some forage crops (e.g. clover, lucerne) can obtain a part of their nitrogen from the air by bacterial fixation in their root nodules; other crops obtain their nitrogen only when it has been mineralized to plantavailable form from the organic residues in the soil and from applied fertilizers and manures.

A productive soil should contain all the essential plant nutrients in sufficient quantity and in balanced proportions. The nutrients must also be present in an available form before plants can use them. Inadequacy of any one of these elements will inhibit plants from growing to their full potential (Fig. 1).

Table 3 NUTRIENT ELEMENTS AND CHEMICAL FORM IN WHICH THEY ARE TAKEN UP FROM THE SOIL

Primary nutrients	Chemical form	Secondary nutrients	Chemical form	Micro-nutrients	Chemical form
Nitrogen	NH_4^+, NO_3^-	Calcium	Ca^{++}	Iron	Fe^{++}, Fe^{+++}
				Zinc	Zn^{++}
Phosphorus	HPO_4^-, $H_2PO_4^-$	Magnesium	Mg^{++}	Manganese	Mn^{++}, Mn^{+++}
				Copper	Cu^{++}
Potassium	K^+	Sulphur	SO_4^{--}	Boron	BO_3^{--}
				Molybdenum	MoO_4^{--}
				Chlorine	Cl^-

Each of the essential nutrients has a definite and specific function to perform in the growth and development of plants and a deficiency of any of them causes abnormal or restricted growth. The main functions of each nutrient and the effects caused by its deficiency are given in Table 4 (see page 7).

2.2 NUTRIENT INTERACTIONS AND MULTIPLE DEFICIENCIES

Crop growth can be effected in a number of ways by interactions between two or more plant nutrients. Multiple deficiencies can occur where soil supplies of several nutrients are inadequate. In such cases diagnosis may be difficult because one nutrient deficiency may mask the symptoms of a second, a situation that can arise, for example, when deficiencies of iron and zinc or manganese and zinc occur together. Multiple deficiency may also be aggravated by application of one nutrient which accentuates or induces deficiency of another, e.g. copper adversely affecting iron nutrition, phosphorus affecting zinc, or potassium affecting magnesium. Conversely, application of one nutrient often increases uptake and use of another, e.g. nitrogen often increases micronutrient uptake, magnesium may increase phosphorus uptake and high levels of phosphorus can favour molybdenum uptake.

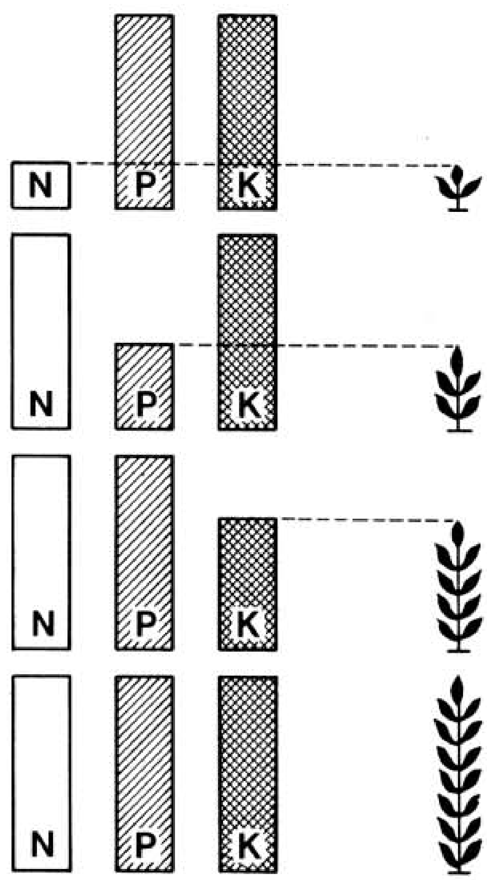

Fig. 1 Balanced application of N, P, K (Balanced does not imply that they are required in equal quantities; they are schematically represented to show their respective importance)

Finally, interactions in terms of crop growth and yield may be seen when an inadequate supply of one nutrient prevents the crop from making full use of others, e.g. when a low level of phosphorus inhibits response to nitrogen fertilizer.

2.3 INDICATOR PLANTS

All crop plants can exhibit the deficiency symptoms described above, to a greater or lesser degree depending on the severity of the deficiency. However, some species of plants have been found to be specially useful as indicators of particular deficiencies. These species of plants are more sensitive to the particular deficiency and the deficiency symptoms manifest themselves earlier and more prominently than in other crops.

A list of such indicator plant species for various deficiencies is given in Table 5.

Table 5 INDICATOR PLANT SPECIES FOR NUTRIENT DEFICIENCIES

Deficient element	Indicator plants
Nitrogen	Cereals, mustard, apple, citrus
Phosphorus	Maize, barley, lettuce, tomato
Potassium	Potato, clover, lucerne, bean, tobacco, cucurbits, cotton, tomato, maize
Calcium	Lucerne, other legumes
Magnesium	Potato, cauliflower, sugarbeet
Sulphur	Lucerne, clover, rapeseed
Iron	Sorghum, barley, citrus, peach, cauliflower
Zinc	Maize, onion, citrus, peach
Copper	Apple, citrus, barley, maize, lettuce, oats, onion, tobacco, tomato
Manganese	Apple, apricot, bean, cherry, citrus, cereals, pea, radish
Boron	Lucerne, turnip, cauliflower, apple, peach
Molybdenum	Cauliflower, other *Brassica* spp., citrus, legumes, oats, spinach
Chlorine	Lettuce

2.4 ELEMENTS WITH TOXIC EFFECTS

Application to plants of amounts of nutrients much in excess of their need may be harmful. This is more likely to occur in practice with micronutrients which are required by plants in very small quantities. Their excessive application may produce toxicity and affect the normal growth and development of plants. Toxicity of micronutrients causes characteristic symptoms which are specific for each nutrient but vary from crop to crop. For example, an excess of boron produces dry root in beet and chlorosis and defoliation in citrus. Excess of molybdenum causes golden shoot in tomato and manganese toxicity results in "stem streak necrosis" in potatoes.

It is therefore important to guard against over-application of nutrients, especially those which are required by crops in minute quantities.

Fig. 2

Nitrogen deficiency in maize (photo by courtesy of PPI, USA/Canada)

Fig. 3

Phosphorus deficiency in maize (photo by courtesy of von Uexküll, Kali und Salz AG, FR Germany)

Fig. 4

Potassium deficiency in soybean (photo by courtesy of Fauconnier, Kali und Salz AG, FR Germany)

Table 4 ROLE OF PLANT NUTRIENTS AND THEIR DEFICIENCY SYMPTOMS

Functions	Deficiency symptoms
Nitrogen (N)	
1. An important constituent of chlorophyll, protoplasm, protein and nucleic acids.	1. Stunted growth
2. Increases growth and development of all living tissues.	2. Appearance of a light-green to pale-yellow colour on the older leaves, starting from the tips. This is followed by death and/or dropping of the older leaves depending upon the degree of deficiency (Fig. 2).
3. Improves the quality of leafy vegetables and fodders and the protein content of food-grains.	3. In acute deficiency, flowering is greatly reduced.
	4. Lower protein content.
Phosphorus (P)	
1. A constituent of phosphatides, nucleic acids, proteins, phospholipids and coenzymes NAD, NADP and ATP.	1. Overall stunted appearance, the mature leaves have characteristic dark to blue-green coloration, restricted root development.
2. Constituent of certain amino acids.	2. In acute deficiency, occasional purpling of leaves and stems; spindly growth (Fig. 3).
3. Necessary for cell division, a constituent of chromosones; stimulates root development.	3. Delayed maturity and lack of or poor seed and fruit development.
4. Necessary for meristematic growth; seed and fruit development; stimulates flowering.	
Potassium (K)	
1. An activator of enzymes involved in photosynthesis and protein and carbohydrate metabolism.	1. Chlorosis along the leaf margins followed by scorching and browning of tips of older leaves; these symptoms then gradually progress inwards (Fig. 4).
2. Assists carbohydrate translocation; synthesis of protein and maintenance of its stability; membrane permeability and pH control; water utilization by stomatal regulation.	2. Slow and stunted growth of plants.
	3. Stalks weak, and plants lodge easily.
3. Improves utilization of light during cool and cloudy weather and thereby enhances plant ability to resist cold and other adverse conditions.	4. Shrivelled seeds or fruits.
4. Enhances the plant's ability to resist diseases.	
5. Increases size of grains or seeds and improves the quality of fruits and vegetables.	

Fig. 5 Calcium deficiency in cacao (photo by courtesy of BASF, FR Germany)

Fig. 6 Magnesium deficiency in maize (photo by courtesy of Kali und Salz AG, FR Germany)

Fig. 7 Sulphur deficiency in rice (photo by courtesy PPI, USA/Canada)

Functions	Deficiency symptoms
Calcium (Ca)	
1. Constituent of cell walls in the form of calcium pectate; necessary for normal mitosis (cell division). 2. Helps in membrane stability, maintenance of chromosome structure. 3. Activator of enzymes (phospholipase, argine kinase, adenosine triphosphates). 4. Acts as a detoxifying agent by neutralizing organic acids in plants.	1. Calcium deficiencies are not often seen in the field because secondary effects associated with high acidity limit growth. 2. The young leaves of new plants are affected first. These are often distorted, small and abnormally dark green. 3. Leaves may be cup-shaped and crinkled (Fig. 5) and the terminal buds deteriorate with some breakdown of petioles. 4. Root growth is markedly impaired; rotting of roots occurs 5. Desiccation of growing points (terminal buds) of plants under severe deficiency. 6. Buds and blossoms shed prematurely. 7. Stem structure weakened.
Magnesium (Mg)	
1. Constituent of chlorophyll molecule and therefore essential for photosynthesis. 2. An activator of many enzyme systems involved in carbohydrate metabolism, synthesis of nucleic acids, etc. 3. Promotes uptake and translocation of phosphorus. 4. Helps in movement of sugars within plant.	1. Interveinal chlorosis, mainly of older leaves, producing a streaked or patchy effect; with acute deficiency the affected tissue may dry up and die (Fig. 6). 2. Leaves usually small, brittle in final stages and curve upwards at margin. 3. In some vegetable plants, chlorotic spots between veins, and marbling with tints of orange, red and purple. 4. Twigs weak and prone to fungus attack, usually premature leaf drop.
Sulphur (S)	
1. Constituent of sulphur-bearing amino acids. 2. Involved in the metabolic activities of vitamins, biotin, thiamine and coenzyme A. 3. Aids stabilization of protein structure.	1. Younger leaves turn uniformly yellowish green or chlorotic (Fig. 7). 2. Shoot growth is restricted, flower production often indeterminate. 3. Stems are stiff, woody and small in diameter.

Fig. 8

Zinc deficiency in maize
(photo: Gupta, FAO 1983)

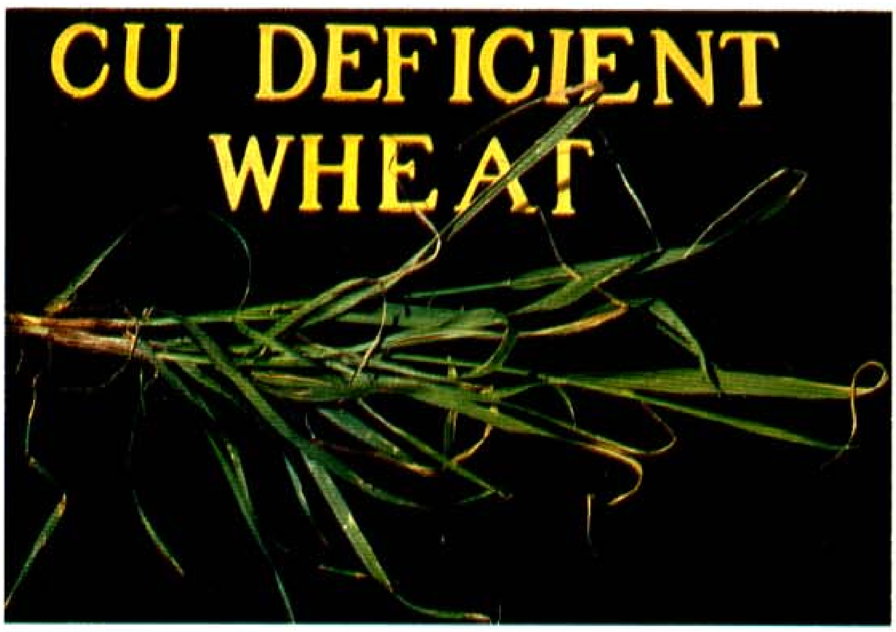

Fig. 9 Copper deficiency in wheat
(photo by courtesy of PPI,
USA/Canada)

Functions	Deficiency symptoms
Zinc (Zn)	
1. Involved in the biosynthesis of indole acetic acid. 2. Essential component of a variety of metallo-enzymes - carbonic anhydrase, alcohol dehydrogenase, etc. 3. Plays a role in nucleic acid and protein synthesis. 4. Assists the utilization of phosphorus and nitrogen in plants.	1. Deficiency symptoms mostly appear on the 2nd or 3rd fully mature leaves from the top of plants. 2. In maize, from light yellow striping to a broad band of white or yellow tissue with reddish purple veins between the midrib and edges of the leaf, occurring mainly in the lower half of the leaf (Fig. 8) 3. In wheat, a longitudinal band of white or yellow leaf tissue, followed by interveinal chlorotic mottling and white to brown necrotic lesions in the middle of the leaf blade; eventual collapse of the affected leaves near the middle. 4. In rice, after 15-20 days of transplanting, small scattered light yellow spots appear on the older leaves which later enlarge, coalesce and turn deep brown; the entire leaf becomes rust-brown in colour and dries out within a month. 5. In citrus, irregular interveinal chlorosis; terminal leaves become small and narrowed (little-leaf); fruit-bud formation is severely reduced; twigs die back.
Copper (Cu)	
1. Constituent of cytochrome oxidase and component of many enzymes - ascorbic acid oxidase, phenolase, lactase, etc. 2. Promotes formation of vitamin A in plants.	1. In cereals, yellowing and curling of the leaf blade, restricted ear production and poor grain set, indeterminate tillering (Fig. 9). 2. In citrus, die back of new growth; exanthema pockets of gum develop between the bark and the wood; the fruit shows brown excrescences.

Fig. 10

Iron deficiency in berseem (*Trifolium alexandrinum*) (photo: Gupta, FAO 1983)

Fig. 11

Manganese deficiency in soybean (photo: Agarwala, Sharma, Nautiyal, Khurana, FAO 1983)

Fig. 12

Boron deficiency in sugar-beet (photo: Agarwala, Sharma, FAO 1983)

Functions	Deficiency symptoms
Iron (Fe)	
1. Necessary for the synthesis and maintenance of chlorophyll in plants.	1. Typical interveinal chlorosis; youngest leaves first affected, points and margins of leaves keeps their green colour longest (Fig. 10).
2. Essential component of many enzymes.	
3. Plays an essential role in nucleic acid metabolism - affects RNA metabolism or chloroplasts.	2. In severe cases, the entire leaf, veins and interveinal areas turn yellow and may eventually become bleached.
Manganese (Mn)	
1. A catalyst in several enzymatic and physiological reactions in plants; a constituent of pyruvate carboxylase.	1. Chlorosis between the veins of young leaves, characterized by the appearance of chlorotic and necrotic spots in the interveinal areas (Fig. 11).
2. Involved in the plant's respiratory process.	2. Greyish areas appear near the base of the younger leaves and become yellowish to yellow orange.
3. Activates enzymes concerned with the metabolism of nitrogen and synthesis of chlorophyll.	3. Symptoms of deficiency popularly known in oats as "grey speck", in field peas as "marsh spot", in sugarcane as "streak disease".
4. Controls the redox potential in plant cells during the phases of light and darkness.	
Boron (B)	
1. Affects the activities of certain enzymes.	1. Death of growing plants (shoot tips) (Fig. 12).
2. Ability to complex with various polyhydroxy-compounds.	2. The leaves have a thick texture, sometimes curling and becoming brittle.
3. Increases permeability in membrane and thereby facilitates carbohydrate transport.	3. Flowers do not form and root growth is stunted.
4. Involved in lignin synthesis and other reactions.	4. "Brown heart" in root crops characterized by dark spots on the thickest part of the root or splitting at centre.
5. Essential for cell division.	
6. Associated with the uptake of calcium and its utilization by plants.	5. Fruits such as apples develop "internal and external cork" symptoms.
7. Regulates potassium/calcium ratio in plants.	
8. Essential for protein synthesis.	

Functions	Deficiency symptoms
Molybdenum (Mo)	
1. Associated with nitrogen utilization and nitrogen fixation.	1. Chlorotic interveinal mottling of the lower leaves, followed by marginal necrosis and infolding of the leaves (Fig.13)
2. Constituent of nitrate reductase and nitrogenase.	2. In cauliflower, the leaf tissues wither leaving only the midrib and a few small pieces of leaf blade ("whip-tail").
3. Required by *Rhizobia* for nitrogen fixation.	3. Molybdenum deficiency is markedly evident in leguminous plants.

Fig. 13 Molybdenum deficiency in sugarbeet (photo: Agarwala, Sharma, FAO 1983)

Functions	Deficiency symptoms
Chlorine (Cl)	
1. A constituent of auxin-chloroindole-3-acetic acid which in immature seeds takes the place of indole acetic acid.	1. Wilting of leaflet tips, chlorosis of leaves and finally bronzing and drying.
2. Constituent of many compounds found in fungi and bacteria.	
3. Stimulates the activity of some enzymes and influences carbohydrate metabolism and water holding capacity of plant tissue.	

3. SOIL AS THE BASIS OF CROP PRODUCTION

Soil is the medium which supports the growth of plants. It provides mechanical support, the water and oxygen supply to plant roots as well as the plant nutrients. Soil fertility is the capacity of soil to supply plant nutrients, water and oxygen in adequate amounts for optimum growth of the plant. The term soil fertility includes the chemical make-up and availability of nutrient elements to plants, the physical arrangements and properties of the soil particles and organic matter, which control water and oxygen availability, and the nature and activity of soil micro-organisms. The fertility of a soil is an important factor determining fertilizer requirements as well as the level of crop production that can be obtained.

3.1 SOIL FORMATION

Soils are formed from rocks by a process known as weathering. Weathering acts by both physical and chemical agencies. Physical agencies break the rock into smaller fragments and move them from place to place while chemical agencies change the mineral composition of the soil components. The effect of physical weathering is known as disintegration while that of chemical agencies is called decomposition. Temperature is the main factor in disintegration of rocks through alternate heating and cooling; the force of expansion due to the freezing of water in cracks and holes results in rapid disintegration of rocks. Disintegration of rocks is also caused by erosion under the influence of water, ice and wind and is also brought about by plant, animal and human factors. The action of water, and of the oxygen and carbondioxide in solution in it, is the main agent of decomposition of rocks. Some of the products of decomposition are water-soluble and can be leached from the soil in drainage water. The most highly weathered materials, formed by a combination of disintegration and decomposition, are the clay particles, the smallest in the soil. Many important soil properties - adhesion and cohesion of particles, plant nutrient holding power, water holding capacity - are governed by the content and nature of the clay fraction.

Weathering provides a medium the nature of which depends on the original parent material and which finally develops into soil by further soil-forming processes. Soil micro-organisms (fungi, bacteria, etc.) act on both the parent rock and the products of weathering, higher plants gain a hold and small animals also start to live on and in the soil. The activities of these organisms along with the decomposition of their remains accelerate the soil-forming process and turn the products of weathering into a biologically active medium, its fertility depending on the nature of the original rock, on the weathering process and on the climatic environment. Formation of a productive soil may take centuries or even thousands of years, but by misuse it may be destroyed in a few years. Thus, soil conservation and maintenance of fertility are of the greatest importance.

Disintegrated rock material can be moved from its place of formation by various agencies and deposited to form a soil elsewhere; material deposited by running water forms alluvial soils, wind-blown deposits are known as aeolian and ice movements lead to the formation of glacial deposits. Running water and wind transport small particles more readily than large, leading to considerable sorting by particle size. Soils formed from material remaining in its place of origin are known as residual soils.

Some of the products of weathering, including both water-soluble material and fine clay, can be removed from the surface layers and deposited lower down. Thus, different strata with different colour, texture

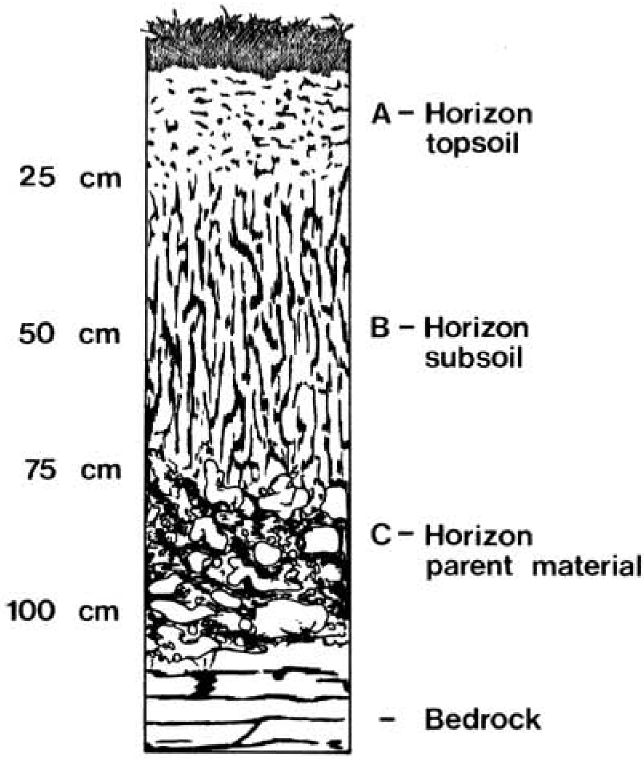

Fig. 14 Typical soil profile - a vertical cross-sectional view showing soil horizons

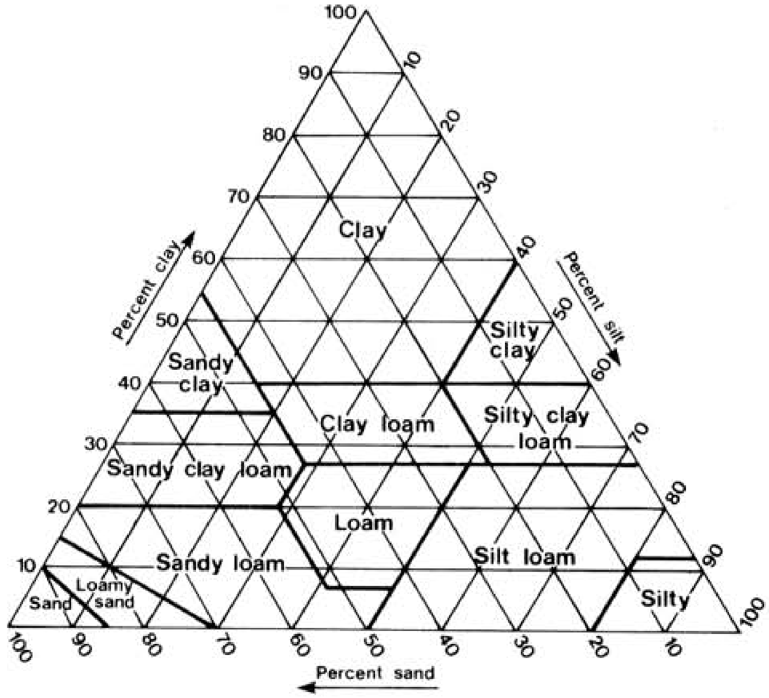

Fig. 15 Proportions of sand, silt and clay in different soil textural classes

and physico-chemical properties develop and the vertical section of a soil with these defined layers is described as a soil profile (Fig. 14). The individual layers are known as horizons.

In agriculture, the soil is often taken to be the shallow upper layer (the furrow slice) which provides much of the rooting medium, water and nutrient supply. However, most crops root much more deeply than this and obtain considerable sustenance from the soil's lower horizons, so that it is important to consider the whole soil profile in soil management decisions.

3.2 SOIL COMPOSITION

Mineral matter, air, water and organic matter are the main constituents of soil. The size of the mineral particles varies from coarse materials, such as stones, gravel and coarse sand to very fine particles of silt and clay. The organic matter is formed by the decay of plant and animal residues. The air and water occupy the empty spaces in the soil.

For proper crop growth the soil must be in a good physical, chemical and biological condition, the main requirements for which are described in the following sections.

3.2.1 Physical Properties

i. Soil texture

Soil texture refers to the proportion in which different sized mineral particles (2 mm and below in diameter) are present in the soil. The soil particles are generally divided into three basic textural classes (as per USDA) known as sand (2 to 0.05 mm in diameter), silt (0.05 to 0.002 mm) and clay (less than 0.002 mm). Soils are classified on the basis of the relative proportion of these particle sizes into texture groups such as sand, sandy loam, clay loam, clay, etc. (Fig. 15).

Soil texture can be approximately determined by the sense of feel in the field. Laboratory determinations can be done for confirmation. The farmers' terms "light" for sandy soils and "heavy" for clay soils are based on practical perception of ease of cultivation.

Soil physical properties such as ease of cultivation, nutrient and moisture holding capacity, aeration, drainage and to some extent suitability for cultivation, are much influenced by soil texture. Sandy soils provide good aeration and drainage and are generally loose and friable, and their cultivation is therefore easy. Soils with high clay content, having internal surface areas, have high absorptive capacity and retain nutrients and moisture well. Clayey soils generally have fine pores, are poorly drained and aerated and tillage operations are relatively difficult. Silty soils are intermediate between sandy and clayey soils and are suitable for most crops.

ii. Soil structure

Soil particles (sand, silt and clay) usually remain grouped together in the form of aggregates. The aggregation of soil particles in a definite pattern is known as soil structure. It can be best studied in the field under natural conditions.

The type of structure (Fig. 16) is determined by the size, shape and build up of soil aggregates. Granular structure having rounded porous particles is considered to be the best for crop growth. Soils with a granular structure usually have satisfactory porosity, moisture retention capacity, aeration and drainage characteristics and are said to have a good tilth. Tilth is promoted by timely tillage operations and by the maintenance of an adequate soil organic matter content, e.g. by application of organic manures.

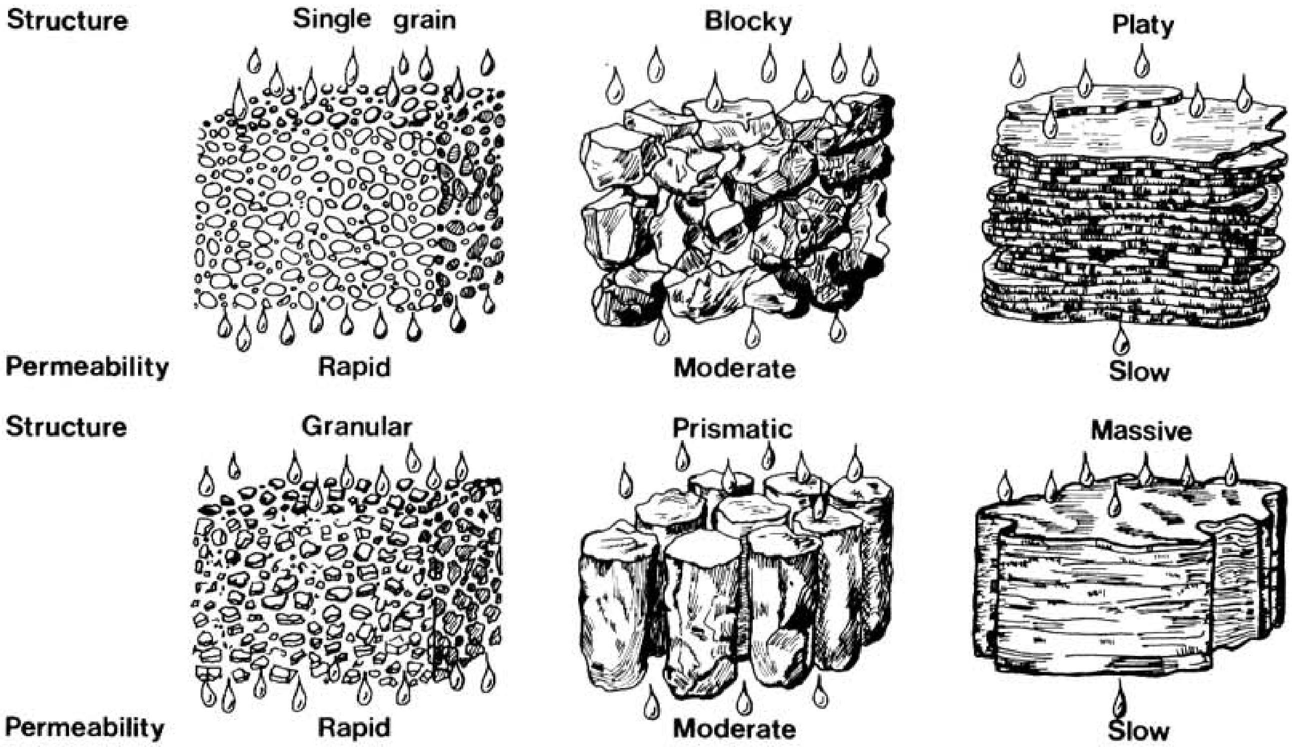

Fig. 16 Types of soil structure and permeability (rate of water movement through soil)

iii. <u>Soil water</u>

The space between soil particles is known as "pore space" and is filled by water and air in varying proportion, depending upon the moisture content of the soil. Fertile soils should supply plant roots with water and with oxygen from the soil air. The soil receives water in the form of precipitation or irrigation and loses it by drainage through the profile, by evaporation from the soil surface and by uptake and transpiration by plants. After a good rain or irrigation, all or almost all the pore space will be filled with water and the soil is said to be saturated. Some of this water can be lost by drainage, while some is held by and around the soil particles; when the free water has drained out (over a period of days, in some soils weeks) the soil is said to be at field capacity. Much of the water held in the soil at field capacity can be used by plants, but a proportion is too firmly held by the soil for crops to take it up. When crops have exhausted soil water to this level, the soil is said to be at wilting point. The amount of water between field capacity and wilting point is that available to crops. It varies very much, mainly in relation to soil texture and where rainfall is inadequate or sporadic is an important determinant of soil productivity.

iv. Soil air

The composition of soil air is about the same as that of the atmosphere but it contains more carbon dioxide and water (moisture) and less oxygen. The composition of soil air can change very quickly. A proper balance between soil water and air is necessary for the normal growth of plants. Rainfall, irrigation, drainage and tillage operations are the main factors governing the share of the pore spaces that are filled with water and air. Maintenance of adequate aeration is more difficult on clayey than on sandy soils.

3.2.2 Clay Minerals and their Effect on Soil Properties

The larger particles (sand and most silt) are chemically inactive. The seat of chemical activity in soil resides in the colloidal particles of clay and humus, less than 2 micron (μ i.e. 10^{-6}) in diameter. All soils except pure sands contain particles of colloidal size. Inorganic (clay) and organic (humus) colloidal particles exist in very intimate mixture and their properties are difficult to separate.

Clay is composed predominantly of secondary minerals (clay minerals) formed as products of weathering of the parent rock but not found as such in the parent material. Silicate clays and iron-aluminium hydrated oxide clays are the two recognized groups. The former generally occur in temperate regions while the latter are formed when weathering takes place in tropical and subtropical climates.

Each clay particle is made up of a large number of plate-like structural units. Because of their small size, clay particles expose a large amount of surface area and in addition have a plate-like structure which provides a large internal surface. The clay particles are hygroscopic and therefore attract large quantities of water to be held more or less firmly on their internal and external surfaces.

Because of their incomplete crystal lattice structure, clay colloids are negatively charged and exhibit many of the properties of anions. They thus attract positively charged ions (cations) and act as the storehouse of those plant nutrients that are held in soil or taken up as cations (NH_4^+, K^+, Mg^{++}, Ca^{++} and others). Clay minerals thus influence very strongly the nutrient and water supplying power of the soil.

3.3 CHEMICAL PROPERTIES OF SOIL

3.3.1 Plant Nutrient Sources

Plant nutrient sources in the soil may be divided into native and added components. Native sources are those derived from soil minerals and also those derived from decomposition of plant residues and soil organic matter. Added sources are those directly added in fertilizers or organic manures. All nutrients are subject to processes of immobilization and re-mobilization into plant-available form; the processes involved vary from nutrient to nutrient, and are both biological and chemical in nature. The biological processes are mainly uptake into soil microflora and release on its death and decomposition; they are particularly important in relation to nitrogen supply and moderately so for sulphur and phosphorus. Chemical processes include precipitation as insoluble compounds, to which phosphorus

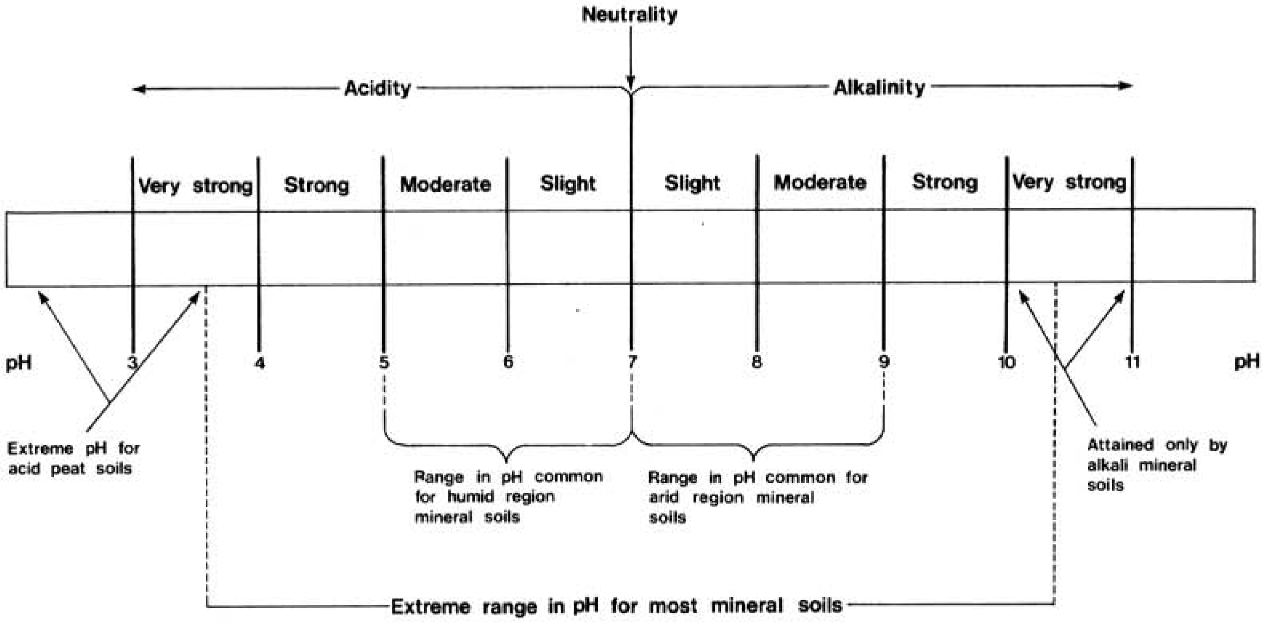

Fig. 17 Scale of soil pH values

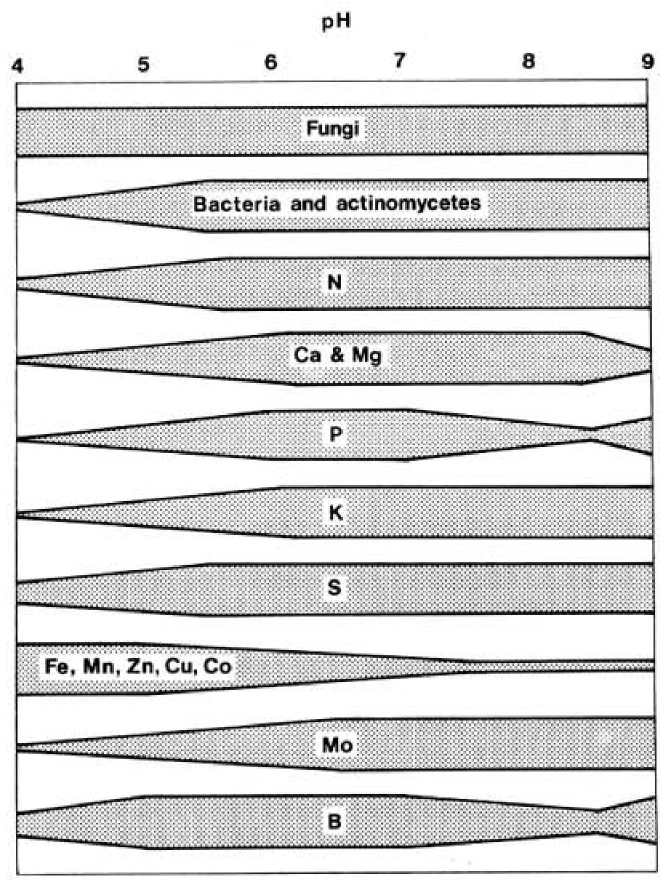

Fig. 18

Soil pH and relative availability of plant nutrients and activity of soil microflora (the wider the band, the greater the availability/activity) is especially subjected, and immobilization of cations in parts of the clay mineral cation adsorption complex, which can affect NH_4^+ and K^+ ions.

It is important to note that, for almost all nutrients the proportion of total soil nutrient content that is available to plants at any one time is very small.

3.3.2 Soil Reaction and its Effect on Nutrient Availability

Suitability of a soil as a medium for the growth of plants and desirable microorganisms depends considerably on the soil reaction (i.e. whether the soil is acidic, neutral or alkaline). The degree of acidity or alkalinity is expressed in terms of pH and it is conveniently expressed in the form of a scale (Fig. 17). The degree of acidity or alkalinity is largely controlled by the ratio of H^+ ions (acidic) to basic cations, mainly Ca^{++}, Mg^{++}, K^+ and Na^+. Very acid soils are dominated by H^+ ions, less acid and neutral soils by Ca^{++} (with Mg^{++}, K^+ and H^+) while the presence of considerable Na^+ gives an alkaline reaction.

Soil reaction has a great influence on the availability of plant nutrients which is generally highest between pH 6.5 and 7.5 (Fig. 18). In particular, phosphorus is rendered unavailable in very acid soils because of precipitation as insoluble iron and aluminium phosphates, and in high pH soils by precipitation of insoluble forms of calcium phosphate. Biological activity is also greatest at intermediate pH levels (around pH 7) so that the breakdown of soil organic matter and release of nutrients such as nitrogen, phosphorus and sulphur to plant available forms is enhanced. Acidic soils can be limed and alkaline soils can be reclaimed by application of gypsum or sulphur to bring the pH nearer to 7.0 (neutral).

3.3.3 Optimum Soil Reaction for Crops

Crops differ in adaptability to soil reaction. Many important crops, e.g. barley, tobacco, lucerne, are sensitive to acidic soils and suffer injury when grown on them, while others such as oats, potatoes and tea tolerate acidity fairly well. Rice under wetland (waterlogged) conditions can be grown very well over a wide pH range. The pH ranges suitable for important crops are shown in Figure 19.

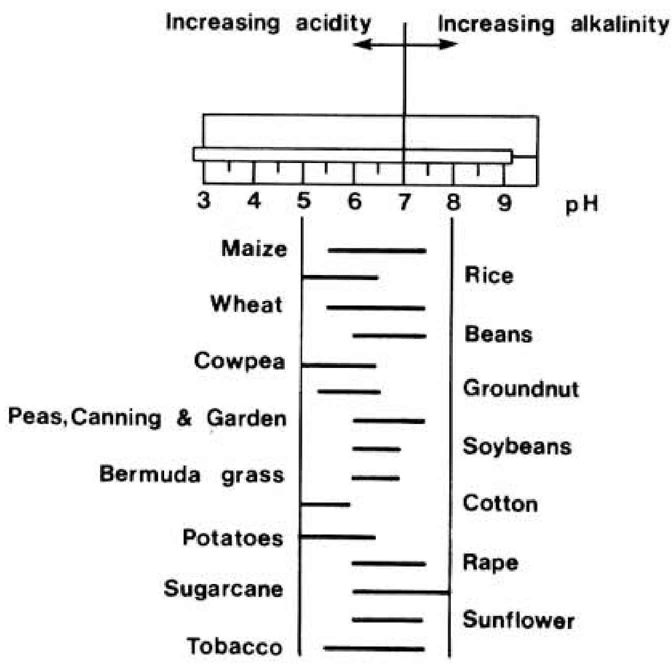

Fig. 19 Optimum soil pH for different crops

3.4 SOIL ORGANIC MATTER

3.4.1 Sources of Organic Matter

Generally, soil contains a variable but relatively small percentage of organic matter in intimate mixture with its mineral components and derived from the remains of plants and animals, including roots, stubble and other residues of harvested crops, and soil micro-organisms such as bacteria, fungi, earthworms. The type and amount of organic matter present in the soil are determined by a number of factors including soil reaction, type of vegetation, the kind of soil microbes present, drainage, rainfall, temperature, and management practices. Under field conditions, crop residues, green manure, straw, compost and other organic manures contribute to the replenishment of soil organic matter. All these materials are decomposed by soil organisms of different kinds and finally converted into a fairly stable amorphous brown to black material known as "humus", not resembling in any way the materials from which it originated.

3.4.2 Role of Organic Matter

Soil organic matter has many important functions:

i. it helps in binding fine particles together into structural units (soil aggregates), thus helping to maintain the soil in a loose and open granular condition and to improve its tilth;

ii. it improves soil aeration and the percolation and downward movement of water and thus reduces risk of soil erosion;

iii. it increases the water and nutrient holding power of the soil and in this way many nutrients are protected from losses due to leaching;

iv. it increases the amount of available water in sandy and loamy soils;

v. it provides a reserve of plant nutrients. Most of the soil nitrogen and much soil phosphorus and sulphur exist in organic forms which, when the organic matter decomposes, are made available to growing plants;

vi. it supplies a number of micronutrients and growth promoting substances such as hormones;

vii. raw organic matter acts as a source of food for soil microbes and thus maintains microbial activity and release of nutrients from organic to plant-available form;

viii. organic acids, which are breakdown products of soil organic matter, solubilize soil phosphorus and other micronutrients and make them available for crop growth.

In tropical zones, soil organic matter content is generally low due to rapid breakdown at high temperature and it is difficult to increase it, but in temperate areas it is usually relatively higher and maintenance is also easier. Whenever necessary, efforts should be made to maintain or increase it by adding farmyard manure, compost, green manure, etc., to improve the physical and chemical properties of the soil and thus obtain the benefits of higher crop production.

3.5 SOIL ORGANISMS

The soil organisms include animals such as rodents, insects and earthworms as well as various forms of microflora including algae, fungi and bacteria. Some of them are useful while others are harmful to plants. The useful microbes attack the fresh organic matter and release the plant nutrients in simple inorganic forms to be used by crop plants. For example, through decomposition of organic matter by microbes, nitrates, sulphates, phosphates and micronutrients are released from the organic matter and are then utilizable by crops. The harmful organisms and insects attack crop plants and cause numerous plant diseases and pest problems.

Some bacteria are also capable of fixing atmospheric nitrogen for their own metabolic purposes. After their death and decomposition, the fixed nitrogen becomes available for the growth of crop plants. Some of these bacteria live in association with higher plants while some are independent. The former are known as symbiotic while the latter are called free-living bacteria. Free-living bacteria can live independently of crop plants provided environmental conditions (soil moisture, temperature and nutrients) are suitable. Symbiotic bacteria living in the nodules on the roots of legumes (clovers, peas, beans, etc.) fix the atmospheric nitrogen in a form usable to themselves and the host plants and also to the subsequent crops grown in the same field.

3.6 MAIN SOIL UNITS AND THEIR CHARACTERISTICS

World soils have been classified according to their main characteristics into a number of soil units (FAO/Unesco). Constraints and management practices in relation to the properties of soils of some major units are briefly described below.

3.6.1 Ferralsols (Oxisols)[1]

Constraints with Ferralsols result from a low level of plant nutrients, low cation exchange capacity and weak retention of bases applied as fertilizers or amendments, and strong fixation and deficiency of phosphates on fine-textured soils. Also included are sulphur deficiency; nitrogen losses through leaching in the high rainfall areas unless a continuous plant cover ensures rapid recylcing; acidity; exchangeable aluminium, which at high saturation becomes toxic to plants; and very low calcium content resulting in limited rooting volume and increased hazard of moisture stress. Trace element deficiencies are frequent. Microelement toxicities may occur, especially in soils formed from ultra-basic rocks.

The degree of the constraints varies considerably between the different kinds of Ferralsols. Acric Ferralsols show a higher aluminium toxicity than the orthic ones, which in turn have higher aluminium contents that the rhodic groups.

Within the humid zone, Ferralsols under semideciduous forest have a considerably higher content of plant nutrients in the surface layer than those under evergreen forest. Coarse-textured Ferralsols are less prone to phosphate fixation, but they are less resistant to erosion than the better structured clayey ones.

3.6.2 Acrisols (Ultisols pp.)[2]

Acrisols have constraints of low nutrient levels, presence of exchangeable aluminium, nitrogen losses through leaching under high rainfall, and trace element deficiencies, e.g. boron and magnesium. Nutrient reserves are concentrated in the surface horizon and their maintenance depends on a continuous recycling through vegetation unless fertilizers are added. An additional constraint is sensitivity to erosion because of less favourable structure in the surface layers and the decrease of permeability in the argillic B horizon. Short-term surface waterlogging may occur during heavy rains. Acrisols are easily damaged by compaction and loss of surface

[1] Equivalents in USDA Soil Taxonomy are given in parentheses.

[2] pp. = *pro parte*, i.e. the two terms correspond only in part.

soils when heavy equipment is used for deforestation or tillage operations. With adequate management, the presence of the argillic B horizon is an asset for moisture retention.

3.6.3 Nitosols (Paleudults, Paleustults, Paleudalfs, Paleustalfs, pp.)

Nitosols have a nutrient deficiency status simular to that of Ferralsols but less acute. A subdivision is made in dystric and eutric Nitosols, the latter having medium to high base saturation and hence no constraints of exchangeable aluminium. Moderate phosphate fixation occurs.

Manganese toxicity may arise in the more acid Nitosols. The deeply stretched argillic B horizon and the progressive textural change favour moisture retention and reduce the hazard of erosion to which Acrisols are subjected.

3.6.4 Luvisols (Alfisols, pp.)

By definition Luvisols have a moderate to high base status and do not have major constraints related to acidity, calcium deficiency, or phosphate fixation. Luvisols straddle the subhumid and the semi-arid zones. In the former, they often occur on strongly weathered parent materials, the clay fraction of which is of low activity. Hence the total amount of plant nutrients is still low and major elements are deficient. In the semi-arid zone, Luvisols develop from a variety of parent materials - generally less strongly weathered - which determine their chemical composition. The saturation complex is dominated mostly by calcium, as a result of which microelement deficiencies - e.g. zinc - may occur. Moisture stress and sensitivity to erosion, particularly when there is inadequate crop cover, are major constraints. Low aggregate stability and surface sealing by rains, resulting in increased runoff and impeded plant germination, are common in Luvisols. In the subhumid wooded savannah, subsurface layers of plinthite, ferruginous concretions, or hardpans are present over relatively large areas. Erosion is then particularly damaging, because layers unfit for production are surfacing irreversibly.

3.6.5 Vertisols (Vertisols)

Constraints with Vertisols are related to their physical properties and moisture regime. Their heavy texture and the presence of expanding-type clay minerals result in a very narrow range between moisture stress and water excess. Tillage is hampered by stickiness when wet and hardness when dry. Base saturation is high, with calcium and magnesium prevailing in the sorptive complex. Phosphorus availability is generally low. Erosion during fallow and seasonal waterlogging are serious hazards to crop production. They can be overcome through appropriate management practices.

3.6.6 Planosols (Albaquults, Albaqualfs)

The occurrence of Planosols in flat or depressed topography and the slow permeability of the subsurface horizons result in very slow external and internal drainage. Waterlogging in the wet season and acute water stress in the dry season are major constraints to crop production. Strong leaching and low cation exchange capacity in the surface horizons entail nutrient deficiencies. Aluminium toxicity may occur in strongly developed Planosols. When Planosols are used as rangeland, copper and cobalt deficiencies often have to be remedied.

3.6.7 Arenosols (Psamments, pp.)

The low productivity of the Arenosols is linked with a general paucity of nutrients in coarse-textured quartzy materials, low water retention, low cation exchange capacity, and a deficiency in minor elements normally bonded to the clay or organic matter (zinc, manganese, copper, iron). The efficiency of applied nutrients, especially nitrogen, is impeded by strong leaching. Sulphur and potassium deficiencies are common in the Arenosols. Weak structure leads to compaction and favours water and wind erosion. These characteristics equally apply to large areas of coarse-textured Regosols.

3.6.8 Andosols (Andepts)

The presence of amorphous hydrated oxides in Andosols induces a very high phosphate, borate, and molybdate fixing capacity. In basic volcanic ashes, nutrient imbalances may occur in the presence of a high proportion of ferro-magnesium minerals, which by weathering provide a dominance of magnesium over calcium in the exchange complex. Aluminium toxicity is frequent in the more acid Andosols. Manganese deficiencies occur.

3.6.9 Podzols (Spodosols)

Nutrient deficiencies in Podzols are acute and related to coarse-textured quartzy materials, excessive leaching, and the formation of complex organic matter-metallic compounds. There is a general lack of nitrogen and potash, and phosphate availability is reduced by the presence of exchangeable aluminium. Improvement of the Podzols is hampered by an extremely low retention capacity and rapid losses of applied nutrients. Copper and zinc deficiences are common. Most of the Podzols in the tropics are of the groundwater type and have waterlogging during the wet season and water stress during drier weather. Shifting cultivation on these soils is hazardous because of very slow regeneration of the natural vegetation.

3.6.10 Cambisols (Tropepts)

Constraints on the various types of Cambisols (vertic, ferralic, calcic, dystric, gleyic) are similar, but normally less strongly pronounced than those of the more developed soils with which they are associated: Vertisols, Ferralsols, Luvisols, Acrisols, Gleysols.

3.6.11 Xerosols (Aridisols, pp.)

Moisture stress is the most serious limiting factor to plant growth on Xerosols. When water is available, fertility problems may result from high calcium carbonate content, reduced availability of phosphorus, salinity and alkalinity hazards, and deficiencies or iron and zinc. Xerosols with high gypsum contents may cause serious engineering problems for irrigation construction.

3.6.12 Yermosols (Aridisols, pp.)

Drought is a permanent feature with Yermosols. When irrigation is applied, fertility problems and salinization hazards are similar to those described for Xerosols.

3.6.13 Solonchaks (Salorthids and saline phases, pp.)

As a result of the high concentration of salt in the soil solution, moisture stress and hindrance to normal ion uptake by plants are major constraints in Solonchaks. Depending on the nature of the salt present, different elements may be in excess. The economic implications of reclaiming saline soils are a major constraint to increased production.

3.6.14 Fluvisols (Fluvents)

The great variability of the Fluvisols (alluvial soils) does not permit a characterization of the nutrient status for the group as a whole. The fertility of Fluvisols is directly related to the materials from which they are derived, which are not necessarily those adjacent to their location. Flood hazard is a common constraint on Fluvisols, especially in areas with seasonal rainfall patterns. Special mention should be made of thionic Fluvisols, which are widespread in the tropics. Waterlogging under natural conditions, and extreme acidity upon drainage leave a very narrow margin for the management of these soils. The very low pH is accompanied by toxicities of aluminium, manganese, and iron.

3.6.15 Gleysols (Aquepts, Aquents)

Water excess is a major feature of Gleysols. Their base status is usually related to the nutrient content of the surrounding upland soils. The effectiveness of nitrogen application is hampered by denitrification under wet conditions. Profile development varies considerably and determines the response to management techniques. In the humid and subhumid zones, Gleysols often show plinthite or concretionary layers in depth. Drainage designs should take account of these phenomena so as to avoid hardening or pan formation.

3.6.16 Histosols (Histosols)

Waterlogging, low bearing capacity, weak foothold for plants, subsidence upon drainage, frequent microelement deficiencies - e.g. copper - and irreversible shrinking of the organic material upon drying are major constraints to agricultural production on Histosols. Acid peats are very low in major nutrients. Soils that contain 60 percent or more organic matter on a dry weight basis show silica deficiency in plants that require this element for tissue strength. Poor accessibility and lack of infrastructure hinder reclamation of the Histosols.

4. HOW THE PLANT FEEDS AND SOIL NUTRIENT CYCLES

4.1 NUTRIENT UPTAKE

Plants normally absorb nutrients through their roots, but they can also absorb some quantity through leaves if applied to them in solution. The nutrients enter the plant roots as ions - very minute, ultramicroscopic particles carrying electrical charges. Ions may carry a positive electrical charge when they are called cations; these include ammonium (NH_4^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), manganese (Mn^{++}). Negatively charged ions are called anions and include phosphate ($H_2PO_4^-$ or HPO_4^{--}), nitrate (NO_3^-), sulphate (SO_4^{--}).

4.1.1 Root Systems

When a seed germinates the first root that appears is known as the primary root. It gradually elongates, grows in diameter and produces lateral branches, or secondary roots. The primary root and its branches together are known as the primary root system and in many species this remains the only root system throughout the life of the plant. In perennial plants, such primary root systems may become very large. Roots that develop later, e.g. from the hypocotyl region of cereal plants, are called adventitious roots.

The depth to which roots penetrate in soils is in part a species characteristic but prevailing soil conditions usually exert a pronounced effect. The presence of a compacted soil layer or hardpan greatly hinders the penetration of the lower soil layers by roots. If a water table is close to the soil surface the downward growth of roots of most species (except hydrophytes) is retarded because of the poor aeration of saturated soils. Dry soil conditions also inhibit extensive root growth. In deep, moist and well drained soils, on the other hand, the depth of penetration of roots is limited not by soil conditions but by plant growth potential.

The lateral extent as well as the depth of penetration is an important feature of any root system. In general, the lateral roots lying close to the soil surface attain the greatest horizontal spread but this varies according to the environmental conditions to which the root system of the plant is subjected. Arid climates increase the lateral spread of the root system of many species and with increased lateral development there is usually a decrease in the depth of penetration. Plant density is also a factor influencing the lateral spread of roots, since surrounding crop plants will restrict lateral spread from an individual plant.

Most of the absorption of water and mineral salts occurs near the root tips, in microscopic side-growths known as root hairs. Because of the extensive branching of roots there are often millions of root tips on the root system of a mature plant. The number of root tips borne by a root system seems to be the most important index of its effectiveness in obtaining water and mineral salts from the soil.

4.1.2 Soil Solution as Nutrient Medium

The soil solution comprises water and dissolved substances held in the soil pores. Its composition varies considerably from soil to soil, depending mainly on the nature of the parent material of the soil and on the vegetation. Saline and non-saline clay soils yield solutions rich in calcium, sodium and chloride. Particularly for those ions which are mainly present in a dissolved state (e.g. NO_3^-, Cl^-), the concentration of the soil solution tends to be inversely proportional to the moisture content of the soil. This relationship is less marked with cations, a high proportion of which are adsorbed by soil colloids, and hardly exists for phosphate, whose concentration is controlled by the low solubility of calcium and other phosphates. The concentrations of all ions, including sodium but excepting phosphate, increase with decreasing volume of soil solution more rapidly than can be accounted for on the assumption of a simple solution of salts in water, probably because much of the soil water is bound to colloidal particles and does not form a true solution.

4.1.3 Physico-chemical Process of Nutrient Uptake

Plant roots excrete carbon dioxide (CO_2) which combines with water to form carbonic acid (H_2CO_3). The roots also excrete other organic acids and the components of these acids dissociate into positive and negative ions. These ions are exchanged for similar ions present in the soil solution, such as K^+, NH_4^+, $H_2PO_4^-$, NO_3^-, SO_4^{--} which are absorbed by the root hairs and tips and translocated to other parts of the plant for its various metabolic processes. The plant roots thus excrete cations or anions in exchange for nutrient cations or anions which they absorb (Fig. 20).

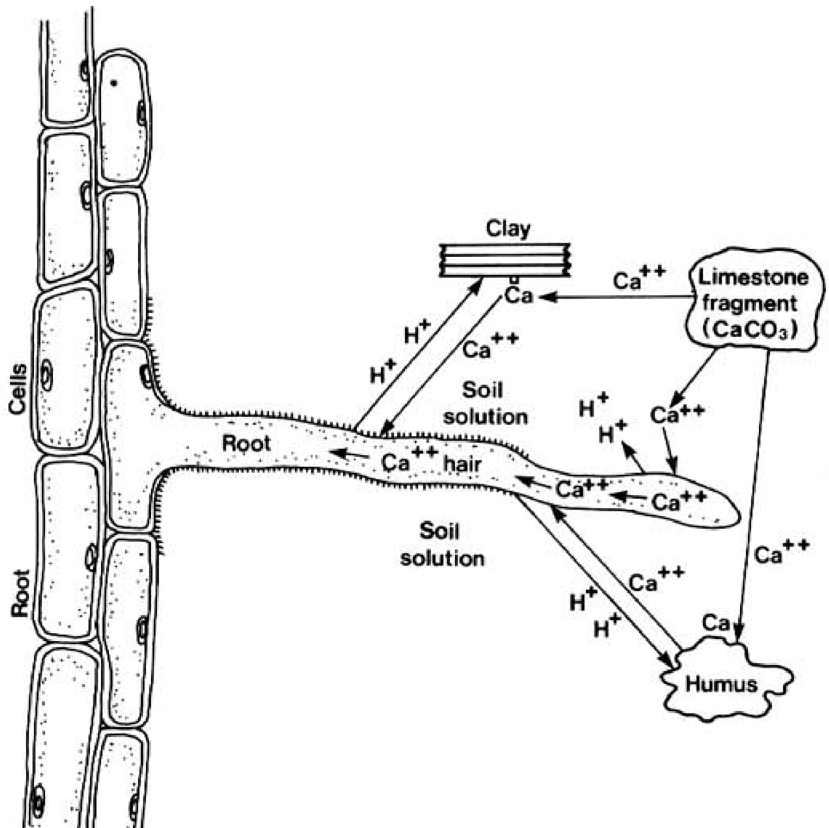

Fig. 20 Absorption of nutrients through root hairs

The details of the process or processes by which plants obtain nutrients from the soil are still controversial but becoming better understood. Two mechanisms are thought to operate:

i. Soil solution mechanism: The primary water layer on the surface of colloid particles is a tightly bound film not readily removed by roots. Around this layer is a lightly held film of capillary water known as soil solution, batheing the roots. Exchange takes place at the root hair surface, ions being absorbed from solution in exchange for ions excreted by the roots.

ii. Contact mechanism: In the contact mechanism the soil solution is bypassed and exchange takes place directly between the soil particle and the root. Both root surface and clay particle have exchangeable ions, and when the root contacts the clay particle, the ion exchange takes place. An example based on H^+/Ca^{++} exchange is as follows:

$$\underset{\text{(root)}}{2H^+} + \underset{\text{(clay)}}{Ca^{++}} \longrightarrow \underset{\text{(root)}}{Ca^{++}} + \underset{\text{(clay)}}{2H^+}$$

This reaction occurs without the nutrient ion entering solution and applies to all ions (e.g. NH_4^- , K^+, Mg^{++}) that are adsorbed by soil colloid particles.

It is now generally considered that the soil solution mechanism accounts for a very high proportion of total uptake and that the contact mechanism is relatively unimportant.

4.1.4 Active and Passive Absorption

Ion absorption by roots may be described as active or passive. Passive absorption occurs when nutrients move from areas of high to low concentration, without the expenditure of energy by the plant. However, nutrient ions can also move against a concentration gradient (i.e. from soil solution into a zone of higher ionic concentration within the plant) by an active process involving the expenditure of energy. This process is not yet fully understood, but involves the use by the plant of chemical "ion-carriers" to which ions are attached for their passage through cell membranes. There are thought to be a number of carriers, each specific to one or more ions.

Soil oxygen supply is critical to active absorption. Lack of soil oxygen hinders production of energy by roots and therefore limits nutrient uptake. This condition prevails in waterlogged soils and explains why N deficiency can occur in maize though soil N supplies are ample, or why K deficiency can occur in poorly drained soils. Cold soils restrict active absorption because low temperatures hinder production of respirational energy. Such conditions frequently induce phosphorus and zinc deficiencies.

4.2 NUTRIENT CYCLES

Nutrient cycles describe the transformation of nutrients from one form to another in the soil and account for the various ways in which a nutrient is added to or lost from the soil.

The transformations are very complex and for individual nutrients are governed by different physical, chemical and biological factors. A proper understanding of them is important as a basis for effective and efficient use of fertilizers.

All the essential plant nutrients undergo a cycle of changes and those for nitrogen, phosphorus and potassium, as important major nutrients, are described below.

4.2.1 Nitrogen Cycle

i. Normal soils: The complex nitrogen cycle in normal soils is shown in Figure 21. In summary, the inputs are by bacterial fixation of atmospheric nitrogen, as ammonia dissolved in rain, in organic manures and in fertilizer. The main losses are by plant uptake, by leaching of nitrate in drainage water, by denitrification (bacterial reductions under anaerobic conditions, of nitrate to nitrogen and nitrous oxide gases which are lost to the atmosphere), and by volatilization of ammonia from the soil surface to the atmosphere. The main bacterial conversions of nitrogen in the soil are from organic form to the ammonium form and then to nitrate. Both ammonium and nitrate nitrogen can be taken up by plants and by soil micro-organisms - the latter converting them back to organic form and thus rendering them temporarily unavailable to plants. Management of fertilizer and organic manure applications should be directed to making mineral nitrogen available during periods of rapid crop growth and nutrient uptake, and consistent with this, to minimizing the amounts of nitrate likely to be present and at risk to leaching or denitrification in periods of heavy rainfall or soil waterlogging. The risk of loss by any cause and the steps necessary to reduce this loss vary very much with climate, soil and cropping conditions. Risks of loss by leaching or denitrification are greater where rainfall is high. Where rainfall is high during the growing season, e.g. in monsoon climates, and leaching or temporary waterlogging can occur, losses of nitrogen are particularly likely and may be minimized by split fertilizer applications. Where surplus rainfall occurs outside the growing season, as in many temperate areas, it is normally possible to apply fertilizer and manures at times of minimum risk of loss.

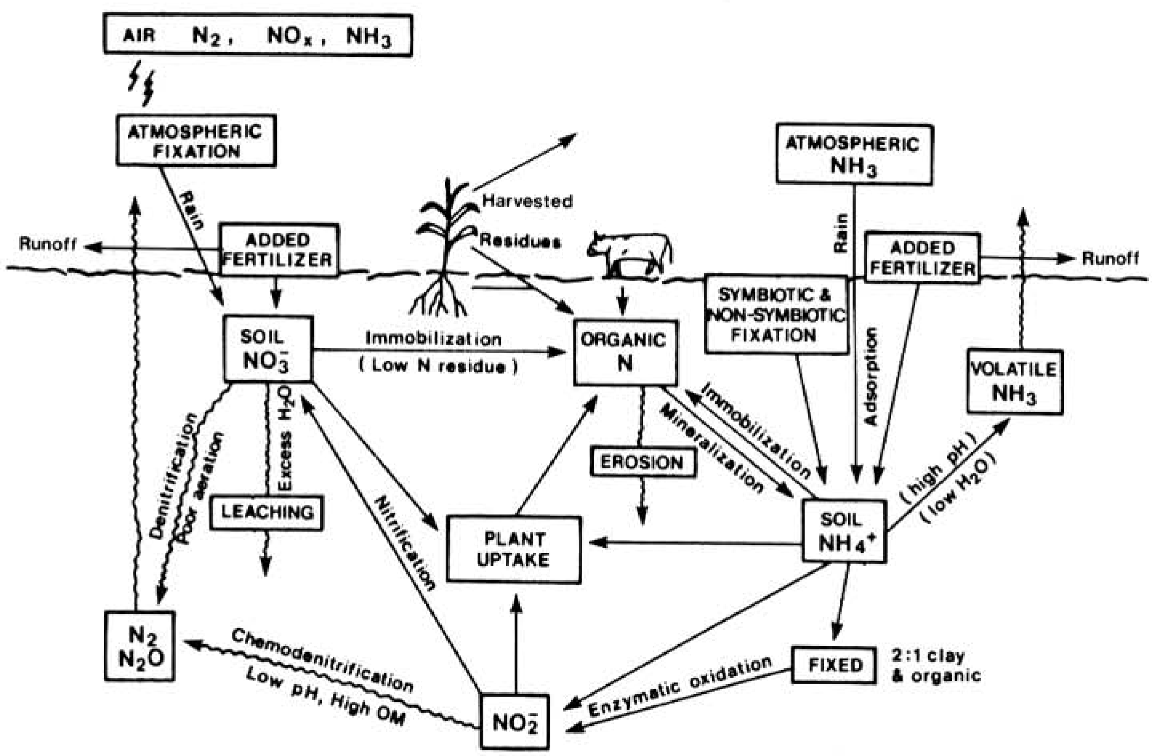

Fig. 21 Nitrogen cycle in soil

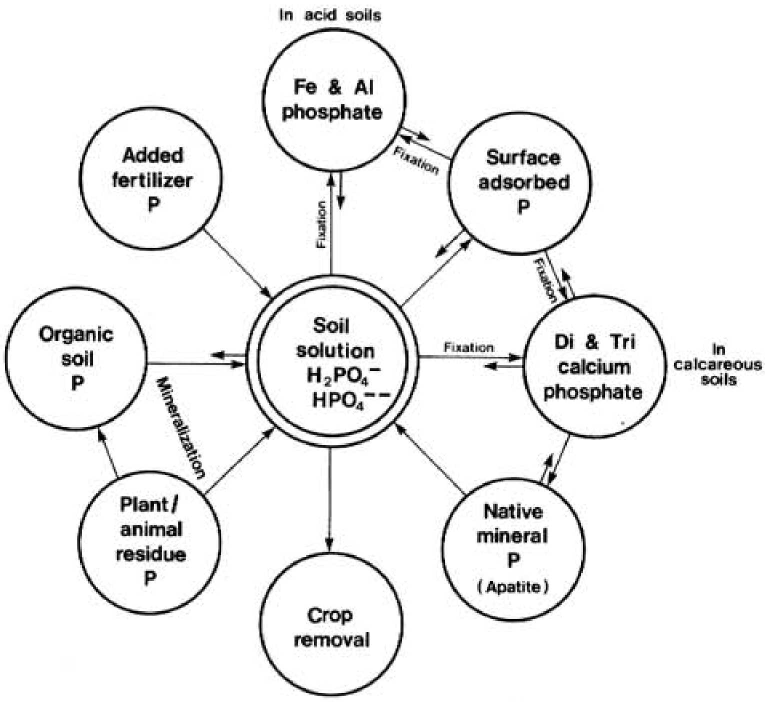

Fig. 22

Phosphorus cycle in soil

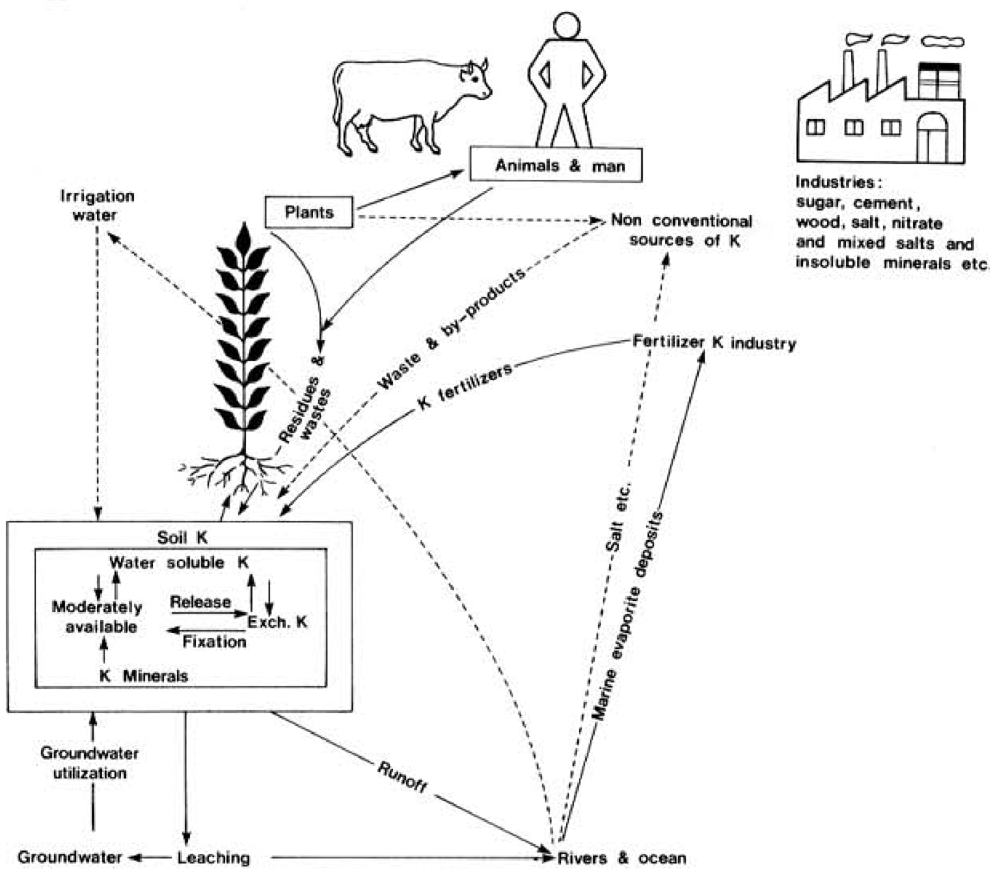

Fig. 23 Potassium cycle in soil

ii. Submerged soil: In submerged soils, e.g. wetland rice, the main transformations are the accumulation of ammonia, denitrification and nitrogen fixation. The mineralization of organic nitrogen in submerged soils stops at the ammonia stage because of lack of oxygen to carry the process to nitrates and so ammonia accumulates in these conditions. Existing nitrate undergoes two transformations in submerged soils: (a) reduction of nitrate resulting in gaseous loss of nitrogen; and (b) nitrate respiration in which nitrate functions as an alternative to oxygen. Consequently the bulk of the natural or added nitrate disappears within a few days in most soils.

Biological nitrogen fixation in which ammonia is formed from nitrogen gas needs an energy input, which can be obtained by photosynthesis or anaerobic respiration. Submerged soils with blue-green algae (and sometimes nitrogen fixing photosynthetic bacteria) at the surface and nitrogen fixing bacteria in the bulk of the soil are favoured conditions for nitrogen fixation.

Choice and management of nitrogen fertilizer are of vital importance for efficient rice production.

iii. Rainfed land: In low rainfall areas the traditional use is most often grazing, with a varying degree of nomadism. The level of inorganic nitrogen in the soil, consisting in a natural ecosystem of both NO_3^- and NH_4^+ ions, is governed by the balance between supply from mineralization of organic nitrogen, obtained through rainfall and nitrogen fixation, and losses through immobilization, leaching, volatilization and uptake by the vegetation. In the grazing situation, there is an additional cycle in which nitrogen passes through the animal's body. Only a very small proportion is retained therein and the balance is returned through faeces and urine to the soil surface.

Circumstances favouring loss of nitrogen by denitrification are rare under low rainfall conditions, as generally no anaerobic situations occur. Under these conditions, temperatures are generally high, favouring volatilization of ammonia, especially from animal wastes.

4.2.2 Phosphorus Cycle

Unlike nitrogen, phosphorus is relatively immobile in the soil/plant system, but it is nevertheless subjected to complex chemical reactions. The solubility of phosphate ions in the soil solution is very dependent on soil pH (see section 3.3.2) and is greatest at pH 6-7. However, at any soil pH added fertilizer phosphorus (usually water-soluble) is slowly converted to less soluble forms which are not available to plants - though they may re-solubilize if the soil solution is strongly depleted of phosphate ions by intensive crop uptake or if large changes in soil pH occur. To maintain a satisfactory level of phosphorus in the soil solution it is therefore usually desirable to apply phosphorus fertilizer for each crop, and to maintain soil pH as near to the range 6-7 as possible. Phosphorus also takes part in the organic immobilization/mineralization cycle, as does nitrogen, and considerable amounts of plant-available phosphate can be released from organic form, particularly in biologically active soils of high organic matter status (Fig. 22).

4.2.3 Potassium Cycle

The main sources of potassium are release from clay minerals and application to the soil in fertilizers and manures; participation of potassium in the organic cycle is less important to crops. The potassium taken up by plants may in part be returned in crop residues and manures, but in many cropping systems there are appreciable net losses from the soil, compensated for to a varying extent by potassium released from clay minerals. Limited leaching of potassium may occur, but normally only with high rainfall and on sandy soils. Maintenance of an adequate soil potassium status by the correct use of fertilizers and manures is important, particularly on soils of low clay content (Fig. 23).

5. SOIL NUTRIENTS AND THEIR MAINTENANCE

5.1 SOIL NUTRIENTS AND CROP YIELD

The continued prosperity of any nation is dependent upon several factors, one of the most important being maintenance of the fertility of its soils as a basis for an indigenous food supply. Soil fertility has a number of components, among which the ability of the soil to supply plant nutrients is of great importance. Nutrient supply interacts with other components of fertility, in particular water and oxygen supply to plant roots, in that if other conditions for root growth are unfavourable, nutrient uptake by the crop will also be restricted. The amounts of nutrients present in a soil are influenced by a number of factors, of which inherent soil composition, cropping management and the use of fertilizers and manures are the most important.

Under natural vegetation, for example in virgin forests, nutrients taken up from the soil by the plant are returned to it in leaf and fruit fall and there is thus no substantial loss of nutrients from the soil-plant system. The system is in or near to nutrient equilibrium and the capacity of the soil to supply essential plant nutrients is maintained. It may well be, however, that the amounts of nutrients available within the natural system are insufficient to enable plants to make their full potential growth.

When land is brought into agricultural use, nutrients will be lost from the soilplant system in a number of ways. Removal of harvested products, e.g. grain and straw, takes with them considerable quantities of all nutrients, amounts varying with crop and level of yield. In addition, plant nutrients are lost from the soil through leaching and erosion, mechanisms that are of little importance under most natural vegetation systems.

Thus, even to maintain soil nutrient status at its existing level it is necessary to apply nutrients to the soil to make good these losses. There is also in many, perhaps most, soils a need to raise status of one or more nutrients to enable crops to reach their full growth and yield potential. The use of fertilizers and organic manures is therefore necessary for the maintenance of cropped soils - arable, tree crops and grassland - in a high state of fertility, and for the achievement of high crop yields.

For sound recommendations on fertilizer use to be possible it is necessary to know the nutrient status of soils and the nutrient requirements of the crops to be grown. Nutrient supplies from organic manures and from biological activity in the soil, the cropping system to be followed and the amounts of nutrients already present in the soil, as shown by suitable methods of chemical analysis, must all be taken into account.

5.2 SOIL NUTRIENT EVALUATION

The type and amount of fertilizer to be applied depends on the crop to be grown and the nutrient-supplying power of the soils concerned. Determination of the level of soil nutrients allows deficiencies to be detected and suitable rates of fertilizer to be recommended. There are a number of methods for determining the nutrient status of soils of which the more important are treated briefly in the following paragraphs.

5.2.1 Visual Diagnosis

Plants exhibit characteristic symptoms when a nutrient is present in insufficient quantity for normal growth and development, and these symptoms can be used to diagnose the nutrient deficiency that is present and decide on remedial actions. The method is rapid and no elaborate apparatus is required, but it has the following disadvantages:

i. the deficiency symptoms must develop before they can be identified and it may then be too late, especially with annual crops, to apply remedial measures for that crop;

ii. symptoms of certain deficiencies are not very distinct and may be visible only when the deficiency is acute;

iii. deficiency symptoms may be complicated or suppressed by such factors as weather or pest and disease incidence.

5.2.2 Plant Analysis

Plant analysis may be semi-quantitative, as in rapid tissue tests, or fully quantitative.

Semi-quantitative analysis, mainly used for nitrate, measures the unassimilated soluble contents of plant sap. The constituents measured are *en route* from the point of entry to the site of utilization within the plant. Though accurate determinations are not possible with tissue tests, they can be an effective tool in convincing farmers of nutrient shortages.

Total or quantitative analysis measures both the elements that have already been incorporated into the plant tissues and those that are still present as soluble constituents in the plant sap. The estimation may be made by any of a number of analytical procedures of varying complexity and with different equipment requirements, including gravimetric, colorimetric, flame photometry, emission spectrography and X-ray spectrography methods.

Both tissue tests and chemical analysis of the plant sap may be capable of providing an indication of shortages of nutrients which are not severe enough to cause recognizable deficiency symptoms. However, full plant analysis of short duration crops and the visual method of diagnosis are essentially in the nature of post mortems. Though the results of these two methods may be useful in determining the fertilizer requirements for subsequent crops, they are usually available too late to be used as a guide for correcting the condition of the standing crops. Analysis of perennial or long duration plants such as fruit trees or sugarcane can, on the other hand, be useful in enabling deficiencies to be corrected.

5.2.3 Biological Tests

Biological tests are generally carried out using micro-organisms, e.g. *Azotobacter, Aspergillus niger*, and are based on the principle that the general requirements for mineral nutrients of these organisms are similar to those of certain crop plants, although the absolute amounts differ, and that micro-organism and higher plant draw on the same nutrient reserves. The *Azotobacter* group of organisms are made use of for determining deficiencies of lime, phosphorus and potassium, while *Aspergillus niger* is used to determine potassium and magnesium requirements. The chief advantage of these tests is that they can be performed quickly (within 3-4 days) compared to field experiments, but because of difficulties in interpretation they have not gained wide acceptance.

5.2.4 Soil Testing

Soil testing is a better method than deficiency symptom and plant and tissue analysis, because it helps in determining the nutrient need of the plant before the crop is planted. It is simpler and less time consuming than the biological method.

5.3 SOIL ANALYSIS

5.3.1 Soil Analysis Objectives

The main aim of soil testing is to evaluate the fertility status of the soil. It provides a basis for the recommendation of fertilizer and soil amendments such as gypsum (for alkaline soils) and lime (for acid soils). The laboratory test is a means of making an inventory of the chemical condition of the soil and determining the treatments required. The soil test information is then used together with an evaluation of specific crop requirements, cropping history and physical characteristics of the soil to determine the amounts of different nutrients and soil amendments required. Soil testing laboratories have been established in most countries of the world by national governments and the fertilizer industry, to enable fertilizer recommendations to be made to farmers on the basis of the fertility status of their soils.

5.3.2 Soil Sampling Procedure

It is essential that soil samples are properly collected and are representative of the area to be tested. Soil analysis and its interpretation is as reliable as the soil sample drawn. Important points to note are:

i. Each field should be sampled separately. When areas within a field differ distinctly in crop growth, appearance of the soil, elevation or known cropping or manuring history, the field should be divided suitably and each area sampled separately.

ii. Drawing samples from areas which do not represent the field should be avoided. Such areas may be marshy spots, hedges, areas previously occupied by compost heaps, etc. Sampling should not be done in a field within three months after the application of fertilizer or lime.

iii. Samples should be taken with a soil corer or an auger, or in very friable soils a large spoon or trowel can be used.

iv. A composite sample may be taken from each area. After scraping the surface free of litter, a uniform core or a thin slice of soil from the surface to plough depth (15 to 25 cm) should be taken at 15 to 20 sampling points well distributed over the area to be sampled. In a hard soil, a small pit of about 15 cm x 15 cm and of about 15 cm in depth should be made, and a V-shaped slice taken from one of the sides.

v. Where crops have been planted in rows, sampling may be done between the rows.

vi. Individual cores or slices should be collected in clean containers. All lumps should be broken and mixed well in the container or on a clean cloth. The size of the composite sample should be reduced by successive quartering to about 0.5 kg.

5.3.3 Information Sheets

i. Each sample should be identified by name or number, and by the farmer's name and address.

ii. The information sheet furnished by the soil testing laboratory should be filled up completely as it will help the analyst to provide an accurate fertilizer recommendation. The information sheet and the soil sample in its container should be sent to the soil testing laboratory, following prescribed procedures.

If the standard information sheets are not available, information may be given on the following points:

a. field identification, farmer's name and address;

b. crops grown in the last two to three years;

c. date of last ploughing of the field;

d. quantity of fertilizer, gypsum and lime used and when;

e. whether green manuring practised, and when;

f. topography, degree of erosion, drainage, crop growth, etc.;

g. crops proposed for the next year.

If the sample is very wet, it may be dried in shade for an hour or two before bagging and despatching it to the nearest soil testing laboratory. Plastic or cloth bags are suitable and should be available from the soil testing laboratory.

The extension worker or the representative of the fertilizer industry will normally be responsible for the collection of soil samples, filling in the information sheets and despatching the soil samples to the laboratory.

In the laboratory, soil samples are generally analysed for the following five soil properties:

- soil reaction (pH);
- total soluble salts which indicate whether the soil is saline or normal;
- organic carbon (as a measure of organic matter status and available nitrogen);
- available phosphorus;
- available potassium.

Where the need and facilities exist, soils are also analysed for secondary and micronutrients.

In the determination of individual nutrient status of a soil there are two essential steps - the first is the extraction from the soil by suitable means of an amount of nutrient corresponding to that available to the crop, and the second is determination of the amount so extracted. A number of extraction procedures have been developed for each nutrient, involving shaking the soil sample under standard conditions with a suitable extractant; in the case of phosphorus, for example, extractants used in various countries include a number of dilute organic or inorganic acids, mild alkali solutions and anion exchange resins. All have been calibrated against the results of crop experiments on the same soils and give a satisfactory measure of plant-available nutrients. Once the available nutrient has been extracted, the amount can be determined by any standard analytical method.

5.3.4 Interpretation of Soil Tests

The results of the analyses carried out in the laboratory are reported back to the extension worker and farmer, usually together with recommendations on the fertilizers and soil amendments that he should use. The reports normally include:

i. A statement of analytical results, including both the numerical result and a rating interpretation of this result. Numerical results are usually rated in three to five categories by reference to the relationships between soil analysis and fertilizer response discussed in the next section. The nutrient categories may be rated for example "low, medium, high" or "very low, low, medium, high, very high".

ii. Fertilizer recommendations for the proposed crop are given, based on soil analysis, past and future cropping pattern, manures and fertilizers recently applied. The recommendations state the quantities of nitrogen, phosphorus, potash and micronutrients (where appropriate) and also of soil amendments (gypsum and lime) to be applied. Where organic matter additions are important the report also gives the quantities of organic manures as recommended by government advisory departments.

iii. The report should also indicate time and method of fertilizer application and any other practices required to ensure efficient fertilizer use.

5.3.5 Soil Fertility Maps

On the basis of soil analysis many countries have prepared soil fertility maps indicating the nutrient status of nitrogen, phosphorus and potassium and also micronutrients (e.g. zinc) by region and by soil type. These maps provide a useful generalized picture of soil fertility status but will not apply precisely to individual fields or local areas since they are based on limited soil sample analyses. An example is given in Figure 24.

5.4 FERTILIZER RECOMMENDATIONS

5.4.1 Scientific Basis for Recommendations

i. Field experiments

The most satisfactory method for the development of recommendations on the optimum amounts of fertilizer to use is based on series of field experiments carried out on experimental farms and farmers' fields. These experiments include a range of fertilizer treatments, comparison of whose results will enable conclusions to be reached on optimum rates, timing, etc. of fertilizer. They are applied to plots of land in representative fields, plots being assigned at random and replicated several times at each site to give statistically valid results (Fig. 25). Each experiment will give a definitive result for the field and crop on which it is situated, but only for that situation. By carrying out a series of experiments it is possible to establish the variability in fertilizer requirements from field to field and to correlate this variability with soil properties and other features recorded at each experimental site. Well-tried scientific procedures have been developed to enable this to be done. Thus, fertilizer requirement can be related to nutrient status as shown by soil analysis, to soil type, to previous cropping, to the use of organic manures and to crop features such as variety and yield level.

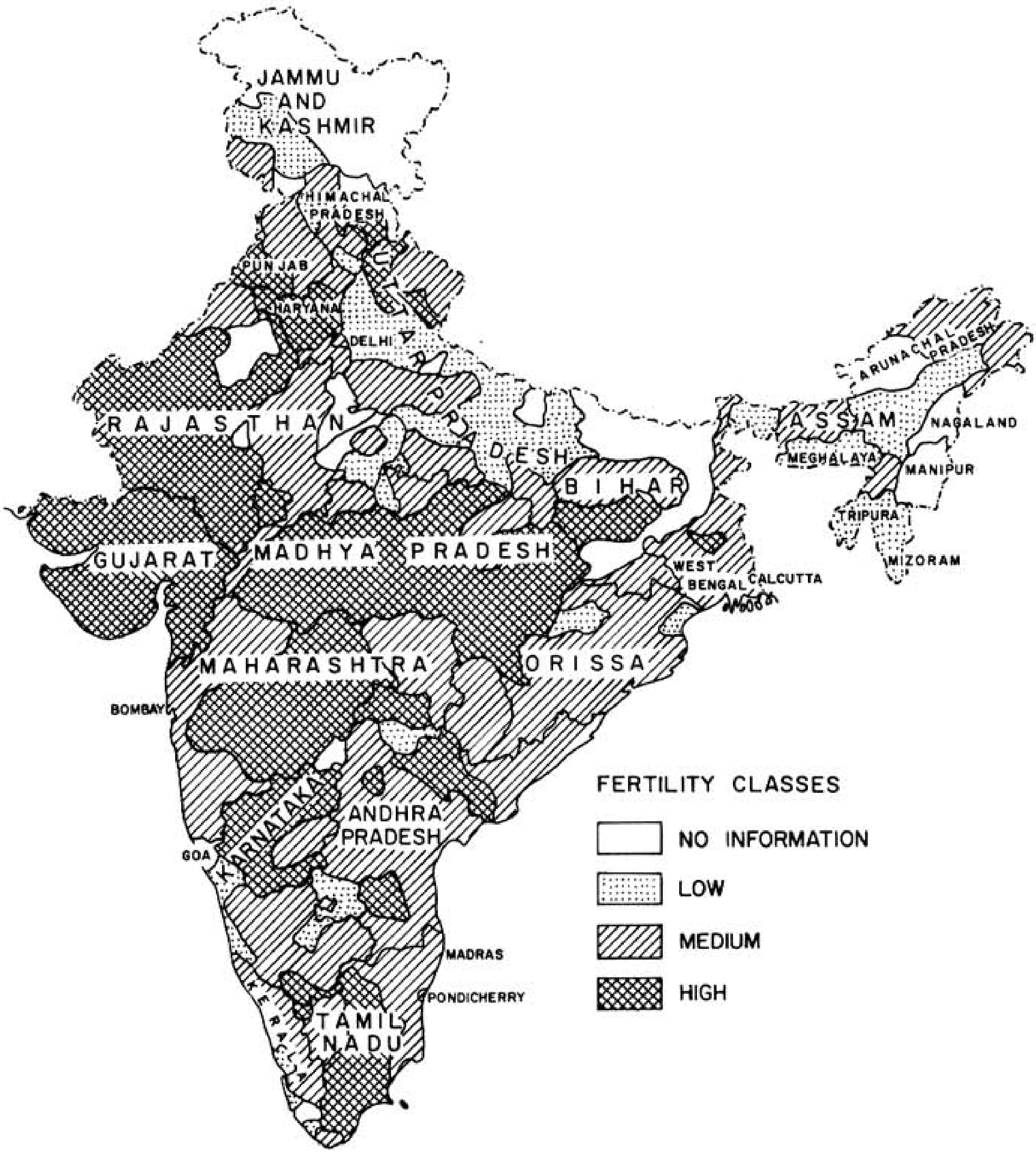

Fig. 24 Available K status of Indian soils

ii. Crop removal of nutrients

The amount of nutrients removed in the harvested crop varies very much between crops and is closely related to yield level. It may bear little relation to the optimum nutrient rate as determined in field experiments; for example, the amount of potassium removed in the tubers of a high yielding, irrigated potato crop will usually be considerably higher than the recommended application rate based on field experiments. Where the amount removed is higher than the recommendation the crop will draw on soil nutrient reserves to make up its requirement; where it is lower, the surplus will usually be added to soil reserves - though in the case of nitrogen it may be lost by leaching or volatilization. It is therefore necessary to take nutrient removal into account, and in particular to ensure that fertilizer recommendations maintain the nutrient status of intensively cropped, high yielding soils.

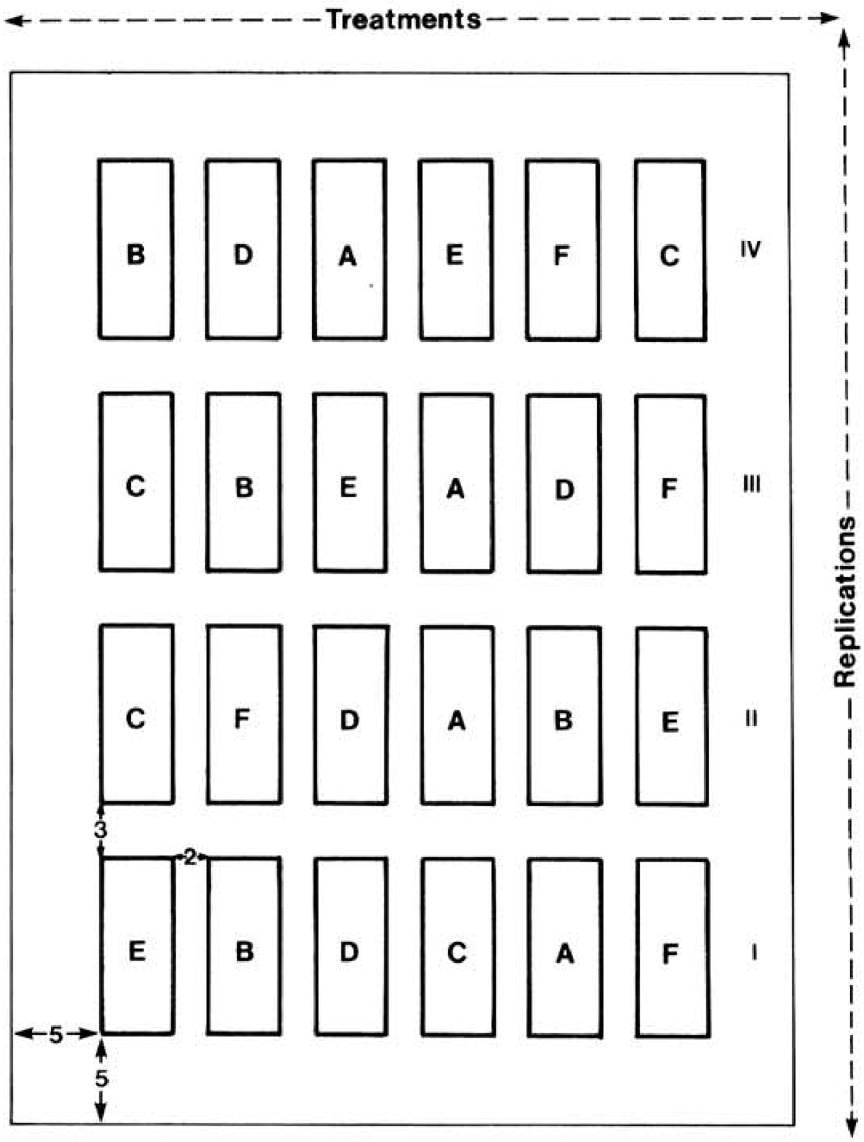

Fig. 25 Plan of a typical randomized block design field experiment (figures are given in feet)

5.4.2 National and Local Recommendations

Fertilizer recommendations based on the above considerations are formulated by the responsible coordinating agency, usually the national or state Department of Agriculture, often after discussion with the research organization, fertilizer industry and farmers' associations. They are generally issued in the form of a pamphlet or booklet for general guidance of the agricultural extension service, farmers, the fertilizer industry and so on. The fertilizer industry or its constituent firms in many countries periodically publish and publicize the latest fertilizer recommendations, closely following the official advice on rates and timings.

The degree of detail in published recommendations depends on the amount of information available and the extent of the area covered. Fertilizer recommendations often apply generally to a region or state, i.e. there is only one fertilizer recommendation for a crop for the entire region covered. Some countries have more localized recommendations, even down to district levels. It is also desirable to make as detailed a range of recommendations as possible, in relation to factors such as soil nutrient status, cropping system and yield. However, in many countries there is not yet sufficient background information to enable this to be done. General recommendations aim to provide all farmers with a reasonable return on money spent on fertilizers but do not maximize profit from individual fields.

Recommendations, whether generalized or detailed, are not final. They require revision when changing agricultural conditions, e.g. new high yielding varieties or the introduction of irrigation, have an influence on soil fertility or response to fertilizer.

Higher crop yield and more intensive cropping need higher levels of fertilizer application, often including micronutrients as well as major nutrients to sustain soil fertility. The change in soil fertility levels with continued fertilization also necessitates reassessment of the amounts of fertilizer needed. Fertilizer recommendations may also need revision when proven research results are available on fertilization based on a cropping system rather than for an individual crop.

Thus it is necessary to review the state of information on fertilizer response periodically, drawing in expert knowledge from scientists and agronomists in universities, departments of agriculture, research stations, extension services and the fertilizer industry. Seminars, workshops and recommendations committee meetings are needed as a basis for updated and up-to-date fertilizer recommendations.

5.4.3 Fertilizer Recommendations - An example

When soil analysis is reported, the data may be the soil nutrient contents as determined, or they may be converted to kilograms per hectare. An example of recommendations for nitrogen, phosphorus and potassium application in relation to soil analysis is given in Table 6.

Table 6 RECOMMENDED FERTILIZER RATES IN RELATION TO SOIL NUTRIENT STATUS (FOR A YIELD TARGET OF 4 t WHEAT/HA AT PANTNAGAR, INDIA)

NITROGEN		PHOSPHORUS		POTASSIUM	
Soil test $KMnO_4^-$ N kg/ha	Fertilizer rate kg N/ha	Soil test Olsen's P kg/ha	Fertilizer rate kg P_2O_5/ha	Soil test Amm. acetate K kg/ha	Fertilizer rate kg K_2O/ha
200	124	5	118	50	103
240	94	15	85	75	76
280	64	25	51	100	48
320	34	35	18	125	20
360	0	40	0	150	0

Source: Randhawa N.S. and M. Velayuthem. Research and development programmes for soil testing in India. Fertiliser News 27(9):35-64. 1982.

5.5 INTEGRATED PLANT NUTRIENT SYSTEMS

5.5.1 Concept

The basic concept underlying the principle of Integrated Plant Nutrition Systems (IPNS) is the maintenance and often increase of soil fertility for sustaining increased crop productivity through optimizing all possible sources, organic and inorganic, of plant nutrients required for crop growth and quality in an integrated manner appropriate to each farming situation in its ecological, social and economic possibilities.

The approach is not new since the simultaneous and complementary use of mineral fertilizers and organic materials has been practised for many years in many parts of the world. Efficiency-oriented research has since brought about new technologies and methods in the production and use of mineral fertilizers, in the recycling of organic materials and in the development of biological nitrogen fixation. At the same time, cropping practices and systems conserving and enhancing soil fertility have been developed and are still being further developed. What is needed is realistic action for the practical implementation of the approach in so far as it has not been applied already.

5.5.2 Components

The various major sources of plant nutrients are soil, mineral fertilizers, organic matter and atmospheric nitrogen fixed by micro-organisms or carried down in precipitation. The main aim of the integrated approach is to tap all the sources in a judicious way and ensure their efficient use.

i. Soil sources

That soils supply plant nutrients is well known, but due to continuous and intensive cultivation, the nutrient-supplying capacity of many soils is falling so that they tend to become deficient in some nutrients. To enhance the soil nutrient supply it is necessary to reduce losses of nutrients by suitable soil management practices, to ameliorate problem soils so as to mobilize unavailable nutrients, and to use appropriate crop varieties, cultural practices and cropping systems to maximize utilization of available nutrients.

ii. Mineral fertilizers

The major role in plant nutrition played by mineral fertilizers for sustaining and increasing agricultural production needs no emphasis. The FAO Fertilizer Programme is fully geared to increasing fertilizer use efficiency by:

- making recommendations for a cropping system rather than for a single crop in the system;
- improving all other production factors and eliminating limiting factors, including secondary and micronutrients;
- minimizing losses in the field through appropriate time and methods of application;
- minimizing losses in the transport chain;
- use of appropriate products including supergranule and coated urea, direct use of locally available phosphate rocks, etc.

iii. Organic sources

Organic manures are valuable by-products of farming and allied industries, derived from plant and animal sources. The available organic resources include farmyard manure and animal droppings, crop wastes and residues, sewage sludge and other human wastes and various industrial wastes.

It is estimated that about 130 million tonnes of plant nutrients are theoretically available in this form, although the quantity actually usable is much lower. Problems in their use are: low content of nutrients, slow release of the nutrients due to slow mineralization, transporation difficulties and cost owing to their bulky nature, and widespread use as fuel and feed for cattle for which alternative sources are not available.

Improvements in use of organic nutrient sources can be sought under the headings of rural composting, mechanical composting, biogas technology, better use of crop residues and of sewage.

iv. Biological sources

Legumes contribute to soil fertility directly through their unique ability, in association with *Rhizobia*, to fix atmospheric nitrogen. This nitrogen may be made available to the legume crop by transfer from the site of fixation in the legume root nodules, or it may be made available to subsequent crops by growing legumes and ploughing them in as green manure. Enough is known to generate optimism about the prospect of enhancing the efficiency of *Rhizobium*-legume symbiosis and to expand other associations such as blue-green algae, *Azolla*, *Azotobacter* and *Azospirillum* (see Chapter 7).

5.5.3 Practical Application

In recent years, as a result of increasing mineral fertilizer prices, the concept of integrated plant nutrition has gained increasing importance. Though more scientific information on the complementary and supplementary role of mineral fertilizers, organic materials and biological nitrogen fixation in crop production for different agroecological zones is needed, a simplified action-oriented pattern of research-cum-demonstration trials in farmers' fields has been initiated in about seventeen countries in Asia and Africa within the framework of the FAO Fertilizer Programme. The operational details are given below:

i. there is a bench mark survey to assess actual availability of farm residues and other organic sources which are not appropriately used at present and could be used effectively for agricultural production;

ii. major multiple cropping systems are selected (including one grain or forage legume) depending on the agro-ecological conditions, produce markets, dietary preferences, etc.;

iii. appropriate soil management and conservation practices are followed, including amelioration of problem soils and crop management practices;

iv. nutrient application rates are scheduled, including secondary and micronutrients for the cropping system as a whole;

v. N, P, K and micronutrients are applied to that crop which makes best use of the nutrient in question; the following crop would benefit from the residual effect;

vi. use is made of all available organic materials for the farm lands; farmers are educated and encouraged to plant quick-growing trees for fuelwood on common lands and along the borders of farms, thereby reducing their dependence on cattle dung for fuel; biogas plants are installed where appropriate;

vii. farmers are encouraged and taught how to make good composts from easily available farm or agricultural wastes and other organic sources by using the right technology; the composts and FYM are applied in the best season;

viii. where the situation is correct, alley-cropping or green manuring is practised or a legume crop (grain or fodder) is introduced in the cropping system and, if suitable, it is inoculated with efficient *Rhizobium* strains;

ix. in the rice based cropping systems, in appropriate agro-ecological situations, efforts are made to introduce effective strains of *Azolla* and blue-green algae;

x. nutrients supplied through the above organic sources are assessed and the balance of the recommended dose is then applied through mineral fertilizers, taking into account a 15 percent increase in efficiency of the mineral fertilizers due to the complementary effects of the organic sources and mineral fertilizers being applied together;

xi. soil nutrient status is monitored against the crop yield performance and necessary adjustments are made in the fertilizer schedule;

xii. economic evaluation is made of the integrated system.

Models for each country depend on the agro-ecological conditions, cropping systems, available plant nutrient sources, and on the infrastructural, organizational, research and development support. As an illustration a hypothetical model is given below[1]:

Step I	Soil testing to estimate initial nutrient levels			
Step II	Cropping system:	Wheat	Grain legume	Rice
Step III	Nutrient recommendation: ($N+P_2O_5+K_2O$ kg/ha)	120+60+60	20+30+0	120+30+60
Step IV	Contribution from organic manures[2]: (4 tons/ha each for wheat and rice)	20+24+20	-	20+24+20
Step V	Contribution from *Rhizobium* inoculation:	-	-	20+0+0

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1 Roy R.N. and Braun H. Proc. FAI/FAO Seminar on Systems Approach to Plant Nutrition, Fertiliser Association of India, New Delhi, India. 1984.

2 Efficiency factors for N and K are taken as the same as those of fertilizers, i.e. 50 percent and 80 percent respectively. For P the factor is 60 percent compared to 20 percent for fertilizers.

Step VI	Inoculation with or BGA or green manuring:	-	-	25+0+0
Step VII	Requirement of mineral fertilizers:	100+36+40	20+30+0	80+6+40 (only OM) 75+30+60 (only *Azolla* or BGA or GM) 55+6+40 (both OM and *Azolla* or BGA or GM)
Step VIII	Actual amount of mineral fertilizers to be added when complementary effect of organic materials and mineral fertilizers and increased efficiency of the latter are taken into account (approx.15 percent and final figure rounded off):	85+30+35	20+25+0	70+5+35 (only OM) 65+25+50 (*Azolla*/BGA/GM) 45+5+35 (OM and *Azolla*/ BGA/GM)
Step IX	Soil testing after harvesting the last crop in each year to monitor fertility status and to effect necessary adjustments in mineral fertilizer dose against the crop yield performance			
Step X	Economic evaluation of the integrated system.			

6. ORGANIC SOURCES OF PLANT NUTRIENTS

Organic sources of plant nutrients comprise the residues of plants, animals and human beings. Some of the more important as sources of plant nutrients are farmyard manure, compost, green manure and various animal wastes.

Most organic manures are bulky in nature. They contain small amounts of nutrients and their main value lies in the supply of organic matter to the soil. Unless they are applied in large amounts they do not contribute much to the nutrient supply to plants. Nevertheless, the organic matter added in the form of manure performs certain other essential functions. It promotes microbial activity in the soil and improves its structure, aeration and water holding capacity, enabling it to respond more to modern inputs including fertilizers, improved crop varieties and irrigation. It also supplies micronutrients and helps to make the phosphate in the soil more available to plants.

Because of their bulky nature, organic manures are not readily transported over long distances, neither is it cheap to arrange special storage facilities for large quantities. In countries where manpower is in short supply, or expensive, special treatment of organic manures is seldom a priority, so that the greatest scope for improved efficiency of use tends to be in some of the developing countries.

6.1 FARMYARD MANURE (FYM)

In countries where housed livestock are important in agriculture, farmyard manure is the most important of the bulky organic manures. It is a decomposed mixture of the dung and urine of cattle or other livestock with the straw and litter used as bedding and residues from the fodder fed to them.

FYM repays care and attention in preparation, storage and application, as proper management in these respects can help to conserve nutrients against loss by leaching or volatilization. FYM may be produced by allowing litter, dung and urine to accumulate in livestock housing for several weeks, followed by removal and storage in a heap or trench. Alternatively fresh litter may be applied and the FYM removed to storage daily. Storage in a compacted heap reduces the rate of breakdown and the loss of ammonia; in rainy conditions, storage under a roof reduces loss of nutrients by leaching.

FYM may be enriched with phosphate by application of 25 kg of single superphosphate per tonne of the manure, which may also reduce the loss of nitrogen. However, superphosphate fertilizer is likely to be used more efficiently if applied separately according to crop fertilizer recommendations.

FYM can be applied to all soils and almost all crops. For greatest nutrient efficiency it should be applied a few weeks before sowing the crop, spread uniformly over the field and incorporated in the soil without delay. Local climatic or management considerations may necessitate a longer interval. FYM is of very variable nutrient value depending on the type of livestock and storage conditions.

6.1.1 Poultry Manure

Poultry manure differs from other livestock manure in that it has a higher nutrient content, but as with all FYM it is variable in composition depending on management, storage and amount of litter used. The manurial value per tonne is particularly influenced by the amount of water, sand or litter present. Water may range from 75 percent in some wet, fresh samples to 8 percent in a manure dried artificially, but poultry manure from intensive systems is usually towards the low end of this range. The fresh manure is liable to loss of ammonia by fermentation and also of soluble constituents by leaching, so that as with FYM quality depends on the method of storage. Its nitrogen percentage varies from about 1.5 percent in a poor weathered sample, to more than 4 percent for kiln dried manure.

Those using poultry manure for small-scale operations are often able to handle and store it more satisfactorily. The fresh manure may be stored in shallow layers and even mixed with dry sand, sawdust, or rice husk to obtain a dry and friable product. Manure from deep litter houses makes a compost which is dry and easier to handle.

Large producers of poultry manure often find difficulty in disposing of the moist product. Some form of artificial drying (kiln drying) is the most practical treatment and gives a more uniform product composition than that of ordinary samples. Smaller poultry units may not justify an artificial drying system, which may, however, be possible on a cooperative basis.

Poultry manure can be used on most crops but, because of its high nitrogen content, it is important to adjust nitrogen fertilizer use to avoid excess. Conversely, its potassium content is relatively low, so that potassium fertilizer may be especially needed.

6.2 COMPOST

Large quantities of waste materials are available as vegetable refuse and litter on farms and as vegetable and animal waste in urban areas. They can be converted into useful compost manures by conserving them and subjecting them to a controlled process of decomposition.

6.2.1 Rural Compost

In rural areas where adequate manpower is available, farm refuse such as crop residues, stubble, weeds, etc. can be collected and stored in a pit. The accumulated refuse is thoroughly mixed and spread in a layer 30 cm thick, well moistened and inoculated with micro-organisms to break it down by sprinkling with a slurry of cow dung and water or soil and water. The layers are repeated to a height of 0.5 m above ground level. After turning and storage for about six months in total, the compost is mature and ready for application to the field.

Single superphosphate can be added to the compost to enrich the manure and conserve the nitrogen but, as with FYM, it is more efficient if applied to the soil separately. Low grade rock phosphate (1 to 2 percent), where available, could be used successfully.

Compost is used in the same way as FYM, on all soils and almost all crops.

6.2.2 Urban Compost

Urban (town) compost is prepared from human and industrial waste products, primarily town refuse and human excreta, the liquid wastes in sewage being separately utilized on sewage farms. The preparation of town compost on a large scale is being adopted by many municipal and also some state industrial corporations in a number of countries.

6.2.3 Biogas Compost

Biogas production is one of the means by which bulky organic wastes can be made to yield energy in the form of combustible gases (Fig. 26). In this process, animal dung and other cellulose materials are allowed to ferment for a few days in the absence of oxygen. A mixture of gases consisting mainly of methane, hydrogen and carbon dioxide is produced under these conditions and can be used as fuel for cooking and other purposes. The residual material provides useful manure.

The main advantages of the biogas plant are:

- Both fuel gas and manure can be obtained from organic wastes without loss of manurial value.
- The plant works under fully hygienic and sanitary conditions, with no bad odour or fly and mosquito nuisance.
- The loss of nitrogen in the process is much less than in normal composting.

A limitation to the use of the system is that low temperatures retard the rate of decomposition of the dung and other raw materials. The maintenance, repairs, and initial costs, etc. are also high and act as important constraints to its large-scale adoption by farmers.

Fig. 26 Biogas plant (Indian type)

6.3 GREEN MANURING

Green manuring is another way of adding organic matter to the soil. A leafy crop, generally a legume grown in the field itself or cut and brought from elsewhere, is incorporated in the soil prior to flowering. Leaves of bushes and trees may also be used for green manuring. Green manure crops can also be grown on bunds and waste lands. *Crotalaria juncea* (sunhemp), *Sesbania aculeata* (dhaincha), *S. speciosa*, *S. cannabina*, *Astragalus sinicus* (milk vetch), *Vigna* spp. (cowpea), *Tephrosia* spp., etc. are some of the important green manuring plants.

The green manure crop supplies organic matter and, if it is a legume, fixes nitrogen. The amount of nitrogen fixed per hectare varies from crop to crop and may average about 30-40 kg/ha. Green manuring is effective only when there is sufficient water supply for growth of the green manure crop, for its decomposition in the soil and for the subsequent cereal or other crop. The economics of green manuring also need to be examined carefully, especially in intensive agriculture.

6.4 LIQUID MANURE

The problems of the conservation and use of liquid manure concern farmers who have to deal with the drainings from cow stalls, piggeries and stables. A large proportion of the potassium and nitrogen in the food finds its way into the urine; in the case of dairy cows, about 40 percent of the nitrogen and 65 percent of the potassium appear in the liquid manure, in water-soluble and readily available form. Phosphorus is practically absent from urine.

The quality of liquid manure depends on type and management of livestock and on any dilution with rain or washing water. Under ideal management conditions, liquid manure may contain about 0.6 percent nitrogen and 0.8 percent potassium. The potassium in liquid manure is stable and suffers no loss but nitrogen in the form of urea is quickly transformed to ammonia, which is subject to volatilization loss. Consequently, a liquid which initially contained 0.8 percent of nitrogen may easily fall to 0.3 percent nitrogen if stored in an open tank. Thus, minimum nutrient loss requires ready separation of the liquid from dung and litter, isolation from rain or wash water and storage in a tank - in warm climates preferably covered.

A high analysis liquid has the advantages of lower transport and distribution costs. In the countries where the management of liquid manure has reached a high level, the liquid is actually drilled into the land in order to eliminate the loss of ammonia which would occur if it was merely sprinkled over the surface, though this high standard management is far from universal.

Liquid manure rich in nitrogen and potassium is suitable for intensive grassland production and is generally applied to this crop in winter and spring. However, continuous use of this type of liquid manure results in a shortage of phosphorus and calcium, which can be avoided by regular dressings of lime and phosphorus fertilizer. If high analysis liquid manure is applied to grassland in dry weather, a certain amount of burning may take place. Application when the grassland is wet and the soil is moist, or in more dilute form, may minimize this problem.

Liquid manure may also be used on other crops, for which it is best applied and incorporated before sowing. In some tropical countries it has been used successfully for rice.

6.5 SEWAGE SLUDGE

The use of sewage sludge as manure is not new, and indeed the practice is almost as old as man's life on earth. Many nations or societies have for centuries used human and animal excreta to improve soil fertility. This material is a source of nitrogen, phosphorus, potassium and other nutrients for plants, and contributes to the maintenance of desirable physical properties of soils, thus providing more abundant food and fibre than would be possible without it.

It takes on average about 50 000 people in a community to produce the equivalent of 5 tonnes of dried, anaerobically digested sewage sludge per day. It can be calculated that a community of this size could produce sufficient sludge in a year to fertilize 100 to 200 ha of productive land.

Like most products of biological systems, sewage sludges vary greatly in chemical, biological and physical properties. These characteristics depend on the source of sewage, the treatment system and its management.

Sewage sludge is a low analysis manure and also provides organic matter. As indicated in Table 7, sewage sludges range from less than 0.1 to 17.6 percent nitrogen (with a median value of 2.3 percent) and 0.02 to 2.6 percent potassium (with a median value of 0.3 percent). Sludge also contains varying and relatively unimportant amounts of other nutrients.

Table 7 NUTRIENT COMPOSITION OF SEWAGE SLUDGE

Component	Concentration (%) Minimum	Maximum	Median
Organic C	6.5	48.0	30.4
Inorganic C	0.3	43.0	1.4
Total N	< 0.1	17.6	3.3
NH_4^+-N	< 0.1	6.7	1.0
NO_3^--N	< 0.1	0.5	< 0.1
Total P_2O_5	< 0.1	14.3	2.3
Inorganic P_2O_5	< 0.1	2.4	1.6
Total S	0.6	1.5	1.1
K_2O	0.02	2.6	0.3

Most of the nutrients in sewage sludge are only partly available to crops in the first growing season, since a proportion of them - about 70 percent of the nitrogen and phosphorus - is in organic form and not available until after mineralization. However, some of the organic nitrogen, phosphorus and sulphur will be mineralized during the growing season and used by the first crop. Most of the potassium is in the inorganic form, and immediately available to plants. The supply of other nutrients in sewage sludge is variable and may not be sufficient to counteract deficiencies in the field.

Of considerable concern in the management of sewage sludge as a manure is its content of excessive amounts of elements such as zinc, copper, lead, nickel, and cadmium that can accumulate in the soil to toxic levels - toxic either to the plants that can grow in the soil or to the animals (including man) that eat the plants. The heavy metal content of sewage sludge should be carefully monitored and sludge application rates and frequency should be restricted so as not to exceed the established maxima for heavy metal application to soils. Sludge may also contain parasitic or pathologically active organisms and care is therefore necessary to avoid contamination of operators and foodcrops.

6.6 WASTE PRODUCTS OF PLANT ORIGIN

A number of plant residues can be used with advantage as organic manures, such as:

i. wastes from industrial or food processing plants including sugarcane, coffee pulp, coconut husk, rice husk, etc.;

ii. non-edible cakes and meals from oilseed crops, such as castor (*Ricinus communis*) meal, *neem* (*Azadirachta indica*) cake, *karanj* (*Pongamia glabra*) cake; edible oilcakes are best reserved for animal feed; nutrient contents are given in Table 8;

iii. cereal straw, which is a good supplier of potassium, but due to its low nitrogen content may temporarily immobilize soil nitrogen;

iv. water hyacinth (*Eichhornia crassipes*) is an obnoxious aquatic weed but can be converted into good compost and used as a raw material in biogas production.

Table 8 AVERAGE NUTRIENT CONTENTS OF OIL CAKES

Material	Nitrogen N (percent)	Phosphate P_2O_5 (percent)	Potash K_2O (percent)
a. Non-edible oil cakes			
1. Castor cake	5.5 - 5.8	1.8 - 1.9	1.0 - 1.1
2. Cotton seed cake (undecorticated)	3.9 - 4.0	1.8 - 1.9	1.6 - 1.7
3. *Mahua* cake (*Bassia latifolia*)	2.5 - 2.6	0.8 - 0.9	1.8 - 1.9
4. *Karanj* cake	3.9 - 4.0	0.9 - 1.0	1.3 - 1.4
5. *Neem* cake	5.2 - 5.3	1.0 - 1.1	1.4 - 1.5
6. Safflower cake (undecorticated)	4.8 - 4.9	1.4 - 1.5	1.2 - 1.3
b. Edible oil cakes			
7. Cotton seed cake (decorticated)	6.4 - 6.5	2.8 - 2.9	2.1 - 2.2
8. Groundnut cake	7.0 - 7.2	1.5 - 1.6	1.3 - 1.4
9. Linseed cake	5.5 - 5.6	1.4 - 1.5	1.2 - 1.3
10. Niger cake	4.7 - 4.8	1.8 - 1.9	1.3 - 1.4
11. Rape-seed cake	5.1 - 5.2	1.8 - 1.9	1.1 - 1.3
12. Sesame (Til) cake	6.2 - 6.3	2.0 - 2.1	1.2 - 1.3

6.7 WASTE PRODUCTS OF ANIMAL ORIGIN

Animal waste products include:

i. slaughterhouse wastes such as dried blood, meat meal, hoof and horn meal; these have a high nitrogen content and are essentially concentrated organic manures, fairly quick acting, safe to use and effective on all crops;

ii. fish manures, applied as dry or wet fish residues or as fish meal; they supply nitrogen and phosphorus and act as concentrated organic manures in the same way as the slaughterhouse products referred to above.

Bone meal: bones and bone products were the earliest phosphatic materials used, but their use is now confined to horticultural crops. Raw bone meal is prepared by grinding raw bones. It contains 2 to 4 percent nitrogen and 22 to 24 percent P_2O_5, of which about 40 percent is citric-acid soluble. Steamed bone meal is made by steaming bones to remove gelatin etc. and then grinding. It contains a little nitrogen and 22 to 30 percent P_2O_5, of which about 70 percent is citric-acid soluble.

Steamed bone meal is a better phosphorus source than raw bone meal, but both are slow-acting, must be ground and are most effective on acid soils.

Composition of important animal wastes is given in Table 9.

Table 9 NUTRIENT CONTENTS OF MANURES OF ANIMAL ORIGIN

	Material	Nitrogen N (percent)	Phosphate P_2O_5 (percent)	Potash K_2O (percent)
1.	Dried blood	10.0 - 12.0	1.0 - 1.5	0.6 - 0.8
2.	Fish manure	4.0 - 10.0	3.0 - 9.0	0.3 - 1.5
3.	Bird guano	7.0 - 8.0	11.0 - 14.0	2.0 - 3.0
4.	Hoof and horn meal	14.0	1.0	-
5.	Bone meal (raw)	2.0 - 4.0	22.0 - 24.0 (8.8 - 9.6 citric-acid soluble)	-
6.	Bone meal (steamed)	-	22.0 - 30.0 (15.4 - 21.0 citric-acid soluble)	-

7. BIOLOGICAL NITROGEN FIXATION

Biological nitrogen fixation has been taken advantage of for many centuries by growing leguminous crops, e.g. peas, beans, chickpea, in whose root nodules atmospheric nitrogen is fixed by rhizobial bacteria living in symbiotic association with the crop plant. It is now evident that there are a number of other micro-organisms in or on the soil that can fix atmospheric nitrogen. The quantities fixed by these organisms are unlikely ever to be sufficient to supply the nitrogen requirements of high yielding crops, but they can in some circumstances supply significant amounts of nitrogen to crops and allow economies in the use of nitrogen fertilizer. However, it should be noted that nitrogen fixation is an energy-consuming process, and that the symbiotic nitrogen fixers obtain this energy from the associated crop, in principle resulting in some loss of crop production. Also, the non-symbiotic nitrogen fixing organisms appear to be able to operate effectively at high soil temperatures, but (apart from *Azotobacter*) are ineffective in temperate conditions.

The nitrogen fixing organisms of importance or potential importance are discussed below.

7.1 *RHIZOBIUM* BACTERIA

Bacteria of various *Rhizobium* species live symbiotically in the root nodules of leguminous plants, use the carbohydrates of the host as an energy source and pass a proportion of the fixed nitrogen to the host plant. The rest remains in the bacteria and the nodule tissue. Most of it is mineralized and becomes available to plants after the nodules have sloughed off and died. There are a number of *Rhizobium* species, each able to form nodules on one or more legume species. For symbiotic nitrogen fixation to take place, the *Rhizobium* species and the legume must be compatible. Many soils contain *Rhizobium* inoculum; for example, the species associated with white clover is present in most temperate grassland, but there are many situations in which the necessary *Rhizobium* species is absent or ineffective. Much progress has been made in identifying improved strains of *Rhizobium* which can be used as inoculant in fields where legumes are to be grown. The amounts of nitrogen fixed by legume-*Rhizobium* associations can be very large, up to several hundred kilograms per hectare per year in favourable circumstances. Thus, legumes may obtain their total nitrogen requirement from the rhizobial association, or may need a combination of symbiotic and fertilizer nitrogen for full yield. Additionally, there may be a residual effect to the extent of 20-25 kg/ha nitrogen on the succeeding crop.

7.2 FREE-LIVING BACTERIA

Azotobacter and related species of free-living bacteria are present and fix nitrogen in many soils, and it is commonly stated that the amount fixed in fertile temperate soils may be 10 to 20 kg/ha per annum. However, many soils, especially rather acid soils, do not have active populations of these bacteria and it has been widely (but not universally) found that the use of bacterial inoculants can increase yields. Apart from fixing nitrogen, *Azotobacter* produces a number of biologically active compounds and at least a part of the reported yield increases may be due to this factor.

7.3 *AZOSPIRILLUM*

The bacterium *Azospirillum* is widespread in tropical soil and grows on and inside the roots of grasses and other graminaceous crops, where it is able to fix atmospheric nitrogen. At high soil temperatures, inoculation of soils with *Azospirillum* has increased cereal yields by providing fixed nitrogen, but it can apparently only provide part of the total nitrogen requirements of the crop. It may be particularly useful where crops such as barley, oats and millet receive little nitrogen fertilizer, and may thus have potential for the small and marginal farmers of the developing countries.

7.4 BLUE-GREEN ALGAE

Blue-green algae have long been known to be free-living nitrogen fixers and the soil in waterlogged rice fields provides a good environment for their growth. Field trials conducted in India and elsewhere have shown significant increases in grain yields of many rice varieties by inoculation of rice fields with blue-green algae and this approach shows promise of providing part of the crop's nitrogen requirements (about 25-30 kg/ha of N).

Besides fixing atmospheric nitrogen, blue-green algae excrete several vitamins and growth promoting substances which contribute to better growth of rice plants.

7.5 *AZOLLA*

Azolla is a floating aquatic fern with nitrogen fixing blue-green algae (*Anabaena azolla*) associated with it in cavities in the leaf surface.

The merits of the *Azolla-Anabaena* association lie in its ability to fix nitrogen and also to photosynthesize and give high yields of biomass, which can be used as green manure, particularly if *Azolla* is grown in rotation with rice, or even in association with rice.

The agronomic value of *Azolla* has been recognized in rice cultivation in some countries of southeast Asia. A contribution of 25 to 30 kg/ha of N has been generally observed.

7.6 OTHER MICRO-ORGANISMS

7.6.1 Mycorrhiza

Endophyte fungi known as vesicular-arbuscular fungi are common inhabitants of roots of a number of plants and help in the uptake of phosphorus. This type of beneficial association between a plant root and its fungal associate is known as vesicular-arbuscular mycorrhiza (VAM).

VAM is receiving renewed attention because of its role in increasing the nutrient uptake by the plant it infects, and because of reports that VAM-infected plants can utilize water more efficiently than non-affected plants.

The role of these fungi in the nutrition of leguminous crops is a synergistic action on the associated *Rhizobium* organism. Their presence has been found to increase nodulation and the rate of nitrogen fixation. They may also produce useful plant growth substances.

7.6.2 Phosphate Solubilizing Micro-organisms

Several soil bacteria and fungi possess the ability to bring insoluble phosphates into soluble forms by secreting organic acids. These acids lower the pH and bring about the dissolution of immobilized forms of phosphates. In addition, some of the hydroxy acids may chelate with calcium and iron resulting in effective solubilization and thereby higher utilization of soil phosphate by plants. The magnitude of these effects has not been found to be of importance in practice.

7.7 CONCLUSIONS

It is important to note that all these micro-organisms require specific, optimum soil and environmental conditions. Their beneficial effect on crops has not been found to be consistent under all soil and climatic conditions. There are also problems in storage and transport of the cultures. Quality control of cultures is important, as is proper training of extension workers and farmers in the correct use of the inoculants.

The economics of using these cultures in different agroclimatic situations is of considerable importance for their large-scale adoption in farmers' fields.

8. MINERAL FERTILIZERS

8.1 ROLE OF FERTILIZERS

Mineral fertilizers are materials, either natural or manufactured, containing nutrients essential to normal growth and development of plants. Fertilizers have become an integral part of the agricultural economy of developed countries but their use in developing countries is a comparatively recent occurrence.

Various studies, including those conducted by FAO, have established beyond doubt the existence of a close relationship between fertilizer consumption level and agricultural productivity. Crop yield levels are generally higher in those countries where fertilizer consumption levels are also high, as exemplified in Table 2.

Amongst the various agricultural inputs, fertilizers, perhaps next only to water, contribute the maximum to increasing agricultural production. It has been estimated that about 50 percent of the increase in agricultural production witnessed during the last decade in developing countries is attributable to fertilizer use.

Most developing countries have assigned special priority to fertilizers in their efforts to modernize their agriculture. It has also been increasingly realized that it is relatively cheaper and more in a country's long-term interest to import fertilizer than foodgrains. Many developing countries, within the limitations imposed by availability of raw materials, financial resources, technical manpower, etc., are also making serious efforts to set up fertilizer plants so as to meet part or all of their fertilizer requirements. This phenomenon has resulted in substantial growth in fertilizer consumption during the last decade.

8.2 FERTILIZER PRODUCTION

Production of fertilizer nitrogen, which was a little less than 33 million tonnes in 1970-71, has nearly doubled during the last 12 years, to 63.40 million tonnes in 1982-83. Phosphorus production has increased from about 20.7 million tonnes P_2O_5 to 33.0 million tonnes during the same period and production of potassium fertilizers has increased from 17.7 million tonnes of K_2O to 24.4 million tonnes.

8.3 FERTILIZER CONSUMPTION

Use of fertilizers as a regular farming practice began in most developed countries in the late nineteenth and early twentieth centuries but the greatest increase in fertilizer consumption in these countries occurred in the two decades following World War II. In developing countries, fertilizers were until comparatively recently almost entirely applied to plantation crops such as tea, coffee and rubber, which were in the organized sector, while application to field crops was either low or non-existent. Even where fertilizers were applied, application rates had to be low in view of the traditional tall cereal varieties which were cultivated at that time. The introduction of high-yielding, fertilizer-responsive, dwarf varieties in the mid to late sixties gave a considerable boost to fertilizer consumption and there was a great upsurge in consumption in the developing countries from that period onwards.

World consumption of fertilizer nitrogen, phosphorus and potassium in 1970-71 was 31.8, 19.8 and 16.7 million tonnes respectively (as N, P_2O_5

and K_2O). The corresponding figures for 1982-83 were 61.0, 30.8 and 22.8 million tonnes, increases of approximately 92, 56 and 37 percent.

The growth in fertilizer consumption, however, has not been uniform. In most developing countries of Africa, Asia and Latin America fertilizer consumption is still low both in terms of quantity and, more relevantly, in terms of consumption per hectare of arable land (Table 10). There is thus substantial leeway for the developing countries to make up in increasing fertilizer consumption to economically justified levels. Table 11 shows there is considerable scope to increase use efficiency for increased crop production in developing countries as compared to developed countries.

Table 10 FERTILIZER CONSUMPTION PER HECTARE OF AGRICULTURAL AREA (1982)

Country	Fertilizer consumption (N + P_2O_5 + K_2O) per ha of agricultural area (kg)
Japan	367
Egypt	335
Belgium	286
Korea (Republic of)	275
Germany (Federal Republic of)	268
France	178
Bangladesh	48
China	41
India	32
Philippines	26
Brazil	12
Kenya	11
Morocco	10
World	25

Source: FAO Fertilizer Yearbook, Vol. 33 (1983)

Table 11 CEREAL YIELDS AND FERTILIZER USE PER HECTARE ARABLE LAND AND PERMANENT CROPS

		World	Developed countries	Developing countries
Cereal yields	1974-76	1 954	2 367	1 644
kg/ha (average)	1980-82	2 231	2 660	1 911
Increase, kg/ha		277	293	267
Fertilizer nutrients applied	1974-76	62.3	103.0	26.9
kg N + P_2O_5 + K_2O/ha (average)	1980-82	78.7	113.7	48.9
Increase, kg/ha		16.4	10.7	22.0
kg cereals/kg fertilizer nutrients		16.9	27.4	12.1

Sources: FAO Production Yearbook, Vol. 36 (1982) and FAO Fertilizer Yearbook, Vol. 33 (1983)

9. NITROGEN FERTILIZERS

9.1 CLASSIFICATION

Nitrogen fertilizers can be broadly classified into four groups depending on the chemical form in which the nitrogen is present in them: ammoniacal fertilizers, nitrate fertilizers, combined ammoniacal and nitrate fertilizers, and amide fertilizers.

9.1.1 Ammoniacal Fertilizers

Ammoniacal fertilizers contain nitrogen in the form of the ammonion ion, NH_4^+. When applied to soil, the ammonium ions in the fertilizer are adsorbed by soil colloids and are not lost through leaching, but are fairly rapidly converted to the nitrate form by bacterial action. Most crops are able to take up some of their nitrogen as ammonium ions, particularly in the early stages of growth, so that ammoniacal fertilizers provide a satisfactory nitrogen supply, either before or after nitrification. Ammoniacal fertilizers are acid-forming and their continuous application may result in increasing soil acidity. Examples of ammoniacal fertilizers are ammonium sulphate and ammonium chloride.

9.1.2 Nitrate Fertilizers

Nitrate fertilizers contain their nitrogen in the form of the nitrate ion, NO_3^-. Most plants absorb a high proportion of their nitrogen in this form. Nitrate fertilizers are not retained by soil colloids. Thus, if application of nitrate fertilizers is followed by heavy rains or irrigation there is every possibility of nitrogen being lost by leaching. Nitrates also tend to undergo denitrification particularly when applied to waterlogged soils and are therefore generally not recommended for wetland rice. Nitrate fertilizers are alkaline in their effect when applied to soil. Sodium nitrate and calcium nitrate are examples.

9.1.3 Combined Ammoniacal and Nitrate Fertilizers

These fertilizers contain both the ammoniacal and nitrate ions. They have thus some of the properties - both advantages and disadvantages - of the ammoniacal and nitrate fertilizers. The commonly used straight fertilizers of this type are ammonium nitrate, ammonium sulphate nitrate and calcium ammonium nitrate.

9.1.4 Amide Fertilizers

These are simple organic compounds in which the nitrogen is not readily available to plants. When applied to the soil, amide fertilizers are rapidly converted to ammoniacal form and then later to nitrate form. They are generally soluble in water and, therefore, some care is necessary in application to the soil so that nitrogen is not lost by leaching. Urea is by far the most important example.

9.2 MANUFACTURE

Ammonia synthesis is the first, basic step in almost all nitrogen fertilizer production. It is synthesized by the Haber process, by reacting a gaseous mixture of nitrogen and hydrogen in the presence of an activated

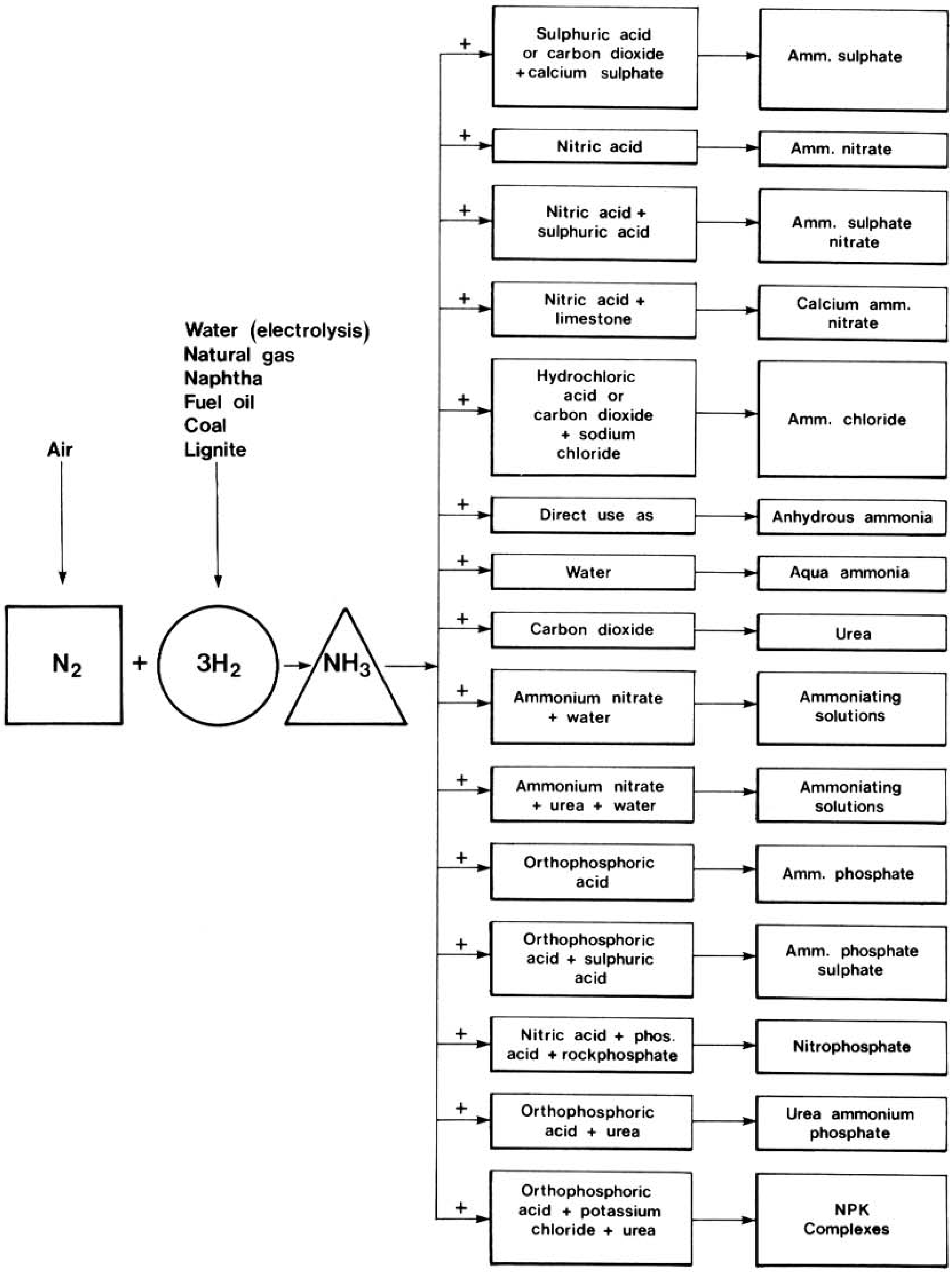


Fig. 27 Role of ammonia in the production of fertilizers

iron oxide at elevated temperature (500 ^oC) and pressure. The chemical reaction may be represented as follows:

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

While the nitrogen for this process is obtained from air, hydrogen is obtained from various raw materials, which can be grouped as solid, liquid or gaseous. Solid raw materials include coal, coke and lignite, while the liquid raw materials are hydrocarbons derived from crude petroleum by distillation. The commonly used ones are naptha and furnace oil. Hydrogen is also produced by the electrolysis of water. The gaseous raw materials are natural gas, liquified petroleum gas, refinery gases and coke oven gas.

Depending upon the raw materials used, four successive steps are involved in the manufacture of ammonia, namely (i) gasification; (ii) conversion of carbon monoxide to carbon dioxide; (iii) gas purification; and (iv) ammonia synthesis.

Ammonia can be used directly as a fertilizer, either as anhydrous ammonia or dissolved in water as aqua ammonia. Direct use of ammonia in this way is discussed in a later section in this chapter. However, in most developing countries ammonia is converted into solid fertilizers for convenience in handling, storage and application. A schematic presentation of the manufacture of various fertilizers starting from ammonia is given in Figure 27.

For the production of nitrate or ammoniacal plus nitrate fertilizers ammonia is converted to nitric acid by passing it over a platinum catalyst in admixture with air and dissolving the nitrogen oxide produced by this reaction in water:

$$NH_3 + 2O_2 = HNO_3 + H_2O$$

9.3 AMMONIUM SULPHATE

Ammonium sulphate (20.7 percent N) was one of the earliest synthetic nitrogenous fertilizers to be produced but because of its low nutrient content and relatively high manufacturing costs its importance has waned and it has largely been replaced by fertilizers of higher concentration.

9.3.1 Manufacture

Ammonium sulphate is produced (i) by reacting ammonia with sulphuric acid; (ii) by treating ammonia with carbon dioxide and gypsum; or (iii) as a by-product in the manufacture of caprolactum.

i. Direct neutralization

Gaseous ammonia is directly neutralized with sulphuric acid to produce ammonium sulphate in spray towers. The heat of reaction removes all the water present and the dry fine product is continuously removed from the base of the tower.

$$2NH_3 + H_2SO_4 = (NH_4)_2\ SO_4$$

ii. Gypsum process

Ammonia gas is absorbed in water and then converted to ammonium carbonate by treatment with carbon dioxide. Ammonium carbonate so formed is reacted with gypsum (calcium sulphate) to produce ammonium sulphate and calcium carbonate.

$$NH_3 + H_2 = NH_4OH$$

$$2NH_4OH + CO_2 = (NH_4)_2CO_3 + H_2O$$

$$CaSO_4.2H_2O + (NH_4)_2CO_3 = (NH_4)_2SO_4 + CaCO_3 + 2H_2O$$

Calcium carbonate is removed by filtration and the ammonium sulphate solution is evaporated, crystallized, centrifuged and dried. Calcium carbonate is a by-product.

iii. By-product ammonium sulphate from caprolactum plants

During the manufacture of caprolactum, which is the starting material for Nylon-6, ammonium sulphate is formed. The waste liquor from the manufacture of caprolactum is concentrated and ammonium sulphate is recovered by crystallization, centrifuging and drying.

9.3.2 Characteristics

Synthetic ammonium sulphate is a white crystalline salt, while by-product ammonium sulphate may have a grey, brown, red or yellow tint due to the presence of impurities. The commercial product contains 20-21 percent nitrogen and 24 percent sulphur, which is an important secondary plant nutrient. Crystalline ammonium sulphate is free-flowing and does not normally pose any problems in handling and storage. However, it generally contains some powdered material which can cause caking, especially under high humidity.

9.3.3 Use

Ammonium sulphate can be applied prior to sowing, at sowing time and as a side or top dressing during the growth period of the crop. Its sulphur content makes it a particularly suitable nitrogen fertilizer where sulphur deficiency occurs. Mixing with seeds should be avoided as germination can be affected. In view of the retention by the soil colloids of the ammonium nitrogen in this fertilizer, and consequent resistance to leaching, it is an excellent fertilizer for wetland paddy. However, under highly reduced conditions or in acid-sulphate soils, use of ammonium sulphate is not recommended as it may cause sulphide injury. Ammonium sulphate has an acidifying effect and its continuous use may increase soil acidity and lower crop yields (though on alkaline soils it can be advantageous). The acidifying effect can be offset by applying calcium carbonate (limestone); 110 kg of this material counteracts the acidic effect of 100 kg of ammonium sulphate.

9.4 AMMONIUM CHLORIDE

Ammonium chloride is produced either by the neutralization of ammonia with hydrochloric acid or as a co-product in the manufacture of soda ash. Only small amounts are made and only in a very few countries. It is a white crystalline material containing 25-26 percent nitrogen. It is soluble in water and has physical properties similar to those of ammonium sulphate.

Ammonium chloride can be applied in the same manner as ammonium sulphate, i.e. prior to sowing, at sowing and as side or top dressing, but is more acidic than ammonium sulphate, requiring 128 kg of calcium carbonate to neutralize the acidic effect of 100 kg of ammonium chloride. The application of ammonium chloride may also result in larger losses of calcium due to its conversion to soluble calcium chloride which is easily leached out. Generally, ammonium chloride is rated as equal to ammonium sulphate and other nitrogen fertilizers in its agronomic suitability. However, its use is not recommended for tobacco, potatoes and a number of other chloride-sensitive crops.

9.5 SODIUM NITRATE

Sodium nitrate occurs naturally in Chile and Chilean nitrate of soda still dominates the market for this fertilizer. Synthetic sodium nitrate is made by treating soda ash with nitric acid, by the following reaction:

$$Na_2CO_3 + 2HNO_3 = 2NaNO_3 + CO_2 + H_2O$$

Sodium nitrate is a white crystalline product and highly soluble in water. Because of its low nutrient content (16 percent N) its use as a source of fertilizer nitrogen is limited and because of the risk of nitrate leaching, it is preferably applied to an actively growing crop.

9.6 CALCIUM NITRATE

Calcium nitrate can be made by reacting crushed limestone with nitric acid as indicated in the following reaction:

$$CaCO_3 + 2HNO_3 = Ca(NO_3)_2 + CO_2 + H_2O$$

It is also a secondary product of some nitrophosphate (complex fertilizer) processes, in which it is precipitated in the final stages.

Commercial calcium nitrate is granular in form and almost pure white. It is extremely hygroscopic, alkaline in reaction and highly soluble in water. The commercial product contains about 15.5 percent nitrogen. It is considered to be an excellent source of nitrogen for a number of vegetable and fruit crops that have a specific need for calcium. Its use as a fertilizer is, however, limited because of low concentration. As with sodium nitrate, calcium nitrate is preferably applied to an actively growing crop to minimize leaching loss.

9.7 AMMONIUM NITRATE

9.7.1 Manufacture

Ammonium nitrate is made by reacting ammonia with nitric acid:

$$NH_3 + HNO_3 = NH_4NO_3$$

It is then usually prilled or granulated to facilitate storage and handling.

9.7.2 Characteristics

Ammonium nitrate is a white crystalline powder but fertilizer grades are granular or prilled. It is hygroscopic, highly soluble in water and contains 33-34.5 percent nitrogen. Granules of ammonium nitrate are free-flowing and do not pose any problem in handling and storage, provided protection is given from moisture being picked up by suitable packaging or storage conditions. Ammonium nitrate can be a fire and, in some circumstances, an explosive hazard when mixed with combustible materials. Codes of practice for handling, transport and storage should be carefully complied with.

9.7.3 Use

Since ammonium nitrate contains nitrogen in both the ammoniacal and nitrate forms, it is ideally suited for most crops, with the exception of wetland rice. It can be applied before the crop is planted or as side and top dressing. Because its nitrogen is half ammonium and half nitrate it is, overall, intermediate in leaching propensity relative to ammoniacal or nitrate fertilizers. Soils tend to become acid but the acidifying effect is less than with ammonium sulphate - 59 kg of limestone are required to neutralize the effect of 100 kg of ammonium nitrate.

9.8 CALCIUM AMMONIUM NITRATE

To reduce the hazards associated with the use of ammonium nitrate, it is often diluted with non-reactive material, usually limestone, to form calcium ammonium nitrate (CAN).

Calcium ammonium nitrate is produced by granulating concentrated ammonium nitrate solution with pulverized limestone or dolomite. After cooling, the granules are coated with a suitable inactive dust to avoid moisture being picked up and caking. CAN granules are grey or light brown in colour (depending on the coating dust) and free-flowing. Storage of CAN presents problems under hot tropical humid conditions and it is therefore stored in air-conditioned silos. Commercial CAN contains 25-28 percent nitrogen, half of it in ammoniacal form and half in the nitrate form. Its agronomic behaviour is similar to that of ammonium nitrate. However, unlike ammonium nitrate, CAN is approximately neutral in its reaction when applied to soil.

9.9 AMMONIUM SULPHATE NITRATE

Ammonium sulphate nitrate (ASN) is the double salt of ammonium sulphate and ammonium nitrate. It is made up of about 62.5 percent ammonium sulphate and 37.5 percent ammonium nitrate and has a nitrogen content of 26 percent.

9.9.1 Manufacture

ASN is manufactured by mixing hot solutions or moist salts of ammonium sulphate and ammonium nitrate. It can also be produced by neutralizing a mixture of sulphuric acid and nitric acid with anhydrous ammonia.

9.9.2 Characteristics

ASN is produced in either crystalline or granular forms. In crystalline form it is white in colour, but the granular form takes the colour of any protective coating dust used. It is completely soluble in water and does not leave any residue. Seventy-five percent of the nitrogen is in the ammonium form and 25 percent in the nitrate form.

Crystalline ASN may cake in storage and must be broken up before it can be applied to the field.

9.9.3 Use

ASN can be applied prior to sowing, at sowing or as side or top dressing. It has the general characteristics of a mixed ammoniacal or nitrate source of nitrogen, the leaching risk being slightly less than with ammonium nitrate. It supplies sulphur as well as nitrogen. ASN produces an acid effect on the soil, intermediate between ammonium sulphate and ammonium nitrate - 85 kg of limestone are required to neutralize the effect of 100 kg of ASN.

9.10 UREA

Urea is the most concentrated solid nitrogen fertilizer and has therefore certain advantages in storage, transport and handling. Its availability on the market is good and it often has a lower cost per unit of N than other nitrogen fertilizers. On a world scale its use is therefore increasing rapidly.

9.10.1 Manufacture

Urea is manufactured by reacting ammonia and carbon dioxide under pressure (160-220 atmospheres) at elevated temperatures (170-190^{o}C) in an autoclave. The first product of reaction is ammonium carbamate which is then decomposed to produce urea. The chemical reactions can be represented as follows:

$$2NH_3 + CO_2 \longrightarrow NH_4\ COO\ NH_2$$

$$NH_4\ COO\ NH_2 \longrightarrow \underset{\text{(Urea)}}{CO(NH_2)_2} + \underset{\text{(Water)}}{H_2O}$$

The urea solution so obtained is concentrated and prilled or granulated.

9.10.2 Characteristics

Urea prills or granules are white in colour and free-flowing. The material is rather hygroscopic and requires suitable packaging to prevent moisture being picked up. The commercial product usually contains 46 percent nitrogen, in amide form.

Urea sometimes contains small quantities of biuret, a toxic impurity. When urea is heated to temperatures above 140^{o}-170^{o}C, biuret is formed from two molecules of urea by the elimination of NH_3.

$$2CO(NH_2)_2 \longrightarrow NH_2CONH\ CONH_2 + NH_3$$

More biuret is formed in the presence of water or ammonia. Biuret toxicity has been reported for a number of crops. The application of urea with high biuret content has been shown to affect adversely the seeds of wheat and maize in the germination and seedling stages. The critical concentration depends upon the rate of nitrogen application, the type of soil, the type of crop and the method of application. The germination of wheat and barley is affected even if urea contains 1-2 percent biuret, when applied in a band in proximity to seed; but when broadcast, a biuret content of even 10 percent has no adverse effect. When urea is applied as a spray, the biuret content should not be more than 1 percent.

Biuret in urea may cause yellowing of leaves and cupped growth in citrus, coffee and pineapple. Chlorosis between the veins, stunted growth and the inhibition of the unfolding of leaves are the symptoms of biuret toxicity in maize. Biuret affects the metabolism of proteins and also causes proteolysis. Though biuret is decomposed in the soil by micro-organisms, yet in plants it has been shown to persist for months.

Commercial supplies are monitored to ensure that the biuret content is below the danger level.

9.10.3 Use

When urea is applied to soil it is converted rapidly to ammonium carbonate. High concentrations of ammonia build up in the soil. If the urea is mixed with the soil the ammonia is held on the soil colloids, but if it is applied on the soil surface considerable amounts of ammonia may be lost by volatilization to the atmosphere; the amounts will depend on soil type, rainfall, soil moisture status and temperature. Also, ammonia may damage young seedlings if urea is placed in contact with them. Thus, urea is an effective fertilizer if used in suitable circumstances, but in others can be appreciably less efficient. Because of its high water-solubility it is well suited for use in solution fertilizers or foliar sprays. It has a slightly acidic reaction in the soil, requiring 80 kg limestone to neutralize the effect of 100 kg of urea.

9.11 AMMONIUM BICARBONATE

Ammonium bicarbonate is used to a limited extent in some Asian countries, particularly China. It contains 17 percent nitrogen. It is somewhat unstable and may lose some of its ammonia to the atmosphere before it can be adsorbed by the soil, especially when it is applied as top dressing to calcareous or alkaline soil.

9.12 LIQUID NITROGEN FERTILIZERS

The use of liquid nitrogen fertilizers is important in a number of developed countries because of cheapness of product, low manpower requirements for handling and application and relatively high nutrient concentration. However, they do require specialized, expensive equipment and considerable expertise, compared with solid fertilizer application. For these reasons they are not used to any extent in developing countries, but a brief account of them is given to cater for future changes.

9.12.1 Anhydrous Ammonia

Ammonia (82 percent nitrogen) is a colourless, pungent and toxic gas at normal temperature and atmospheric pressure. The gas can be easily liquified by cooling or applying pressure and is handled as a liquid in storage and transportation. Anhydrous ammonia is normally not explosive but when mixed in certain proportions with air it may be ignited by a spark; the presence of oil increases the explosion hazard. Anhydrous ammonia can be directly injected into the soil using pressurized equipment, with special lines applying it 10-20 cm below the surface because of its volatile nature. Agronomically anhydrous ammonia is as effective as most solid nitrogenous fertilizers. However, it requires special equipment and care in handling, storage, transport and application. The equipment used is costly and relatively sophisticated and could be justified only in the case of large farms and contractors. Conditions are not suitable at present in most developing countries for the direct use of anhydrous ammonia, though limited trials conducted in India have given promising results.

9.12.2 Aqua Ammonia

Aqua ammonia (ammonia dissolved in water) normally contains 20 percent nitrogen, though grades containing up to 26 percent nitrogen can be made. The major advantages of using aqua ammonia rather than anhydrous ammonia are the simpler requirements in handling and the elimination of most of the hazards as it is a non-pressure solution. Ordinary storage tanks are satisfactory as opposed to the costly stainless steel tanks that are required for storage of anhydrous ammonia. Aqua ammonia also needs to be applied deep into the soil to prevent loss of nitrogen.

9.12.3 Nitrogen Solutions

Nitrogen solutions are of two types: non-pressure and low-pressure. The non-pressure solutions are usually produced from urea and ammonium nitrate and contain up to 28-32 percent nitrogen.

The pressurized solutions are made from a combination of ammonia with ammonium nitrate or urea or both and may have as much as 41 percent nitrogen. The advantage of this type of solution is its higher nutrient content than non-pressurized solutions, but the need for pressurization necessitates the use of more expensive handling, distribution and application equipment.

In developing countries, these types of solutions show promise as they can be applied in some types of irrigation systems.

9.13 IMPROVING NITROGEN FERTILIZER EFFICIENCY

A considerable portion of the applied nitrogen is lost through leaching, volatilization and denitrification. Under upland aerobic conditions, the dominant channel of losses of applied nitrogen is through volatilization from urea and ammonium sources or leaching of nitrate, while denitrification is the major factor under waterlogged conditions, as in paddy soils.

To reduce these losses and to ensure availability of nitrogen throughout the growth period of a crop, several approaches have been developed and can be broadly classified as follows:

i. chemicals that release nitrogen slowly,
ii. coated fertilizers,
iii. adjusted particle size,
iv. chemical inhibition of nitrification.

The use of controlled release fertilizers and nitrification inhibitors is confined mainly to the USA, Japan and Western Europe. Because of their limited availability and high prices, these materials are used almost entirely for fertilizing high value horticultural crops, turf, lawns, etc.

9.13.1 Slow Release Nitrogen Fertilizers

A number of chemicals have been suggested of which the most commonly used are ureaformaldehyde and isobutylidene di-urea (IBDU).

i. Ureaformaldehydes are condensation products of urea and formaldehyde. There is a whole series of compounds ranging from relatively soluble to completely insoluble depending upon the ratio of urea and formaldehyde. Ureaformaldehydes are white granular materials with a nitrogen content varying from 38 to 40 percent. Improvement in efficiency for agricultural use has seldom been sufficient to offset the high cost of these products.

ii. Isobutylidene di-urea (IBDU) is a condensation product of urea and isobutyraldehyde. It is a white crystalline powder containing about 32 percent N, with very low solubility in water (0.01 to 0.1 g/100 ml). It is marketed in Germany and Japan and can be used as a component of mixed fertilizers. It has advantages under very high rainfall conditions.

9.13.2 Coated Fertilizers

Coating the fertilizer prevents its immediate dissolution in the soil so that nitrogen is progressively released for plant growth.

i. Sulphur coated urea (SCU) is produced by spraying molten sulphur uniformly on urea in a rotary drum. The sulphur requirement ranges from 15 to 19 percent of the total product weight depending on the desired effectiveness of the coating and the size and shape of the granules. A sealant such as microcrystalline wax, polyethylene, bright stock oil, etc., constituting 2 percent of the total weight is sprayed on to the sulphur-coated granules. The nitrogen content of the SCU varies from 30-37 percent depending on the amount of sulphur used in coating.

   Experiments carried out in the USA, Philippines, India and elsewhere have shown that SCU is particularly useful for rice grown under poor water management conditions and for long duration crops, such as sugarcane and pineapple. It may not be effective for such crops as maize, wheat, etc., which require large quantities of nitrogen in a relatively short period.

ii. Shellac coating of urea has also been developed and is reported to be effective for rice in India though its cost/benefit analysis prohibits its use.

9.13.3 Adjusted Particle Size

Using urea of large particle size ("supergranules") varying in weight up to 3 g has been found to reduce ammonia losses to an important extent when used on wetland rice, as the granules sink into the flooded soil and the ammonia produced is thus much less liable to volatilization and nitrification-denitrification. This is attributed to slower rates of urea hydrolysis and an increase in the rate of downward diffusion of urea and ammonia. The concentration of ammonia in the vicinity of supergranules may also be toxic to nitrifiers.

9.13.4 Nitrification Inhibitors

In many situations losses of nitrogen from applied ammonium fertilizers and urea take place mainly after their conversion to nitrate. Inhibition or retardation of nitrification of applied ammonium and urea nitrogen can thus reduce these losses and increase the efficiency of applied nitrogen. Several chemicals with nitrification inhibiting properties have been developed and tested and it has been shown that they can increase the efficiency of nitrogenous fertilizers where leaching or denitrification are problems.

The physical and chemical properties of some of the widely tested nitrification inhibitors with their blending/application rates are given in Table 12.

Table 12 PHYSICAL AND CHEMICAL PROPERTIES OF NITRIFICATION INHIBITORS

Common/trade name	Chemical	Solubility in water (g/100 ml)	Normal blending/ application rate
N-serve or Nitrapysin	2-chloro-6-(tri-chloromethyl)-pyridine	0.004 at 20°C	0.15-0.5 kg/ha
AM	2-amino-4-chloro-6-methyl-pyrimidine	0.127 at 20°C	0.3 -0.4 percent
Thiourea	Thiourea	9.2 at 13°C	1.5 -2.5 percent
DCD	Dicyandiamide	2.38 at 13°C	1.0 -2.5 percent
ST	2-sulfanilamide thiazole	0.06 at 26°C	0.3 -0.4 percent

10. PHOSPHORUS FERTILIZERS

10.1 SOURCES OF FERTILIZER PHOSPHORUS

Phosphorus is an important constituent of the earth's crust, but has been concentrated over geological time in deposits of phosphate rock (formed mainly from the remains of aquatic organisms), and is present in most natural and cultivated soils in insufficient quantity for full crop growth. The sources from which phosphorus is obtained for use in fertilizers are:

i. phosphate rock deposits, by far the most important source
ii. basic slag, a by-product of the steel industry.

Phosphate rock is a naturally occurring mineral and known phosphate rock deposits of economic interest are widespread around the world. However, most of the production of this mineral is concentrated in a few countries, especially USA, USSR, Morocco, Algeria, Tunisia, Jordan, Nauru and Christmas Island. Two general types of phosphate deposits are found: one is of igneous origin and the other sedimentary. Both have essentially the same phosphate mineral - calcium phosphates of apatitic origin (fluorapatite, chlorapatite, hydroxyapatite or sulphatoapatite) and may be represented by the chemical formula $[Ca_3(PO_4)_2]_3.CaX$ where X can be F_2, Cl_2, $(OH)_2$ or SO_4. After mining, phosphate rock is separated from impurities by a complex system of washers, screens, classifiers, table agglomeration and flotation. It is usually crushed or ground before it is marketed. Ground rock phosphate can be used direct as a fertilizer, but for most crops and soils it is necessary to convert it into more efficient forms through the chemical reactions given in Figure 28.

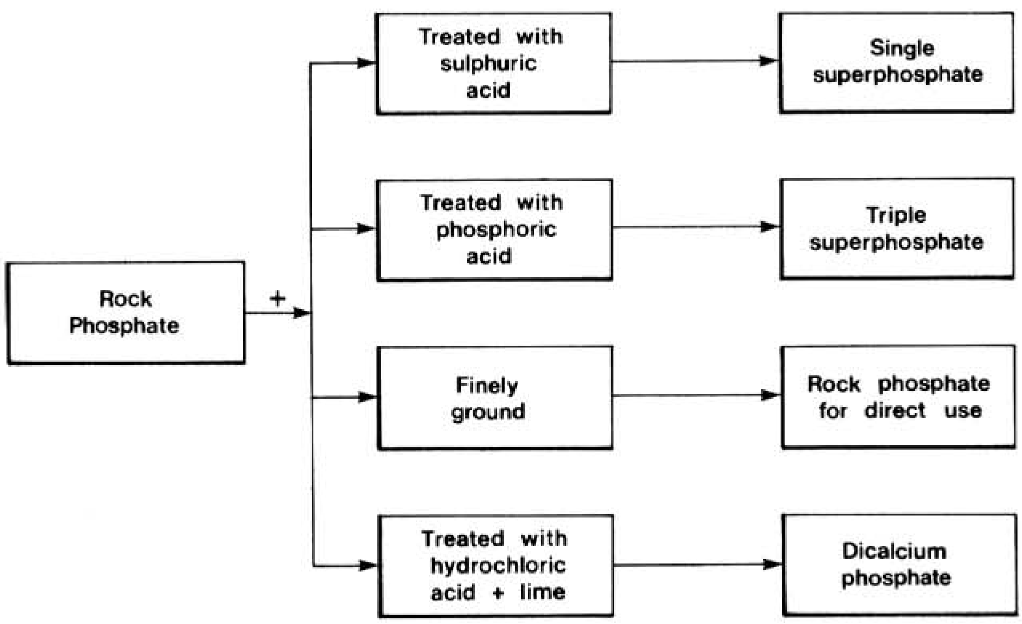


Fig. 28 Production of straight phosphorus fertilizers from rock phosphates

10.2 AGRONOMIC VALUE OF PHOSPHORUS FERTILIZERS

Plants take up phosphorus from the soil solution in the form of phosphate ions (HPO_4^{--} and $H_2PO_4^-$), so that for fertilizer phosphorus to be available it must be released in ionic form to the soil solution. The phosphorus in fertilizers occurs in various chemical and physical forms whose availability varies very much.

The total phosphorus content in a fertilizer does not truly reflect the quantity that the crop plants could make use of, immediately or eventually. Perhaps the most accurate measure of plant availability of phosphorus, or for that matter of any nutrient from a fertilizer, is the extent to which it is absorbed by plants under conditions of favourable growth. Such determinations are not easy to make and are also time consuming but they have been used to calibrate the chemical methods of measuring availability that are discussed below. Chemical methods permit fairly accurate estimates of the availability of phosphorus in different fertilizers. They are included in the legislation regulating the declaration of the phosphorus contents in fertilizers in most countries, though there are many variations from country to country in the details of analytical methods and procedures. It should also be noted that in most countries, for historical reasons, the amount of phosphorus present is declared in terms of the oxide (P_2O_5). Some countries in western Europe and elsewhere have recently changed to the elemental basis (P), but for continuity the oxide basis will be used here.

The principal chemical methods used for statement of phosphorus content are:

i. water-soluble phosphate, by a carefully prescribed procedure: it is soluble in water and is readily available to all crops;

ii. citrate or citric acid soluble phosphate: there are a number of variants of which the most effective are based on the use of neutral or alkaline ammonium citrate solutions or 2 percent citric acid solution. These methods are intended to simulate the action of the soil solution and, in most fertilizers, dissolve more phosphate than the water-soluble method;

iii. total phosphorus, a statement of the total amount present and not necessarily meaningful in terms of plant-availability;

iv. formic acid (2 percent) solubility now used in some countries to estimate the availability of phosphorus in rock phosphates for direct application.

The citrate soluble phosphate content is often taken to represent the "available" phosphate in processed phosphatic fertilizers, a reasonable assumption provided that over 60 percent or so of the cirate-soluble phosphate is in water-soluble form, for agronomic considerations.

10.3 PHOSPHORUS FERTILIZER MANAGEMENT

Depending on the form in which phosphorus is present, fertilizers are classified as those containing mainly water-soluble phosphate, citrate/citric acid-soluble phosphate and citrate-insoluble phosphate. The suitability of a phosphorus fertilizer for a particular soil and cropping situation, as also its management, will depend on the form in which phosphorus is present in it. For example, short duration crops with restricted root systems such as most of the small grain crops will require a fertilizer containing a high proportion of water-soluble phosphate so that it can be immediately taken up by crops. On the other hand, a high degree of water solubility is less important for long duration or perennial crops with extensive root systems, because their requirement is distributed over a longer period of time. Generally, in neutral to alkaline soils a higher proportion of water-soluble phosphorus is required than in acid soils.

For efficient management of phosphorus fertilizers of high water solubility, the fertilizers need to be placed or drilled in the form of granules near the root zone so as to delay conversion to unavailable forms. Thorough incorporation throughout the soil is desirable for fertilizers containing a high proportion of water-insoluble phosphorus, so these fertilizers need to be applied in finely divided form and be well mixed with the soil. These aspects are discussed in greater detail below.

10.4 MANUFACTURE AND USE OF PHOSPHORUS FERTILIZERS

The commonly used straight phosphorus fertilizers are single superphosphate, triple or concentrated superphosphate, basic slag and rock phosphate. A brief description of their manufacturing processes, characteristics and agronomic uses is given below.

10.4.1 Single Superphosphate

Single (normal) superphosphate (SSP) was the first chemically manufactured phosphorus fertilizer. It is still used in many countries but has been and is being replaced by more concentrated phosphorus fertilizers and by complex fertilizers.

i. Manufacture

Finely ground rock phosphate is mixed with concentrated sulphuric acid in a specially designed reaction vessel. The reaction taking place can be represented by the following simplified equation:

$$[Ca_3(PO_4)_2]_3.CaF_2 + 7H_2SO_4 \longrightarrow 3Ca(H_2PO_4)_2 + 7CaSO_4 + 2HF$$

The product is dried and granulated, sometimes with nitrogen and potassium fertilizers to make multinutrient fertilizers.

iii. Characteristics

SSP is grey or brown, usually granular for convenience of storage and application. The powdered product cakes in storage. SSP contains monocalcium phosphate and calcium sulphate (gypsum) in almost equal proportions. Depending on the quality of the rock and acid used, it usually contains 17-20 percent total P_2O_5, of which over 90 percent is water-soluble; it also contains about 16 percent sulphur. Granulated SSP can be easily and uniformly applied in the field without problem. The product contains a small amount of free acid, and packaging should be resistant to acid attack, e.g. polyethylene or polyethylene-lined sacks.

iii. Uses

SSP is a suitable phosphorus fertilizer for most crops and soils, except for highly acidic soil conditions where a water-insoluble phosphate source, such as rock phosphate, can be better. Because of its calcium and sulphur contents it is useful for soils which are deficient in these nutrients. Application of SSP to groundnuts grown in sulphur-deficient soils is particularly beneficial. Immobilization in the soil of the water-soluble phosphate in SSP will take place more slowly if the fertilizer is applied in bands close to the seed rows, thus minimizing the amount of soil-fertilizer contact.

10.4.2 Triple Superphosphate

i. Manufacture

Triple superphosphate (TSP) is produced by reacting finely ground phosphate rock with concentrated phosphoric acid (52-54 percent P_2O_5) in a continuous system, and is usually granulated, either alone or as a component of multinutrient fertilizer.

ii. Characteristics

TSP contains 44 to 52 percent P_2O_5, almost entirely in water-soluble form. TSP in powder form is not free-flowing and has a tendency to cake, but the granulated product has excellent storage and handling properties and is free-flowing. TSP may contain free phosphoric acid so that suitable packaging is necessary.

iii. Uses

TSP has similar uses as a phosphorus fertilizer to SSP, but it is a much more concentrated nutrient source and contains very little sulphur. Because of its high nutrient content it is particularly useful in the preparation of high analysis multinutrient fertilizers.

10.4.3 Dicalcium Phosphate

Straight dicalcium phosphate is now little used as a fertilizer because of the high cost of manufacture and the inconvenience in handling and application of its obligatory powder form. It is made by reacting rock phosphate with hydrochloric acid and adding lime to form a precipitate. This is washed, dried and packed as a grey powder, the commercial product containing about 35 percent P_2O_5, which is citrate-soluble but water-insoluble. Dicalcium phosphate is also a citrate-soluble component of nitrophosphates and other compound fertilizers.

The citrate-soluble phosphate in dicalcium phosphate does not undergo immobilization in the soil as rapidly as monocalcium phosphate, so that for long duration crops such as sugarcane or in acidic soils dicalcium phosphate is considered to be an effective source of fertilizer phosphorus.

10.4.4 Basic Slag

Basic slag is a by-product of the steel industry but because of changes in technology and in the ores used, the amounts of phosphate-rich slag available have declined rapidly in many parts of the world. In the course of steel manufacture the non-ferrous elements, including phosphorus, from the ore are separated off as slag together with residues of the lime added during the process. The phosphorus content of the slag may be from 8 to 18 percent P_2O_5, and the slag also has considerable liming value. Basic slag contains water-insoluble but citric-acid soluble phosphate in the form of calcium silicophosphates; it is unstable and becomes available slowly, particularly in acid soils. Basic slag is therefore most suited to long duration crops, especially on acid soils; it also supplies available phosphorus on neutral and slightly acid soils.

Basic slag must be finely ground for optimum release of phosphorus to the soil solution. It is not hygroscopic and stores well but application in powder form is a very dusty operation; achieving uniform application may also be difficult.

10.4.5 Rock Phosphate

For direct application, rock phosphate is finely ground to increase contact with and dissolution in the soil. Rock phosphate varies in suitability for direct application from source to source, the best being the soft, sedimentary rocks such as those from Tunisia and Morocco.

i. Characteristics

Finely ground rock phosphate is often light grey or brown in colour and neutral in reaction. The composition varies with the source, the phosphorus content being in the range from 29 to 37 percent P_2O_5. The calcium content ranges from 35 to 38 percent, but there is no liming value. In addition, the mineral contains fluorine, chlorine, aluminium, and iron oxides, organic matter and trace elements such as manganese, but these are not agronomically useful. Its phosphate is water-insoluble and only slightly soluble by citrate based methods. There is little correlation between chemical analysis and phosphorus availability to crops, and the efficiency of different rocks is best evaluated in pot or field experiments.

ii. Uses

Rock phosphate is essentially a slow-acting phosphorus fertilizer. Its efficiency as a direct source of fertilizer phosphorus depends on:

a. physical and chemical composition, in which crystal structure and fluorine content (presence of more sparingly soluble fluorapatite) are important;

b. fineness of grinding, which influences the surface area present for solvent action of the soil acids and hence the rate of phosphorus availability. It is generally considered that 90 percent of the rock should pass through a 100 mesh sieve;

c. soil reaction: the phosphorus of ground rock phosphate is generally utilized best in acid soils with a pH below 5.5 or in soils containing a high percentage of organic matter. On neutral or alkaline soils it is almost unavailable to crops;

d. nature of the crop: crops vary somewhat in their capacity to utilize phosphorus from rock phosphate, though much of the perceived variation can be due to the soil type on which they are grown. The most efficient utilizers of rock phosphate include turnips, sweet clover, mustard, tea, rubber and coffee, while the least include cotton, rice, wheat, barley and potatoes;

e. method of application: since it is important to maximize contact with the soil, rock phosphates should be broadcast, not placed. Application some while before sowing also allows time for solubilization to take place.

11. POTASSIUM FERTILIZERS

Potassium is one of the major nutrients essential for plant growth. Because of long usage, the potassium content of fertilizers is usually expressed in terms of potassium oxide (K_2O) or "potash" but, as with phosphorus, some European countries and others have changed over to the elemental basis, K.

Potassium fertilizers are obtained by mining and purification of natural deposits containing potassium salts found in various countries, notably Canada, USA, USSR, France, Germany, and Spain. The principal potassium minerals are sylvinite (a mixture of sylvite (KCl) and halite (NaCl)), carnallite ($KCl.MgCl_2.6H_2O$), kainite ($KCl.MgSO_4.3H_2O$), langbeinite ($K_2SO_4.2MgSO_4$) and nitre (KNO_3).

The commonly produced and used potassium fertilizers are potassium chloride (muriate of potash), potassium sulphate (sulphate of potash) and potassium magnesium sulphate.

11.1 POTASSIUM CHLORIDE

11.1.1 Manufacture

Practically all commercial potash is recovered from underground deposits of soluble minerals or from potash-bearing brines. Basically three types of process are employed to recover potassium from minerals: (i) extraction by solution and recrystallization; (ii) flotation; (iii) electrostatic beneficiation. In the first of these, crushed ore is mixed with a sufficient quantity of recycled brine (which is nearly saturated with NaCl) and heated almost to boiling to dissolve potassium chloride. The potash-rich brine undergoes clarification and cooling, and vacuum evaporation produces potassium chloride crystals, which are centrifuged, washed, dried and packed. The filtrate (brine) is recycled for the extraction of further potassium chloride.

The flotation process operates at normal temperature. The crushed ore is added to a salt-saturated solution which does not serve as solvent but as carrier liquid. The brine is treated with an amine acetate or other agent which selectively coats the potassium chloride particles. Air is then bubbled through the slurry. The air bubbles attach themselves to the coated particles and float them to the surface while the uncoated particles sink. The floated potassium chloride is centrifuged, dried and packed.

Electrostatic beneficiation is a dry process which minimizes environmental problems and needs less energy. The process has been introduced to separate kieserite ($MgSO_4.H_2O$) from the crude salt. It makes use of the specific surface charges of different minerals. After special pre-treatment, the finely ground material is fed to a free-fall separator where the negatively charged potassium chloride and kieserite are separated from the positively charged sodium chloride in the electric field. In a second step kieserite is separated from potassium chloride, again using the electrostatic process.

11.1.2 Characteristics

Potassium chloride contains about 60 percent potash (K_2O). In pure form it is a white crystalline salt but the colour of fertilizer grade potassium chloride ranges from white to red depending on the impurities present in the potash minerals. The colour has no influence on fertilizer effect. Crystalline potassium chloride is free-flowing and does not normally pose any problems in handling and storage. Formerly, caking occurred under conditions of high humidity, but the use of anti-caking agents eliminates this.

11.1.3 Uses

Potassium chloride is completely soluble in water. On application to the soil, the potassium ion is adsorbed and retained by soil colloids and thus the possibility of loss by leaching is small. It is subsequently taken up in the ionic form by plant roots. The salt is neutral in reaction and does not produce any acidity or alkalinity in the soil. Potassium chloride is suitable for most crops and soils but for crops such as tobacco and potatoes, where quality is affected by excess chloride, potassium sulphate is preferable. Usually the entire requirement for potassium may be applied as a basal dose but in sandy soils, high rainfall areas and for wetland rice a split application may be more beneficial.

11.2 POTASSIUM SULPHATE

While potassium chloride is the most widely used potassium fertilizer, potassium sulphate is used to a limited extent for certain special crops.

11.2.1 Manufacture

Potassium sulphate occurs to some extent in nature as langbeinite, a double salt with magnesium ($K_2SO_4.2MgSO_4$), but can also be manufactured by the action of sulphuric acid on potassium chloride.

$$2KCl + H_2SO_4 \longrightarrow K_2SO_4 + 2HCl$$

The reaction is carried out in a special furnace consisting of a cast iron muffle with rotating ploughs to agitate the reaction mixture. The gaseous hydrochloric acid is cooled and absorbed in water.

11.2.2 Characteristics

Potassium sulphate is a white crystalline salt and contains 48 to 52 percent of potash (K_2O), plus 18 percent of sulphur. The crystalline potassium sulphate is free-flowing and does not normally pose any problem in handling and storage.

11.2.3 Uses

Like potassium chloride, potassium sulphate is soluble in water and when applied to the soil, the potassium ion is retained by soil colloids and does not easily leach out. It is an excellent fertilizer and can be applied to all soils and crops. However, due to its higher cost per unit of K_2O, relative to potassium chloride, its use is generally restricted to chloride-sensitive crops. Its sulphur content makes it a two-nutrient fertilizer. It is used for tobacco, potatoes, fruits and vegetables. It may also be preferable on saline soils and in glasshouses where chloride accumulation can be a problem.

11.3 POTASSIUM MAGNESIUM SULPHATES

There are several fertilizers which contain both potassium and magnesium in the sulphate form, such as the above mentioned langbeinite or schoenite ($K_2SO_4.MgSO_4.6H_2O$) which is prepared in limited quantities from mixed salt obtained from solar evaporation of bittern in salt pans in India. Commercial grades of potassium magnesium sulphate are produced in Europe and the USA. Their nutrient contents are about 22-30 percent K_2O, 10-19 percent MgO, 16-23 percent S. They are especially recommended for application on acidic and magnesium deficient soils and for crops with high Mg requirements such as potatoes, fruits, vegetables, and forest trees.

11.4 KAINITE

Kainite is a naturally occurring mineral deposit. The pure form, kainite, has the composition $KCl.MgSO_4.3H_2O$, though in nature it rarely occurs as such. The commercial product, kainite, consists largely of a mixture of potassium chloride, magnesium sulphate and magnesium and sodium chlorides. Low grades of kainite contain 14-22 percent K_2O. It usually contains 46 percent chlorine and is alkaline in reaction. When kept in storage, unlike most other potassic fertilizers, it may cake and needs breaking up. It can be useful for sodium-using crops such as sugarbeet.

12. MULTINUTRIENT FERTILIZER

12.1 DEFINITIONS

Before dealing with the preparation of multinutrient fertilizers, definitions of some of the terms used will be helpful

i. "Fertilizer grade" (or fertilizer analysis) refers to the guaranteed minimum percentages of total nitrogen (as N), available phosphorus (usually as P_2O_5) and soluble potassium (usually as K_2O) contained in the fertilizer. Thus 100 kg of a 12-6-6 fertilizer contains 12 kg of N, 6 of P_2O_5 and 6 of K_2O.

ii. "Fertilizer ratio" or nutrient ratio refers to the ratios of the three nutrient analyses, e.g. the 12-6-6 fertilizer referred to above has a 2-1-1 nutrient ratio.

iii. "Filler" is a non-nutrient material such as sand or limestone chips added to the available fertilizer ingredients to bring them to a specified analysis.

iv. "Conditioner" is a material added to fertilizer to improve its physical condition.

v. "Coating" describes the dust or clay used to coat many granular fertilizers to prevent moisture being picked up and caking in storage.

vi. "Intermediate" is a material made in a first manufacturing stage for subsequent incorporation into multinutrient fertilizers.

Multinutrient fertilizers produced by processes involving chemical reaction between constituents which contain the primary plant nutrients are termed complex fertilizers. Fertilizers produced by granulating together single-nutrient sources, or mixing granules of single-nutrient fertilizers are referred to as compound or mixed fertilizers. The nomenclature dividing these classes is not specific and may be ambiguous, because of the various ways in which fertilizer raw materials and intermediates can be combined.

12.2 ADVANTAGES OF MULTINUTRIENT FERTILIZERS

The general advantages of using multinutrient fertilizers are as follows:

i. all necessary plant nutrients are available in one package and the farmer is saved the trouble of purchasing, transporting and storing various fertilizer materials separately;

ii. less time and labour are required to apply a single fertilizer than to apply straight fertilizers separately;

iii. application of recommended quantities of suitable multinutrient fertilizers ensures balanced fertilization and therefore higher yields and profitability as well as maintenance of soil fertility;

iv. micronutrients can readily be applied in small amounts incorporated in multinutrient fertilizers.

12.3 COMPLEX FERTILIZERS

Complex fertilizers have a high nutrient content, owing to which the cost of packing, handling and transport per unit of nutrient is lower than in many straight fertilizers. Complex fertilizers are produced in granular form and are free-flowing, thus contributing to ease of handling and application. An advantage, particularly in developing countries, is that complex fertilizers help to ensure balanced fertilization of crops. Production and use of complex fertilizers is therefore gaining ground and accounts for a considerable proportion of world fertilizer use.

Complex fertilizers can be broadly classified into ammonium phosphates, nitrophosphates and NPK fertilizers.

12.3.1 Monoammonium Phosphate

Monoammonium phosphate (MAP) is a high-analysis fertilizer containing 52 to 55 percent P_2O_5, almost entirely water-soluble, and 11 to 12 percent nitrogen. It is used mainly in the manufacture of multinutrient fertilizers, as it is non-hygroscopic and compatible with most other fertilizer materials; some is used for direct application. Its manufacture is by the reaction of ammonia with wet phosphoric acid at 45-52 percent concentration maintaining a $NH_3:H_3PO_4$ mole ratio of 1:1. The concentrated MAP solution is spray-dried to produce the powdered material and then granulated.

The chemical reaction can be represented as:

$$H_3PO_4 + NH_3 = NH_4H_2PO_4$$

12.3.2 Diammonium Phosphate

Diammonium phosphate (DAP) is produced in large quantities. The commercial product contains 18 percent nitrogen and 46 percent P_2O_5, mostly water-soluble. The manufacturing process is very similar to that of monoammonium phosphate except that the required mole ratio of $NH_3:H_3PO_4$ is 2:1 which involves an additional step of ammoniation. The slurry is granulated, dried, screened, cooled and conditioned by a coating agent, if necessary. The chemical reaction can be represented as:

$$2NH_3 + H_3PO_4 = (NH_4)_2HPO_4$$

The material is granular and free-flowing.

12.3.3 Ammonium Phosphate Sulphate

Ammonium phosphate sulphate is about 60 percent ammonium sulphate and 40 percent ammonium phosphate, with a nitrogen content of 16 percent and P_2O_5 content of about 20 percent. By adding urea, the nitrogen content can be increased and a number of $N:P_2O_5$ analysis products can be made.

There are two methods of manufacture:

i. direct neutralization of a mixture of sulphuric and phosphoric acids by ammonia and granulation of the resulting slurry in the blunger;

ii. addition of ammonium sulphate solution from the gypsum ammonium carbonate process to phosphoric acid followed by ammoniation. If required, urea can be added to the blunger.

Ammonium phosphate sulphate is free-flowing and does not normally pose any handling and storage problems.

12.3.4 Urea Ammonium Phosphate

Urea ammonium phosphate (UAP) is manufactured by reacting ammonia and phosphoric acid. The resulting ammonium phosphate slurry is pumped into the granulator where more ammonia and urea are added. The material is then dried, screened, cooled and coated with a coating agent to prevent caking. Various $N:P_2O_5$ analyses are available. It is also possible to produce liquid (solution) UAP direct, thus avoiding drying costs. The nitrogen is partly in ammoniacal and partly in urea forms and almost all the phosphorus content is water-soluble. The granules are free-flowing and the fertilizer has good physical properties but may cake in humid conditions.

12.3.5 Ammonium Polyphosphates

Ammonium polyphosphates (APP) are produced by reacting ammonia with superphosphoric acid. They are made both in liquid and solid forms. While the typical APP solutions used in the USA have analyses 11-33-0, 10-34-0, 12-40-0 and 8-27-0, it is possible to produce a granular product having a high nutrient content, up to 15-61-0, depending on the purity of the acid used. APP is completely water-soluble.

The nitrogen in APP is entirely in ammoniacal form and the phosphate is present as monoammonium phosphate ($NH_4H_2PO_4$) and as orthoammonium polyphosphates. Apart from its high analysis, APP solutions offer the advantage that large quantities of micronutrients can be added without causing precipitation. The manufacture and use of ammonium polyphosphates is mainly confined to the USA.

12.3.6 Agronomic Aspects of Ammonium Phosphates

Ammonium phosphates are in general agronomically satisfactory on all crops and soils, having the expected characteristics of ammonium-containing nitrogen fertilizers and of highly water-soluble phosphate. Nitrogen present as urea in urea ammonium phosphate may be less efficient in some circumstances. The polyphosphate in ammonium polyphosphates is not immediately fully available to crops but is rapidly converted to the available orthophosphate form in soil.

DAP, due to its high content of phosphorus finds greater use in areas and for crops where the phosphate requirement in relation to nitrogen is relatively high, while because of its very wide $N:P_2O_5$ ratio, MAP is usually granulated or mixed with additional nitrogen and potassium intermediates.

12.3.7 Nitrophosphates

The term nitrophosphates describes fertilizers made by a number of related processes in which phosphate rock is acidulated with nitric acid or a mixture of nitric and phosphoric or sulphuric acids, followed by ammoniation of the resulting slurry. The slurry is then granulated or prilled, with the addition if required of more nitrogen, usually as ammonium nitrate, and potassium chloride or sulphate to give the required NPK analysis.

Nitrophosphates have good granulation characteristics, and are coated to minimize moisture being picked up. Caking is not a problem provided proper packaging and storage conditions are provided.

The agronomic performance of nitrophosphates depends on the solubility of the phosphate. Almost all the phosphate is citrate-soluble, but water-solubility can range from nil to over 80 percent depending on process and degree of ammoniation. Those nitrophosphates with 60 percent or more of water-soluble phosphate are fully satisfactory for all crops and soils. However, those with low water-solubility are satisfactory only for long duration crops such as sugarcane or grassland, and for acid soils. They are less satisfactory for short duration crops such as cereals and potatoes.

12.3.8 NPK Complex Fertilizers

Solid NPK complex fertilizers contain nitrogen, phosphorus and potassium in varying proportions. They are granular, free-flowing and generally trouble-free in handling and application. Depending on soil and crop needs, varying grades are produced and marketed. They can be produced both by the ammonium phosphate and nitrophosphate routes by the addition of potassium and, if necessary, nitrogen and depending on the process employed the proportions of ammonium, nitrate and urea nitrogen vary as also do the water-soluble and citrate-soluble phosphorus contents. They are best applied as basal dressing. A very wide range of NPK analyses is available but for operational reasons most factories limit their output to a few products.

The main advantage of NPK complex fertilizers is convenience of use, including ease of handling and application of all three nutrients in one operation. They can also be formulated to contain Ca, Mg, S and micronutrients. However, the grades available may not always meet the specific requirements of all farming situations and it may be necessary for farmers to apply additional amounts of these nutrients separately.

12.4 COMPOUND FERTILIZERS

Compound fertilizers, sometimes referred to as mixed fertilizers, differ from complex fertilizers essentially in their method of preparation. They may be:

i. single nutrient or two-nutrient intermediates granulated together;

ii. granular intermediates or straight fertilixers mixed together to form a blend, each granule retaining its original composition; or

iii. powders mixed together.

The agronomic performance of compound fertilizers is essentially that of their components, as described in earlier sections. The physical nature and storage, handling and application characteristics of granular compound fertilizers depend on correct manufacturing procedures, but are normally good, with no moisture collection or caking problems, provided coating, packaging and storage conditions are good. It is also important when granular materials are blended together that the components should be homogeneous in size and shape, to avoid segregation in handling and application. Powdered mixed fertilizers usually have poor storage properties and are more difficult to apply uniformly than are granules. Their suitability for application by distributor is limited.

12.4.1 Granular Compound Fertilizers

Granular compound fertilizers are made at factory sites from straight N, P and K fertilizers, sometimes including two-nutrient intermediates such as MAP. The intermediates are usually in powder or slurry form and are metered into a granulating plant, typically a large rotary drum. Water or steam is added as required and rotation causes the formation of granules which are dried, screened for size and bagged or bulk stored. Granular compounds contain a range of components depending mainly on agronomic suitability and availability. Some ingredients are not compatible, e.g. using urea and superphosphate together can result in the phosphorus losing water-solubility.

Granular compound fertilizers offer the following advantages:

i. uniformity of granulation avoiding segregation of components;
ii. good storage and handling characteristics;
iii. even application using a wide range of types of distributor.

12.4.2 Powdered Mixed Fertilizers

Where powdered (or crystalline) straight fertilizers are available they may be mixed together on the farm to make multinutrient fertilizers, thus reducing the number of fertilizer applications to be made to a field.

The choice of ingredient for powdered multinutrient fertilizers depends on:

i. agronomic suitability, taking into account the agronomic properties of fertilizer sources described earlier. For example, for annual crops on neutral or alkaline soils, a phosphorus source with high water-solubility is preferable; for tobacco, potassium sulphate is required and not potassium chloride;

ii. desired fertilizer grade: low analysis components such as ammonium sulphate or SSP cannot give high analysis fertilizers and vice versa;

iii. physical and chemical compatibility: some intermediates cannot be granulated together without causing problems, e.g. loss of phosphorus water-solubility when lime-containing materials and superphosphate are granulated or mixed, severe fire hazard when urea and ammonium nitrate are mixed. Granular and powdered materials should not be mixed because of the ensuing risk of segregation.

There are thus limitations on the ways in which mixed fertilizers can be formulated. A general guide to the compatibility of ingredients for on-farm mixing is given in Figure 29.

Mixing can be done on the farm, providing sufficient manpower is available, by hand or using a rotary mixer.

Powder mixtures can be made up in a wide range of nutrient ratios by suitable combinations and amounts of ingredients. As an example, an 8-8-8 fertilizer can be formulated as follows:

Ammonium sulphate, 20.6% N	39%
SSP, 16.5% P_2O_5	48%
Potassium chloride, 60% K_2O	13%
	100%

Powder mixtures can be slightly cheaper than granular materials but suffer from the disadvantages that only very short term storage is possible, that application is more time consuming and less uniform and that some of the more concentrated intermediates such as ammonium nitrate and urea cannot easily be used.

	Potassium chloride	Potassium sulphate	Sulphate of potash magnesia and schoenite	Ammonium sulphate	Calcium ammonium nitrate	Urea	Superphosphate, single and triple	Ammonium phosphates	Basic slag	Rock phosphate (powdered)	Calcium carbonate (Lime)
Potassium chloride	□	□	□	□	☒	☒	□	□	□	□	□
Potassium sulphate	□	□	□	□	☒	☒	□	□	□	□	□
Sulphate of potash magnesia and schoenite	□	□	□	□	☒	☒	□	□	□	□	□
Ammonium sulphate	□	□	□	□	□	☒	□	□	■	☒	■
Calcium ammonium nitrate	☒	☒	☒	□	□	☒	☒	☒	■	□	□
Urea	☒	☒	☒	☒	☒	□	☒	☒	☒	☒	☒
Superphosphate, single and triple	□	□	□	□	☒	☒	□	□	■	■	■
Ammonium phosphates	□	□	□	□	☒	☒	□	□	■	■	■
Basic slag	□	□	□	■	■	☒	■	■	□	□	□
Rock phosphate (powdered)	□	□	□	☒	□	☒	■	■	□	□	□
Calcium carbonate (Lime)	□	□	□	■	□	☒	■	■	□	□	□

□ Fertilizers which can be mixed.

☒ Fertilizers which may only be mixed shortly before use.

■ Fertilizers which cannot be mixed (for chemical reasons).

Bonemeal which is often used as "drier" may be mixed with other fertilizers.

Fig. 29 Guide for mixing fertilizers

12.4.3 Bulk Blends

Where intermediates such as CAN, MAP, and potassium chloride are already available in granular form, the cost of re-granulation can be avoided by simply mixing or blending these intermediates together. This operation can be carried out at small blending plants supplied with storage bins, metering and mixing equipment, e.g. by a merchant or cooperative.

The principle of bulk blending is to mix together granular intermediates with compatible properties - granule size, surface properties, density - so that no segregation occurs during storage, handling and application of the blended granular fertilizer. Bulk blended fertilizers are sold without bagging, with the risk that segregation will occur in transport; control of granule specification of intermediates is therefore of prime importance. With bulk blending, the analysis of small batches of product can be varied to suit the specific needs of a farmer, including the addition of secondary and micronutrients if required. Bulk blending avoids bagging costs, and since bulk-blended fertilizer is prepared and sold just prior to application, storage properties are irrelevant.

Bulk blending is most developed in the USA, where it is usually associated with contract application by the supplier, thus simplifying the farmer's operations and enabling large capacity equipment belonging to the contractor to be used for application.

12.4.4 Fluid Mixed Fertilizers

Fluid mixed fertilizers are of two types - clear liquids and suspension fertilizers. Clear liquids are solutions in water containing primary nutrients and formulated so that they are not liable to precipitate or salt out at prevailing temperatures, since such deposits are difficult and expensive to clear. The nutrient sources usually used are ammonium nitrate and urea, ammonium phosphate or phosphoric acid and potassium chloride. However, rather pure and therefore more costly grades are required than for solids. The concentrations achievable are considerably lower than for solid fertilizer, e.g. about 9-9-9 compared with 17-17-17. Suspension fertilizers contain a small quantity of special clay, which delays the settling from suspension of any salts that crystallize out. As a result, a level of concentration higher than clear liquids, but not as high as solids, can be achieved, and specially high quality ingredients are not needed. However, suspension fertilizers require continuous agitation in storage and special application equipment.

The main advantages of fluid mixed fertilizers over solids are in the area of reduced manpower requirements, availability of contract application, and facility of applying herbicides and pesticides in one operation with fertilizer.

Fluid mixed fertilizers are used quite widely in the USA and some other developed countries, as is the case for nitrogenous liquids. The need for specialized and expensive equipment for transport, storage and application makes their use unattractive in developing countries.

13. SECONDARY AND MICRONUTRIENTS

13.1 EFFECT OF RECENT AGRICULTURAL CHANGES

Plant uptake of the secondary nutrients, calcium, sulphur and magnesium is quite appreciable, though seldom as large as those of nitrogen, phosphorus and potassium. On the other hand, plants require only very small quantities, usually in terms of grams per hectare, of the micronutrients - iron, zinc, copper, manganese, boron, molybdenum and chlorine. Presence of these nutrients in appreciably higher quantities than the plant requires may prove toxic, because for some of them there is a very small margin between adequacy and excess.

In most developing countries, application of secondary and micronutrients has not received the attention it deserves. While farmers have to a considerable extent understood the benefit of applications of lime and gypsum to correct soil acidity and alkalinity respectively, most farmers are not even aware of the need for application of micronutrients. There are a number of reasons for this lack of awareness.

i. With the traditional tall crop varieties grown in these countries until recently, yield levels were low. The crop's requirements for all nutrients including micronutrients were also correspondingly low, and placed little strain on soil supplies.

ii. Farmers in these countries used to place considerable emphasis on application of organic manures, which though containing a low percentage content of nutrients, could meet crop requirements for them if application rates were high enough.

iii. The traditional low analysis fertilizers ammonium sulphate and single superphosphate, which were of major importance until recently, contain calcium and sulphur, and some micronutrients as impurities. With low yield levels, the quantities of these elements present in these fertilizers were sufficient to meet crop needs.

The situation has undergone a number of changes since the mid-sixties. The tall crop varieties have given way to dwarf, high yielding varieties. To meet their higher nutritional needs, particularly of major plant nutrients, and in the interest of economy in logistics, high analysis fertilizers such as urea, triple superphosphate and diammonium phosphate have largely replaced the low analysis fertilizers ammonium sulphate and single superphosphate. These materials are relatively purer and contain little in the way of other nutrient elements, either as impurities or associated ions. Organic manures are still being applied by farmers, but generally in lower quantities than when they were the only source of plant foods. Cropping intensity has also increased to a great extent. There is, therefore, greater need to apply secondary and micronutrient elements in many countries than in the past in order to maintain soil fertility and crop productivity.

13.2 CALCIUM

The calcium content of soils, plants and liming materials may be expressed as CaO (calcium oxide) or as elemental calcium, with a factor of 0.72 between them.

The total calcium content of soils is very variable depending on parent material and may be considerable in soils formed from limestones, igneous rocks such as granites, syenites, diorites, gneisses and schists.

On the other hand, soils derived from noncalcareous sandstones and shales in humid areas may contain little.

Irrespective of the total calcium content in the soil, the calcium that is present in the soil's base exchange complex constitutes the readily available supply of this element to plants. The lower the pH (i.e. the higher the acidity) and exchange capacity values, the smaller the amount of exchangeable calcium. A number of vegetable and fruit crops are particularly susceptible to calcium deficiency.

13.2.1 Correcting Calcium Deficiency

Since low supplies of calcium in soils are usually associated with soil acidity, correction of acidity through liming also overcomes calcium deficiency. However, soil acidity may not be the only reason for low soil calcium status. Liberal use of sodium nitrate over a period of years or repeated applications of irrigation water with a high sodium chloride content may result in the development of an alkaline soil in which sodium rather than calcium is the dominant cation.

Calcium is supplied to the soil mostly as liming materials which are discussed in Chapter 15. As a corrective for calcium deficiency in alkaline soils, calcium sulphate (gypsum) is used. Fruit and vegetable crops that suffer from calcium deficiency due to immobility of calcium within the plant often benefit from a foliar spray of calcium chloride or calcium nitrate.

13.3 MAGNESIUM

The magnesium content of soils or plants and of materials supplying magnesium may be expressed as MgO (magnesium oxide) or as elemental magnesium, with a conversion factor of 0.61.

Soil magnesium content varies from a trace to as much as 1 percent. Soils in arid areas or with a high clay content tend to be well supplied with magnesium, while sandy soils in high rainfall areas tend to have a low magnesium content because of loss by leaching. Magnesium deficiency may be intensified by excessive potassium application. Normally the crop obtains magnesium from the soil base exchange complex.

The quantities of magnesium taken up by crops are much lower than those of potassium and usually lower than calcium (Table 13). Magnesium deficiency has been rare until the last two decades but is now apparent in many crops, particularly potatoes, sugarbeet, various brassica crops and maize.

13.3.1 Correcting Magnesium Deficiency

Magnesium deficiency is best corrected by soil application before crop establishment, using any of a number of materials (Table 14) of which the more important are dolomitic limestone, kieserite and various potassium magnesium fertilizers. NPK fertilizers containing magnesium are also available.

The choice depends on economic considerations and whether liming is required. Magnesium deficiency seen during crop growth may be alleviated by a foliar spray of magnesium sulphate (Epsom salts).

Table 13 MAGNESIUM REMOVAL BY CROPS[1]

Crop	Yield t/ha	Magnesium removal kg ha/MgO	Crop	Yield t/ha	Magnesium removal kg ha/MgO
Alfalfa (hay)	9	40	Orange	27	32
Apple	25	40	Pepper (black)	2	25
Banana	30	136	Pineapple	30	90
Barley	5	26	Potato	30	29
Bean (string beans)	24	40	Radish	40	30
Cabbage	70	57	Rape seed	2.5	26
Carrot	30	30	Rice (paddy)	6	20
Cassava	25	27	Rubber (latex)	1.5	4
Cocoa (dry beans)	1	10	Sorghum	4	18
Coconut (7000 nuts)		38	Soybean	2.4	30
Coffee (dry cherries)	2	33	Sugarbeet	40	90
Cotton (lint)	1.5	55	Sugarcane	100	83
Cucumber	20	42	Sweet potato	20	44
Grapes	20	60	Tea (made tea)	2	11
Groundnut	2	21	Tobacco (dry leaf)	3	35
Hops	1	30	Tomato	40	29
Maize	6	41	Tropical grasses (dry fodder)	30	105
Oil palm (fresh fruit bunches)	25	102	Wheat	5	25
Onion	37	18	Yam	12	18

[1] Contained in the above-ground plant parts and roots/tubers where appropriate. Average values taken from various sources.

Table 14 MAGNESIUM-CONTAINING FERTILIZERS

Material	MgO (%)	Other major ingredients
Dolomitic limestone (Ca and Mg carbonate)	5-20	20-45% CaO
Various complex fertilizers	up to 6	$N+P_2O_5+K_2O+S$
Nitromagnesia	7	20% N+15% S
Ground burnt magnesium lime (Ca and Mg oxide)	9-33	26-58% CaO
Sulphate of potash magnesia (K_2SO_4, $MgSO_4$)	10-18	22-30% K_2O 16-22% S^2
Epsom salts ($MgSO_4.7H_2O$)	16	13% S
Magnesium chloride ($MgCl_2.6H_2O$)	20	-
Kieserite ($MgSO_4.H_2O$)	27	22% S
Magnesium sulphate anhydrous ($MgSO_4$)	33	26.5% S
Magnesite ($MgCO_3$)	45	-

13.4 SULPHUR

Sulphur is a very mobile element in soils. It is immobilized in the soil biomass and when this breaks down is mineralized to the sulphate form in which it is taken up by crops. Sulphate is very readily lost from the soil by leaching. Sulphur reaches soil from the atmosphere dissolved in rainfall and by dry deposition but amounts depend on rainfall and on nearness to industrial and fossil-fuel burning activities. Amounts precipitated range from a few kilograms per hectare per annum to over 100 kg. At the lower end of this scale sulphur deficiency may be expected.

Sulphur uptake is greatest by brassica crops and legumes and can be as high as 40-60 kg/ha (Table 15). These crops are most likely to suffer from sulphur deficiency, which occurs extensively in every continent.

Table 15 SULPHUR REMOVAL BY CROPS[1]

Crop	Yield t/ha	Sulphur removal kg ha/S	Crop	Yield t/ha	Sulphur removal kg ha/S
Alfalfa (hay)	9	24	Orange	50	30
Banana	30	13	Pineapple	40	16
Barley	5.4	22	Potato	30	15
Bean	1	25	Rape seed	3	65
Cabbages	35	47	Rice (paddy)	6	10
Cassava	19	8	Sorghum	2.5	11
Clover (hay)	6-9	17-22	Soybean	3	21
Cocoa (pods)	9	6	Sugarbeet	40	32
Coconut (9000 nuts)		13	Sugarcane	100	60
Cotton (lint)	1.5	30	Sunflower	4	18
Fodder beet	45	45	Table beet	45	37
Groundnut	2	16	Tobacco	3-4	13-24
Hops (corymbs)	1	30	Tomato	40	28
Maize	4.5	26	Tropical grasses		
Millet	2.7	20	(dry fodder)	27	60
Oat	3.6	22	Turnip	45	45
Oil palm	18	20	Wheat	5.4	28
Onion	40	25			

[1] Contained in the above-ground plant parts and roots/tubers where appropriate. Average values taken from various sources.

Source: Kieserite for better crops. Kali und Salz AG. FR Germany.

13.4.1 Correcting Sulphur Deficiency

Sulphur deficiency can be corrected in a number of ways:

i. by applying sulphur-containing fertilizers such as ammonium sulphate or single superphosphate;

ii. by applying gypsum, which also supplies calcium and is a soil ameliorant correcting alkalinity;

iii. by applying elemental sulphur, though this should only be used on very alkaline soils because of its soil acidifying effect; in some soils oxidation of the applied sulphur may be slow.

Sulphur and other nutrient contents of the more important materials are given in Table 16.

13.5 MICRONUTRIENTS

The micronutrients, which are required by plants in very small quantities, are iron, zinc, copper, manganese, boron, molybdenum and

Table 16 SULPHUR-CONTAINING FERTILIZERS

Material	% S	Other major ingredients
Magnesium sulphate anhydrous ($MgSO_4$)	26.5	33% MgO
Ammonium sulphate ($[NH_4]_2SO_4$)	24	21% N
Kieserite ($MgSO_4.H_2O$)	22	27% MgO
Sulphate of potash magnesia ($K_2SO_4,MgSO_4$)	16-22	22-30% K_2O 10-18% MgO
Potassium sulphate (K_2SO_4)	18	50% K_2O
Gypsum ($CaSO_4.2H_2O$)	18	32% CaO
Superphosphate ($Ca[H_2PO_4]_2.2CaSO_4$)	16	18% P_2O_5+20% CaO
Ammonium sulphate nitrate ($2NH_4NO_3.[NH_4]_2SO_4$)	15	26% N
Epsom salts ($MgSO_4.7H_2O$)	13	16% MgO
Various complex fertilizers	up to 9	N+P_2O_5+K_2O+MgO

chlorine. Several elements including cobalt, selenium, vanadium, nickel, lithium, silicon and aluminium, have been shown to be beneficial for crop growth but not essential, and are therefore not discussed here.

13.5.1 Requirement for Micronutrients

Micronutrients are required by crops in very small quantities, usually in terms of grams per hectare, but these few grams may make all the difference between securing high yields and the complete failure of the crop. The amounts of micronutrients required to produce one tonne of dry matter in a few selected crops are given in Table 17 though amounts will vary very much with growing conditions and yield levels.

Table 17 MICRONUTRIENT UPTAKE BY DIFFERENT CROPS (g/t DRY MATTER)

Crops	Fe	Mn	B	Zn	Cu	Mo
Cotton	106	14	15	16	8	0.77
Sorghum	360	27	27	36	3	0.98
Castor	223	41	31	14	9	1.01
Pearl millet	264	23	27	22	9	0.84
Groundnut	499	39	44	9	5	1.32
Wheat	232	26	18	21	8	0.87
Potato	160	12	50	9	9	0.80
Tobacco	692	132	96	21	11	0.60

Deficiencies of micronutrients produce characteristic symptoms in plants (Chapter 2), but taking corrective measures after the symptoms appear may be too late, since the damage has already been done. Application of the necessary micronutrient at this stage may not fully compensate for earlier deficiency and consequently yield may suffer. It is therefore desirable to establish whether the soil in which the crop is to be grown has sufficient available micronutrients for proper growth and development or whether it is deficient in one or more micronutrients, and to take corrective measures accordingly. A blanket recommendation of micronutrients under all soil and cropping situations is not satisfactory; such an application may do more harm than good, because of toxicity risks (section 2.4).

13.5.2 Critical Levels

It is possible to establish by experimentation the levels of each nutrient that should be present in the soil and in plants for proper plant growth. This level, known as the critical level, will vary from soil to soil, species to species and even between varieties. When the nutrient content in the soil or plant is below the critical level, application of additional micronutrients is needed. Research work is currently going on in many countries to determine the critical levels of various micronutrients for specific soil and cropping situations and some results for rice are shown in Table 18. Detailed information according to crop is given in FAO Fertilizer and Plant Nutrition Bulletin 7 on Micronutrients.

Table 18 CRITICAL NUTRIENT CONTENTS FOR DEFICIENCY AND TOXICITY IN RICE PLANTS

Element	Deficiency (D) or toxicity(T)	Critical content	Plant part analysed	Growth stage[1]
Fe	D	70 ppm	Leaf blade	Til
	T	300 ppm	Leaf blade	Til
Zn	D	10 ppm	Shoot	Til
		1500 ppm	Straw	Mat
Mn	D	20 ppm	Shoot	Til
	T	2500 ppm	Shoot	Til
B	D	3.4 ppm	Straw	Mat
	T	100 ppm	Straw	Mat
Cu	D	6 ppm	Straw	Mat
	T	30 ppm	Straw	Mat
Si	D	5.0%	Straw	Mat
Al	T	300 ppm	Shoot	Til

[1] Mat = maturity; Til = tillering

Source: IPI Bulletin 3, Fertilising for High Yield Rice. H.R. von Uexkull, 1976. IPI Berne, Switzerland.

13.5.3 Correcting Micronutrient Deficiencies

Where the existence of a deficiency has been established there are usually a number of ways of correcting it, which will differ from element to element. For some nutrients, e.g. copper, a soil application of a copper salt will be effective on most soils, because if enough copper is applied it will remain available in the soil for a number of years. For other nutrients, e.g. boron, soil application is effective but short-lived because boron is readily leached from soils. For others, e.g. manganese and iron, soil applications of their salts are relatively ineffective because of rapid conversion to unavailable form. In these cases, the elements may be applied to the soil in the form of chelates, a chemical combination that protects them from immobilization in the soil but allows them to be taken up by crops. Foliar sprays of salts or chelates are effective for most micronutrients, but only if applied early in crop growth. General recommendations on materials and rates of use are given in Table 19. Organic manures provide appreciable amounts of most micronutrients and help to maintain them in the soil if applied regularly. There is also a rather variable content of micronutrients in most fertilizers (Table 20), but this should not be relied on to prevent deficiency. Soil conditions, particularly pH, are often an underlying cause of deficiencies of some micronutrients, such as boron and manganese, and an alteration in pH level may well prevent deficiency.

Table 19 FORMS AND RATES OF APPLICATION OF MICRONUTRIENTS

Micro-nutrient	Soil application	Spray application
Iron	Ferrous sulphate, 10 kg/ha	0.4 percent ferrous sulphate + 0.2 percent lime
Zinc	Zinc sulphate, zinc oxide, 10-50 kg/ha	0.5 percent zinc sulphate + 0.25 percent lime
Manganese	Manganese sulphate, 10-50 kg/ha	0.6 percent manganese sulphate + 0.25 percent lime
Copper	Copper sulphate, 10-50 kg/ha	0.1 percent copper sulphate + 0.05 percent lime
Boron	Borax, 5-20 kg/ha	0.2 percent borax
Molybdenum	Sodium molybdate, 0.1-0.5 kg/ha	0.1-0.2 percent solution of ammonium molybdate

Table 20 MICRONUTRIENT CONTENTS OF SOME IMPORTANT FERTILIZERS AND MANURES (ppm)

Fertilizer	Copper	Zinc	Manganese	Boron	Molybdenum
Nitrogenous Fertilizers					
Ammonium sulphate	Tr-0.5	0.33	70	6.0	0.1
Urea	0-3.6	0.5	0.5	0.5	0.7
Calcium ammonium nitrate	Tr-18.0	8	10-50	Tr	-
Phosphatic Fertilizers					
Single superphosphate	26.0	60-160	70-270	10	3
Triple superphosphate	2-12	50-100	160-240	530	9
Basic slag	10-80	5-30	28000-68000	33	10
Rock phosphate	6-10	25-140	130000	15	6
Bonemeal	270	660	500	715	-
Potassic Fertilizers					
Potassium chloride	3.0	3.0	8.0	14.0	0.2
Potassium sulphate	5-10	2.0	2.2-13.0	4.0	0.2
Complex Fertilizers					
Ammonium phosphate	3-4	80	100-220	-	2
Farmyard Manure	10	40-250	200	17	0.2
Compost	300-600	3-13	40-60	15	2

Tr = Traces

Note: The above are representative values, but individual fertilizer samples may be outside these ranges depending on source of raw materials and process used.

Source: Adopted from Kanwar J.S. Indian Farming 18:5-8 (1979).

14. PROBLEM SOILS AND THEIR AMELIORATION

As the name suggests, problem soils are those which suffer from problems that interfere with the normal growth and development of crop plants. In such soils, the problem is usually nutritional in nature owing either to restricted availability of essential nutrients or to an increase in nutrient (or non-nutrient element) concentrations to toxic levels. These problems are often associated with an unfavourable change in pH of the soil. The problem soils may be listed as acid soils, acid sulphate soils, saline, alkali or saline-alkali soils and waterlogged soils.

14.1 ACID SOILS

In principle, soils with a pH below 7.0 are termed acid, but in practice the effects of acidity on soil behaviour only become apparent below pH 6.5. Soil acidity results from the presence of a high concentration of hydrogen (H^+) ions in the soil solution. It is associated with the dominance of H^+ ions over other cations such as calcium (Ca^{++}), potassium (K^+) and ammonium (NH^+) in the soil base exchange complex (see section 3.3.2).

14.1.1 Development of Soil Acidity

The development of soil acidity is brought about by a number of causes, including soil parent material, climate, vegetation and the use of soil-acidifying inputs in crop production.

i. Soil parent material influences the development of acidity since soils formed from acidic minerals such as quartz, feldspars, granite, gneisses, etc. frequently contain very few bases, while soils formed from limestone initially contain a high base content. Soils with low clay and organic matter content also become acid relatively rapidly because the amount of bases that can be held on their small base exchange complex is rather low.

ii. Climate: acid soils form most rapidly in humid regions where rainfall appreciably exceeds evapotranspiration. Excess rainfall containing dissolved carbon dioxide and organic acids formed in the soil passes down the soil profile taking with them bases (mainly calcium) from the soil base exchange complex. These bases are replaced by hydrogen ions thus increasing soil acidity. As acidity falls to a pH level of about 5.0, aluminium hydroxide in the soil is hydrolyzed, a process which releases further hydrogen ions and further lowers the soil pH.

iii. Vegetation influences the rate of acidification: where the natural vegetation is coniferous forest or other acid-loving plants, the plant residues have an acidifying effect and cause intense acidification, as in the formation of podzolic soils. Grasses and broad-leaved forest produce residues without significant acidifying effect.

iv. The use of acidifying inputs in agriculture has an important effect. Ammoniumcontaining fertilizers are the most important example, as their use results in loss of bases from the soil. For example when ammonium sulphate is added to the soil, the first reaction is the cation exchange, in which ammonium displaces some other cations, usually calcium, on the exchange site. The reaction can be represented as follows:

$$Ca\ Soil + (NH_4)_2SO_4 \longrightarrow \begin{matrix} NH_4 \\ NH_4 \end{matrix} > Soil + CaSO_4$$

Calcium sulphate, so formed, may be leached and lost in drainage water, particularly in a humid climate, thus resulting in a loss of soil calcium. The ammonium on the exchange sites may be taken up as such by the plants, or it is nitrified in well-aerated soils. The process of nitrification, which is microbiological in nature, can be represented by the following equation:

$$2NH_4 + 3O_2 \longrightarrow 2NO_2 + 2H_2O + 4H$$

$$2NO_2 + O_2 \longrightarrow 2NO_3$$

It is apparent from the reaction shown above that hydrogen is formed during nitrification, which results in the acidification of the soil. The nitrate formed as a result of the above reaction may be taken up by the plants or leached in drainage water in combination with calcium as calcium nitrate. Thus the application of ammonium sulphate to the soils having no reserve of calcium carbonate results in the depletion of exchangeable calcium.

Thus regular use of ammonium-containing fertilizers in soils having no reserve of calcium carbonate can cause serious increases in acidity, unless their use is accompanied by a suitable programme of corrective liming.

Elemental sulphur is also an acidifying material, but is normally only used on alkaline soils to reduce pH.

14.1.2 Effects of Soil Acidity

i. Nutrient availability: availability of almost all nutrients, except molybdenum, to most crops is optimum in the pH range 6.5 to 7.5 (Fig. 18), and above and below this range crop production can be adversely affected. In acid soils, in particular, poor crop growth may be caused by low availability of phosphorus, calcium and magnesium. Phosphorus in particular can be precipitated as iron and aluminium phosphates, which are unavailable to crops.

Deficiency of magnesium and calcium arises when the level of these nutrients on the base exchange complex becomes seriously depleted by leaching loss and replacement by hydrogen ions. Since most soils contain much less magnesium than calcium, magnesium deficiency is likely to occur earlier than calcium deficiency. In addition to crop deficiencies of magnesium, cattle fed on magnesium-deficient forages may suffer from a condition known as hypomagnesaemia (grass tetany), in which blood magnesium levels are abnormally low.

As the pH of the soil decreases the solubility of a number of elements including iron, aluminium and manganese rises and the amounts available to plants become greater. Plants may take up these elements in amounts much in excess of their normal requirement, resulting in toxicity, poor growth and reduced yield levels.

ii. Biological activity is less intense at pH values below 6.0. As a result less nitrogen is fixed by soil micro-organisms and less mineralization of organic residues takes place. Elements in organic combination including nitrogen, sulphur and phosphorus are released much more slowly owing to a slower rate of decomposition of plant residues.

iii. The physical condition of acid soils is also generally not as good as that of neutral soils. The soil aggregates in such soils are often water-unstable, so that soil structure is difficult to maintain. The soil particles are dispersed when the soil is wet, but on drying hard soil clods are formed.

14.1.3 Correction of Soil Acidity

Soil acidity is most commonly corrected by the application of liming materials. Liming is the application of materials containing cations, usually calcium or calcium and magnesium, which replace hydrogen ions in the base exchange complex and soil solution and thus raise the soil pH.

The optimum soil pH varies according to climate and cropping needs, but for many arable crops is in the range 6.5 to 7.0. In tropical conditions, however, many crops can be grown satisfactorily at pH levels two units or so lower than this. The amount of liming material required to raise soil pH by one unit differs very much from soil to soil, since it is related to the capacity of the soils base exchange complex and not just to pH level. Thus, soils with high clay or organic matter content, and therefore large base exchange complex, need more lime for a given rise in pH than sandy soils of low organic matter content. Measuring soil pH alone does not give information on the amount of lime required.

To provide this information it is usual to determine lime requirement by measuring the amount of one of a number of buffered extractants required to bring about a certain change in pH level. This procedure gives the lime requirement, usually in terms of the amount of calcium carbonate required. The lime requirement given should be adhered to, since overliming can result in unavailability of certain nutrients, e.g. boron and manganese, just as soil acidity can.

The main liming materials are:

i. ground limestone (calcium carbonate);

ii. dolomitic limestone (calcium and magnesium carbonates), which has the advantage of applying magnesium to soils deficient in this nutrient;

iii. quicklime (calcium oxide), very fast acting but unpleasant to handle;

iv. hydrated or slaked lime (calcium hydroxide), also fast acting;

v. various materials including coral or other beach shell deposits and industrial residues, mainly of localized importance.

The liming value of these materials varies and is expressed in terms either of calcium carbonate equivalent or percent CaO.

Lime (a generic term for liming materials) may be applied at any stage in the rotation but is best applied before the most acid sensitive crop, often legumes or crops such as sugarbeet. Lime should be applied at least one month and preferably several months before that crop. Further important aspects are as follows:

a. lime should be fairly finely ground before application;

b. lime should be broadcast uniformly and incorporated in the surface soil by normal cultivations;

c. on very acid soils where large applications of lime (greater than 8 t/ha) are needed, it may be advantageous to apply half before ploughing and half after ploughing.

14.2 ACID SULPHATE SOILS

Acid sulphate and potential acid sulphate soils are extensive in south and southeast Asia and in Africa and also occur in Latin America and Australia. They have very low pH values, as low as 3.0 (when drained), caused by the presence of sulphate, and sometimes show a high degree of salinity. When dry, a yellowish-white encrustation appears on the surface, rich in sulphates, iron and aluminium and toxic to plants. Acid sulphate soils are generally poor in available nutrients, especially phosphorus, potassium and micronutrients and contain toxic concentrations of iron, aluminium, sulphide and organic acids.

Rice is the crop best suited to acid sulphate soils because flooding depresses soil toxicities and rice thrives in flooded soils. The main factors limiting wetland rice growth on acid sulphate soils are Al toxicity in the early stages of flooding, Fe toxicity after soil reduction, and P deficiency. Excess electrolyte is another adverse factor.

Aluminium toxicity disappears after some weeks of flooding because of the pH increase that accompanies soil reduction. Iron toxicity is then the main retarding factor but its severity diminishes with the duration of flooding. Both Al and Fe toxicities are minimized by liming or keeping the soil flooded for as long as possible before planting. Iron toxicity could also be alleviated by applying MnO_2, which counteracts the adverse effects of Fe electrochemically and physiologically. A new and promising approach is to use cultivars that tolerate Fe toxicity, which will enable rice to be grown on acid sulphate soils with the minimum of costly amendments.

If a combination of two or more of the following practices is used with N, P, K fertilizers, rice yields of 8-9 t/ha/year are possible on acid sulphate soils:

i. keeping the soil submerged as long as possible before planting,
ii. liming,
iii. applying manganese dioxide,
iv. growing modern insect and disease resistant varieties tolerant of acid sulphate soil conditions.

14.3 SALINE AND ALKALI SOILS

Saline and alkali soils owe their distinctive character to their excessive concentrations of either soluble salts or exchangeable sodium or both. Soils with excess soluble salts are termed saline, soils with excess exchangeable sodium are termed alkali (or sodic) and those with both are known as saline-alkali soils. The soluble salts that occur in such soils consist mainly of the cations sodium, calcium and magnesium and the anions chloride and sulphate, in varying proportions. Agriculturally, these are problem soils requiring special corrective measures and management practices to enable good levels of yield to be obtained.

14.3.1 Characteristics

Saline soils are defined as having electrical conductivity (EC) of the saturation extract higher than 4 mmhos/cm at 25°C and a sodium adsorption ratio (SAR) value of less than 15. Ordinarily, their pH is less than 8.5.

When dry, saline soils are often recognized by the presence of a white, greyish white or ash coloured crust of salts on their surface. The major problem in these soils is that the excessive salt concentration hinders the normal growth and development of plants, because of its effect on water uptake. Otherwise, the physical condition of such soils is extremely good. Their permeability is equal to or better than similar non-saline soils. The texture of these soils may vary from loamy sand to loam, but the surface soil and subsoil are not compact and dense or inherently impervious to water.

Alkali soils have SAR values greater than 15 (and as high as 100 in some cases) with electrical conductivity of the saturation extract of the soil less than 4 mmhos/cm at $25^{o}C$. The pH of these soils is above 8.5, often exceeding 10.0. These soils may be described as "Black-alkali" soils or by the Russian term "Solonetz". Alkali soils are difficult to manage and have low productivity.

The dominating salts in alkali soils are carbonates of sodium, whose presence in the soil solution results in high sodium saturation of the base exchange complex. The excessive amount of sodium, in turn, causes dispersion and translocation of the clay particles and degradation of the organic matter of the soil. Dispersion of the clay results in poor physical condition of the surface and the development of a columnar or prismatic structure in the subsoil. These soils thus have major structural problems forming cracks and becoming cloddy under dry conditions and becoming puddled when wet. They also have a very poor organic matter status. Alkali soils are usually deficient in available calcium and nitrogen, but have medium phosphorus status and medium to high potassium status. High levels of boron and deficiencies of zinc, iron, manganese and copper are common in alkali soils.

Saline-alkali soils result from the combined processes of salinization and alkalinization. They thus have excessive concentration of soluble salts as well as a high sodium adsorption ratio and present acute management problems.

14.3.2 Occurrence and Formation

Saline soils commonly occur in regions with an arid or semi-arid climate with low rainfall and high temperature. Low rainfall is the main cause. Under humid conditions soluble salts native to the soil are carried downward and away in the groundwater, but in arid regions with no leaching they tend to accumulate near the surface. During the rainy season these salts may move downward to the lower soil layers but in the dry season, the intense evaporation brings them back to the surface.

Salt accumulation is also associated with certain types of topography. It tends to occur in low-lying flat areas, e.g. flood plains, deltas, coastal terraces and where the water table is high. In arid regions, drainage water often accumulates in basins with no outlet to permanent streams. Here it evaporates leaving the salts on the surface. The soils of dry regions tend to become increasingly saline as long as the groundwater remains within capillary reach of evaporation from the surface of the soil.

Alkali soils also occur mainly in arid and semi-arid regions, but are rarely residual in origin, being formed by transport of salts into the soil in water. Where soil materials are also being transported salt movement is accentuated so that a high proportion of the alkali soils of the world is alluvial in origin.

Soils become dominated by sodium in two ways. Firstly, sodium may be the predominant cation entering the soil. Secondly, as the soil solution becomes more concentrated by evaporation or water uptake by plants, salts of calcium and magnesium such as calcium sulphate, calcium carbonate and magnesium carbonate are precipitated with a corresponding increase in the relative proportion of sodium in solution. In this way a part of the original exchangeable calcium and magnesium is replaced by sodium leading to the formation of alkali soils. Under irrigated conditions, saline and alkali soils develop for any one or more of the following reasons:

i. rise in water table, due to excessive application of water or seepage from leaky canals and lateral channels;

ii. use of irrigation water with high salt content;

iii. poor drainage which keeps salts in the surface soil and prevents them from being leached;

iv. erratic irrigation management, e.g. flooding the field at times followed by intense drying out.

14.3.3 Effect on Crop Growth

In saline soils the main restraint on crop growth is that the high salt concentration raises the osmotic pressure of the soil solution, making it difficult for plants to obtain water in amounts adequate for sustained growth. Most plants are more sensitive to salinity during germination than in later stages of growth, so that crops on saline soils frequently have barren spots and stunted growth with considerable variability in their size. The plants that are stunted owing to salinity have cupped and rolled leaves and are often bluish green, in contrast to the yellowish green appearance of foliage of plants growing on soils of low fertility. While the appearance of the crop may be indicative of saline conditions, a reliable diagnosis should normally be based on soil and plant analyses.

Crops growing on saline soil generally respond to applied fertilizers in much the same way as crops on normal soils.

Alkali soils have complex crop growth problems because the physical, chemical and biological properties of these soils are all extremely poor and indeed in severe cases, no crop growth is possible. The main constraints to crop production in alkali soils are low or unbalanced soil nutrient availability, the high level of exchangeable sodium, high pH, low water permeability, lack of adequate aeration and crust formation.

The physical condition of most alkali soils is very poor and they are therefore difficult to cultivate. Water infiltration rates are very low. When wet, alkali soils become very sticky, and when dry they tend to form large clods, resulting in a poor seedbed. The high pH of these soils results in low availability of various essential nutrients, in particular calcium, nitrogen, phosphorus, zinc and iron and also adversely affects the growth and functioning of roots. The germination of seeds and the establishment of most crops on these soils are therefore poor.

14.3.4 Reclamation

Saline soils are improved by leaching the salts downward below the root zone and out of contact with irrigation water. Salinity control therefore depends directly on water management, including irrigation, leaching and drainage.

It is essential that the irrigation water does not have a high salt content and that overuse of irrigation water should be avoided as it contributes to drainage difficulties and salinity problems. This is especially important for soils with low infiltration and drainage rates. In such a situation, however, use of water pumped from the water table may be helpful. It helps to control the water table and ensures flexibility in irrigation.

A number of other methods such as scraping deposited salts from the soil surface, removal of salts through underground drainage systems, or leaching and flooding (alone or in combination) are used for the reclamation of saline soils.

In alkali soils the basic principle of reclamation is to remove the excess sodium from the soil base exchange complex. The calcium required for this purpose is added to the soil, in the form of soluble or insoluble salts. Soluble calcium salts such as calcium sulphate (gypsum), calcium chloride or calcium nitrate are suitable for the purpose. However, gypsum is the cheapest and most abundantly available and is therefore most commonly used.

Under some circumstances, when the calcium carbonate status of the soil is very high, the calcium present in this insoluble form can be utilized to replace soil sodium by the application of either acids (e.g. sulphuric acid) or acid-forming substances, such as elemental sulphur, ferrous sulphate, aluminium sulphate and low grade pyrites.

However, the efficiency of chemical amendments is often considered to be temporary in the absence of biological methods. Thus in salt-saffected soils, the use of fertilizers and soil amendments give better results if they are applied in conjunction with organic manures. Besides stabilizing the effect of chemicals, inclusion of organic manures (FYM, green manure, etc.) in the amendment programme of such soils aids in improving their physical condition and nutrient status.

14.4 POORLY DRAINED SOILS

Soils can be poorly drained and temporarily or permanently waterlogged because of a high water table or because the infiltration rate is very low and excess precipitation accumulates in and on the soil.

The effects of poor drainage are:

i. to affect soil structure adversely, making seedbed preparation more difficult and enhancing the danger of soil compaction and destruction of tilth;

ii. to reduce the air, and therefore the oxygen, content of the soil so that plant roots cannot obtain sufficient oxygen for respiration;

iii. to reduce most microbiological activity in the soil so that plant residues accumulate and the mineralization of plant nutrients is inhibited. However, bacterial denitrification of nitrate to nitrogen gas or nitrogen oxides is encouraged, so that considerable amounts of plant-available nitrogen may be lost;

iv. to bring about changes in the form in which some nutrients, e.g. manganese and iron, occur in soil;

v. in temperate regions, to delay crop growth since wet soils warm up more slowly than well drained ones.

The sum of these effects in a normal arable soil is to make seedbed preparation difficult and plant establishment poor, and to restrict crop growth, mainly because the roots of most crops cannot take up nutrients efficiently in anaerobic conditions.

The remedy for poor drainage is to install a drainage system, usually of underground tile drains and moled channels, to remove water from the subsoil.

Rice is well adapted to grow in waterlogged anaerobic soil conditions and therefore not subject to the above problems. Anaerobic, reducing conditions in the soil only affect rice when they are severe enough to form toxic sulphides. The sulphide toxicity accentuates further when the natural iron status of the soil is low, causing rice plants to suffer from the nutritional disorder known as "akiochii" (imbalance of nutrients associated with hydrogen sulphide toxicity). Iron toxicity may also occur in flooded rice fields because reducing conditions increase the solubility of iron which may be taken up in excessive amounts.

15. EFFICIENT USE OF MANURES AND FERTILIZERS

With the rapid growth in world use of manures and fertilizers and the considerable escalation in their prices over the years the need to utilize every unit of plant nutrient in the most productive and profitable manner has become all the more essential. Efficient use of manures and fertilizers depends on using correct quantities of these materials in relation to crop and soil needs and on applying them in the best way at the correct time.

15.1 OPTIMUM APPLICATION RATE

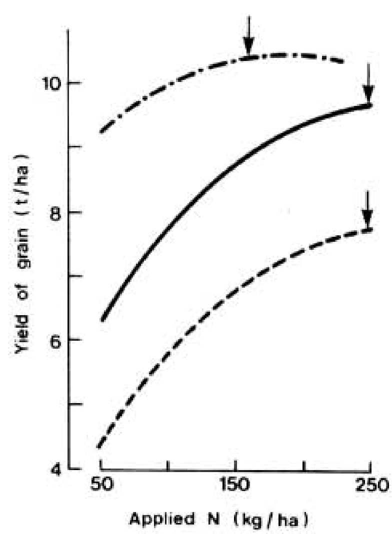
15.1.1 Basis for Rate Decisions

In deciding on the correct rate of fertilizer nutrients to recommend, it is necessary to take into account two objectives: the maximization of response to fertilizer (in economic terms) by the crop for which the fertilizer is applied, and the improvement, or at least maintenance, of soil fertility over a period of years. There are two main components to the decisionmaking process:

i. Crop response. Information on crop response to fertilizer can best be obtained from field experiments testing a range of rates of application. Normally the response will take the form of a curve, the effect on the crop being one of diminishing yield returns to successive incements of nutrient (Fig. 30). Use of excessive amounts often depress yields. The optimum rate in economic terms is near, but not at, the top of the curve, as shown in section 18.3. Single experiments only provide information for one site in one season, but by carrying out a series of experiments over a few seasons and a number of representative sites it is possible to obtain generalized results and to correlate nutrient requirements with field and crop characteristics such as soil analysis, date of sowing, variety and yield level. A set of recommended nutrient rates can be derived from this information, but may need to be qualified by the longer-term considerations involved in maintenance of soil fertility.

Fig. 30

Examples of yield responses of a modern winter wheat variety (Hustler) to the rate of N top-dressing. -·- clay loam over London Clay (Berkshire), second wheat after grass ley; —— clay loam over Boulder Clay (Lincolnshire), second wheat after peas; --- shallow loam over Upper Chalk (Berkshire), continuous cereals. The arrows indicate the economic optima at 1980 prices. All results are from 1980 harvest.



ii. <u>Nutrient removal.</u> Soil fertility, especially in relation to phosphorus and potassium, is influenced by the quantities of nutrients removed in the crop (Table 21). This aspect is less important for nitrogen, since residual nitrogen is very subject to other mechanisms of loss; even if a crop removes little nitrogen from the soil, that remaining may be lost from plant-available form by the action of micro-organisms, or lost completely by leaching or denitrification.

Table 21 NUTRIENT REMOVAL BY CROPS (kg/ha)[1]

Crop	Yield (t/ha)	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Ca
Rice (paddy)	3	50	26	80	-
	6	100	160	19	
Wheat	3	72	27	65	-
	5	140	60	130	24
Maize	3	72	36	54	-
	6	120	50	120	24
Potatoes	20	140	39	190	2
	40	175	80	310	-
Sweet potatoes	15	70	20	110	-
	40	190	75	390	28
Cassava	25	61	39	136	44
	40	120	70	350	57
Sugarcane	50	60	50	150	-
	100	110	90	340	-
Onions	35	120	50	160	-
Tomatoes	40	110	30	150	-
Cucumber	35	60	45	100	-
Alfalfa (hay)	7	215	60	130	164
Soybeans	1	160	35	80	-
	2.4	224	44	97	-
Beans	2.4	155	50	120	-
Groundnuts	1.5	105	15	42	19
Cotton (seed + lint)	1.7	73	28	56	6
	5	180	63	126	
Tobacco (dry leaf)	1.7	90	22	129	48

[1] Plant nutrients contained in the above-ground plant part, and the below-ground harvested portion where appropriate, at the indicated yields.

\- Indicate data not available.

Source: FAO, Rev. 1978. Fertilizers and Their Use. Rome.

Quantities of phosphorus and potassium removed in the crop often bear little relation to crop response levels, and it is therefore important to take account of discrepancies by increasing recommended rates where removal appreciably exceeds the rates suggested by crop response. These adjustments are particularly important where high crop yields are expected and therefore nutrient removals are correspondingly high.

In passing, it should be said that total nutrient uptake by a crop is often much higher than removal in the harvested produce, e.g. rapeseed may take up a total of 250 kg/ha of K_2O of which about 25 kg/ha will be removed in the seed, the rest being returned to the soil in crop residues. The high uptake is only relevant if the crop cannot obtain most of it from the soil; if it cannot, this will be indicated by crop response data from field trials.

15.1.2 Source of Nutrients

Plants rely on nutrients from the soil, from added organic matter, from fertilizers, and in the case of nitrogen from biological fixation. By carrying out soil analysis it is possible to calculate the quantity of available nutrients present, although there is a margin of error, e.g. from soil sampling and changes in availability of nutrients after sampling and before analysis. Also, particularly for nitrogen, but also for all other nutrients, there are large and rapid changes in the amounts of available nutrients in the soil due to losses from the soil and changes in chemical form. The proportion of available nutrients that the crop will take up varies with growing conditions; vigorously growing crops well supplied with water take up a higher proportion than crops suffering from drought or disease. It is therefore difficult to arrive at a "balance-sheet" approach to soil nutrient supply, and the field trial approach referred to in section 15.1.1 is usually preferable.

Uptake of fertilizer nutrients by crops is also rather variable; for example, in a given region the percentage of fertilizer nitrogen taken up by wheat may range from 40 to 85 percent, depending on season and soil type. The reasons for this wide range are two-fold: firstly, fertilizer nutrients may be lost, e.g. by volatilization of ammonia from urea, and the degree of loss will vary with climatic and soil conditions and with nutrient source; secondly, vigour of crop growth can influence fertilizer nutrient uptake in the same way that it affects soil nutrient uptake.

15.1.3 Future Improvements in Fertilizer Recommendations

At the present time, fertilizer recommendations are made for broad categories of field situations: for a region, for soil types within a region, perhaps for more specific sub-divisions by soil analysis category, crop rotation, variety or yield level. They are a useful guide but do not take into account the characteristics of individual farms or fields, or differences between seasons.

In some countries or agricultural regions, e.g. in the USA and some European countries, there is a large mass of information on crop response to fertilizers, nutrient uptake and environmental or management effects thereon. From these data it is becoming possible to develop models of response in particular to nitrogen fertilizer and to predict fertilizer requirements on an individual field basis. Local soil and climatic data and information on variety and other aspects of management supplied by the farmer are used by extension officers and others to run a simple computer programme which produces recommendations on an individual field basis, leading to more efficient nutrient use. This procedure requires a moderate degree of computer expertise to set up, but is not expensive in equipment terms and in principle can be adopted wherever the amount of background data on fertilizer response and requirement are adequate.

15.2 TIME OF APPLICATION

The time of application of organic manures and inorganic fertilizers plays a key role in determining their effective utilization by plants. The criteria for timing is different for manures and for fertilizers.

15.2.1 Manures

Bulky organic manures such as farmyard manure or green manure should be applied to arable soils well before sowing, to obtain a high degree of breakdown and thus of mineralization of nutrients by the time the crop is sown. In warm, moist conditions, a period of four to six weeks may be sufficient, but in temperate climates breakdown is much slower and a period of several months is often desirable. In many management systems it is also desirable to apply manures at "off-peak" periods and to plough them into the soil at normal ploughing time which, because of climatic constraints, may be several months before sowing. Timing of organic manure application to grassland is also often influenced by the opportunity to make the application without affecting grass growth unduly or interfering with grazing livestock.

15.2.2 Fertilizers

The optimum timing for fertilizer application should be determined by the need to make nutrients available over the period or periods at which the crop needs them, at the same time minimizing the risk of loss of available nutrients from the soil. Different considerations apply to the three major nutrients.

i. For nitrogen, most short duration crops have a small demand in the seedling stages of growth, followed by a major demand during the major growth period. For some crops the time interval between sowing and major growth period will be short, but for others, for example a wheat crop sown in autumn in a temperate or Mediterranean climate, the interval may be several months. Nitrogen is a very mobile nutrient and is subject to loss by volatilization or leaching if applied appreciably before the crop can take it up. The degree of risk of loss and the loss mechanism - leaching, denitrification, volatilization of ammonia - depends very much on individual soil and climatic conditions. In low or moderate rainfall conditions, and with a rapidly growing crop it can be quite satisfactory to apply all the nitrogen fertilizer in the seedbed. On the other hand, where rainfall can be high during crop growth, or where the period of growth is prolonged, a split application with a small dressing to the seedbed and one or more top-dressings during crop growth will be more effective. Similar considerations of period of demand and risk of loss apply to every cropping situation, but the actual optimum practices will vary very much from crop to crop.

ii. Phosphorus is required by annual crops predominantly in the early stages of growth. In contrast to nitrogen, it is not mobile in the soil and is best applied to the soil and incorporated in it by cultivations. When water-soluble or mainly water-soluble phosphorus is used, availability to the young plants will best be achieved by applying phosphorus fertilizer in the seedbed. If a water-insoluble phosphorus fertilizer such as rock phosphate is used, application a few weeks before sowing will provide time for some solubilization of the phosphorus to take place.

iii. Potassium is required by the crop over a longer period than phosphorus, but is seldom subjected to serious loss of availability once it is in the soil. Incorporation in the seedbed will provide potassium effectively to the crop with no appreciable risk of loss.

In deciding on fertilizer recommendations and on the fertilizer products needed in a particular region it is necessary to take into account the specific timing requirements for nitrogen, phosphorus and potassium of the crops grown and to relate them to the regional climatic and soil situation.

15.3 METHOD OF APPLICATION

15.3.1 Manure Application

The objective in applying manure should be to broadcast it as uniformly as possible and to incorporate it thoroughly with the soil by ploughing and cultivations. Manures, particularly farmyard manure, can lose appreciable ammonia by volatilization if left exposed in the field, so that ploughing should follow as soon as practicable after distribution on the field.

In countries with adequate manpower much of the operation of spreading manure on the field will be manual. However, complex and efficient, but expensive, equipment is available and used in many developed countries for handling, transporting and spreading organic manure. This equipment is likely to become more relevant in many developing countries in the course of a few years.

15.3.2 Fertilizer Application

The cost of fertilizer application is quite low relative to the cost of fertilizer itself and it is therefore inexpensive to ensure that the optimum method of application is used. The principal methods are described below.

i. Broadcast fertilizer is spread uniformly on the field by hand or by fertilizer spreader. It is effective on crops with a dense stand, where large applications are made and for water-insoluble phosphorus fertilizers, for which contact with as much soil as possible is desirable to accelerate solubilization. When fertilizer is broadcast on unsown fields it may be incorporated by seedbed cultivations.

   Globally, a high proportion of fertilizer is applied broadcast and it is an effective method of application for most circumstances. More efficient methods for particular situations and products are described below.

   Fertilizer can readily be broadcast by hand, provided manpower is available, but achievement of uniform application requires skill and experience. Many types of fertilizer distributor are suitable for broadcasting fertilizer, though some of them perform poorly on powdered materials. The main mechanisms employed are:

   a. spinning disc distributors in which fertilizer is metered from a hopper onto a rapidly spinning disc and flung laterally to a width of 10 m or so;

   b. oscillating spout distributors which similarly fling fertilizer laterally over a given width of spread;

c. full width box distributors, with boxes 2 to 5 m wide from the base of which fertilizer is metered uniformly onto the ground below the box;

d. pneumatic distributors, in which a metered flow of granular fertilizer is carried pneumatically to a series of nozzles placed at intervals along a boom up to 20 m wide.

ii. Placement of fertilizer involves positioning it in specific locations on or in the soil, usually at a specified distance from seeds or established crop rows. Placement has the following advantages:

a. by minimizing contact between soil and fertilizer, immobilization of water-soluble phosphorus is retarded and phosphorus in this form can be used more efficiently, especially on soils of low available phosphorus content;

b. placed fertilizer is usually located near the root zone and is therefore readily accessible to the roots of young plants;

c. fertilizer sideband placed near the rows of wide-row crops is used more effectively;

d. when the amount of fertilizer available is limited so that low rates are applied, it will be used more efficiently if placed;

e. deep placement of part of the fertilizer can be more effective than broadcasting if the surface soil dries out during crop growth, since nutrients placed in the soil that remains moist will still be available.

Fertilizer may be placed at sowing time or during crop growth. Placement may be:

- in a band at a suitable distance from the seed, usually a few centimetres to one side and slightly lower in the soil, or in two bands one on either side of the seed;

- in a band directly below, though this positioning may adversely affect growth of the taproot;

- in immediate contact with the seed (combine drilling). However, this method is only suitable for some crops and at moderate fertilizer rates in moist soils with adequate rainfall to minimize the osmotic effect of fertilizer salts on seedling growth. It is most suited to phosphorus fertilizer application. Ammonia-producing fertilizers such as urea and DAP should not be combine-drilled;

- in a band or bands to one or both sides of plant rows;

- by spot application between plants, e.g. for urea supergranules, or in a circular band (ring placement) around fruit trees.

The best method of placement varies with crop, soil and weather conditions. Tractor-drawn placement drills that apply the fertilizer and sow the seed in one operation are available and widely used in some countries. Different methods have been developed for a wide range of crops.

It must be noted, however, that while placement can improve efficiency of fertilizer use, the benefit is much smaller on fertile soils well supplied with nutrients than on nutrient-deficient soils. Also placement of fertilizer is often a more time consuming operation than broadcasting it. For these reasons, while placement has an important role in many developing countries, there is in many intensive agricultural regions a trend away from this method of application and back to broadcast fertilizer.

iii. Foliar application is a method by which mineral fertilizer or other salts are applied to the foliage in solution form. Most nutrients are readily absorbed by foliar application, and response can be more rapid than from soilapplied fertilizers. However, the amounts of major nutrients that can be absorbed by the leaves are small relative to total requirement.

The concentration of the spray solution has also to be carefully controlled, otherwise serious damage may result from scorching of the leaves. Crops differ in their tolerance to concentration of the spray solution so that no general recommendation can be made. However, for most nutrients concentration should not exceed 3 to 5 percent when conventional high volume sprays are used, but with low volume sprayers it may be higher.

When urea is applied to foliage, the biuret content should be low to avoid leaf injury. Foliar fertilization is also considered useful and effective for the application of trace elements such as iron, copper, boron, zinc and manganese. The quantities involved are very small and these materials can be more effectively and economically applied in the form of a spray. Insecticides and herbicides can also be applied with foliar fertilizers, e.g. in plantation crops such as coffee and tea.

In dry farming areas, foliar application of nutrients, particularly of nitrogen, may have an important place as nutrient uptake is not dependent on adequacy of soil water.

iv. Aerial application of solid or solution fertilizers is extensively practised in the USA, Australia, New Zealand and other countries where large continuous areas are to be fertilized. Materials are applied by aircraft, particularly in hilly regions, to forests, to grasslands, or to paddy fields where ground application by machine is not very practicable.

v. Injection into the soil is necessary for pressurized liquid fertilizers to avoid nutrient loss. Injection of anhydrous ammonia and low-pressure solutions is done normally to 12 to 15 cm depth, using special equipment.

vi. Where overhead spray irrigation or trickle irrigation systems are used, fertilizer can be introduced into the irrigation water using a suitable metering system. This provides good distribution and enables fertilizer to be applied easily in graded doses as and when the crop needs it. Non-pressurized solutions and suspensions are particularly suitable for this application method. Ditch and flood irrigation systems present problems of metering and uniformity and fertilizer cannot readily be applied through them.

16. NUTRIENT REQUIREMENT OF MAJOR CROPS

The principles underlying plant nutrition and fertilizer use have been outlined in previous chapters. For individual crops, fertilizer requirements including optimum timing and method of application vary according to the physiology of the crop, the yield potential and field characteristics of different varieties, the length of growing season (and the number of years duration for perennial crops), the quality standards demanded in the produce, as well as the soil, climatic and management conditions under which the crop is grown. The main facets of fertilizer requirements for some of the principal crops, including the important foodgrains and rootcrops, are described in the sections that follow.

16.1 CEREALS

16.1.1 Wheat

During the last twenty years, wheat production has been revolutionized by the introduction of the high yielding, short strawed varieties. It has usually been necessary to develop suitable varieties regionally, based on the original Mexican high yielding varieties but adapted to local conditions. By removing lodging as a limitation and by breeding in disease resistance it has been possible to apply considerably more nitrogen fertilizer and thus, where environmental conditions permit, enable the crop to reach its full yield potential.

The key fertilizer nutrient for optimum yield of wheat is nitrogen. In modern high yielding varieties under good growing conditions each kilogram of nitrogen applied produces as much as 25 kg of grain. Where high yields are possible the crop responds to high levels of fertilizer nitrogen, while where yield is limited by factors such as water supply, the limitation on growth also limits the amount of nitrogen that the crop can make use of. Optimum fertilizer nitrogen rates range from nil to over 200 kg/ha.

The principal factors determining the optimum are:

i. Variety. Tall, local varieties often respond to no more than 30-50 kg/ha of nitrogen, while short strawed, high yielding varieties can justify 160 kg/ha or more.

ii. Water supply. Irrigated wheat or wheat grown with adequate rainfall, e.g. in northwest Europe, respond to high rates of nitrogen; short duration winter crops in subtropical climates can justify 120-160 kg/ha, while for high yielding, long duration crops in temperate climates the optimum is often over 200 kg/ha. For rainfed crops in regions of low to moderate rainfall, e.g. Pakistan, northern India, many Mediterranean countries, north and west Australia, nitrogen use should be graded according to available moisture, typically from 0-10 kg/ha where rainfall is less than 300 mm to about 80 kg/ha with rainfall of 400-600 mm.

iii. Soil nitrogen supply, which is strongly influenced by previous cropping or application of organic manure, influences fertilizer nitrogen requirement; for example, a reduction of 30-40 kg/ha nitrogen is possible where the previous crop was a legume.

Timing of nitrogen fertilizer application is influenced by phasing of crop demand and by the need to minimize gaseous and leaching losses. Most wheat crops will respond to a small application of nitrogen fertilizer at sowing, but where moderate or high rates are used, the main application should be at the beginning of the period of rapid growth and development from mid-tillering through to ear emergence; sometimes two or three top-dressings can be justified. An application at or shortly after ear emergence can help to raise grain protein content, an important consideration in nutritional terms as well as in improving bread-making quality.

Phosphorus is an important nutrient for wheat, though yield responses are usually smaller than those to nitrogen. The requirement for phosphorus is often high on soils newly brought into cultivation or with only a short cropping history. It can also be especially important in low rainfall areas. In such conditions, placement of phosphorus fertilizer with or near the seed is beneficial. Where soil fertility has been raised by continued fertilizer use, by regular application of organic manure or by silt from flood irrigation, responses to phosphorus are often smaller but a moderate application is usually justified. Soil analysis provides a guide to the requirement for phosphorus fertilizer and local recommendations normally take this into account.

The higher yield levels resulting from intensification of crop production and the use of modern varieties place an additional burden on soil and fertilizer phosphorus supplies. Such productive crops need to be able to obtain more phosphorus from the field, and more will also be removed from the field in the harvested crop - the amount being about 8 kg per tonne of grain. Thus intensification results in a greater need for fertilizer phosphorus, both to support higher crop production and in the longer term to maintain soil fertility by replacing the phosphorus removed in the crop.

The potassium fertilizer requirement of wheat is very variable. Many wheatgrowing soils are fairly well supplied with potassium, either from soil minerals or by repeated use of organic manures. However, some sandy soils and shallow soils over limestones are very deficient in this nutrient and adequate potassium fertilization is essential. Soil analysis provides a good guide to potassium requirements, which are in the range of 60-90 kg/ha on low potassium soils to nil where the soil potassium level is high. As with phosphorus, intensification of wheat production increases the crop's need for potassium and thus the importance of potassium fertilizer in maintaining soil fertility.

Wheat is sensitive to deficiency of a number of secondary and micronutrients. It can suffer from sulphur deficiency, especially when grown in low rainfall areas with a small input of sulphur from atmospheric sources. Copper deficiency occurs widely in wheat on many soils - on leached sandy soils, on shallow soils over limestone, on peaty soils. Zinc deficiency has become increasingly evident in wheat in a number of countries, including India and Australia. Manganese deficiency occurs on high pH soils in both temperate and subtropical regions and seems to be particularly influenced by soil physical conditions.

All these deficiencies can be overcome by soil or foliar applications of the various recommended materials.

16.1.2 Rice

i. Wetland rice. A very high proportion of the world's rice is grown under the wetland cropping system, in which both general growing conditions and in particular fertilizer practice are much influenced by the anaerobic, reducing conditions in the flooded soil. The main effects of the reducing condition are: to restrict biological mineralization of organic nitrogen compounds to the production of ammonium nitrogen - nitrate is only produced in localized or temporary aerobic conditions; to cause denitrification of nitrate in the soil, with loss of nitrogen to the atmosphere; to increase the pH of very acid soils and to decrease the pH of alkaline soils, in both cases improving the availability of phosphorus; to affect micronutrient availability, primarily increasing solubility of iron and manganese but in some conditions reducing zinc availability; and in some problem soils to contribute to the development of toxic levels of sulphide, iron and manganese.

Wetland rice soils vary very much in texture and nutrient status. However, they tend to have a low organic matter content and therefore provide a relatively small supply of nitrogen and phosphorus by mineralization; typically, rice crops obtain about 60 kg/ha of nitrogen from the soil. Paddy soils usually have a low base exchange capacity and therefore small reserves of the nutrient cations potassium and magnesium.

The nutrient status of rice soils can be improved by applying organic manure a week or two before transplanting. There is also considerable scope for biological nitrogen fixation in these soils by blue-green algae or the *Azolla-Anabaena* association, and this may supply 30-50 kg/ha or more of nitrogen.

ii. Nitrogen fertilizer. There is a close association between the amount of nitrogen fertilizer applied to rice and the yield level. Yield responses of 20 kg or more of grain per kilogram of nitrogen are frequently obtained. In traditional, tall rice varieties the amount of nitrogen that can be applied is limited by lodging and by genetic potential, but improved varieties - short, high yielding, lodging and disease resistant - can benefit from a higher level of nitrogen supply (Fig. 31). Whereas traditional varieties could

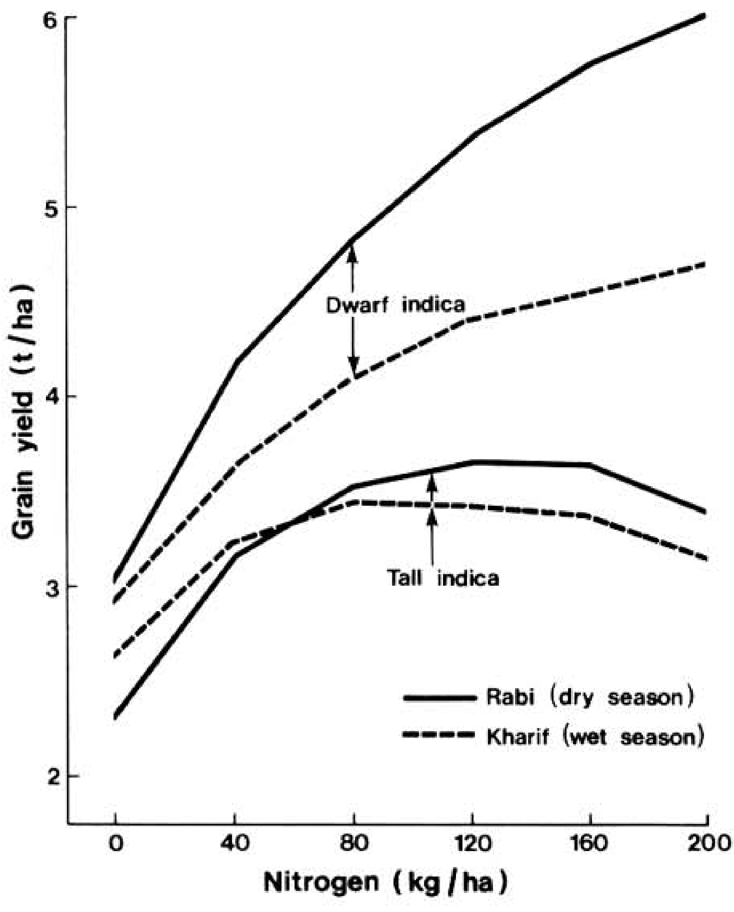


Fig. 31

Average yields of dwarf and tall indica rice varieties in relation to N fertilizer rate

Source: Tanaka A. Ext. Bull. 57. Food and Fertilizer Technologies Centre, Taipei, Taiwan (1975) justify up to 50 kg/ha of nitrogen, 160 kg/ha or more is recommended for improved varieties under good management and with good water supply. The season of planting also influences nitrogen requirement; the higher yielding, irrigated, dry season crops justify 30-40 kg/ha more nitrogen than rainy season crops.

Timing of nitrogen is very important to improve efficiency of nitrogen use by rice. The crop requires a modest basal application and up to three dressings to maintain the nitrogen supply throughout its growth; multiple split applications are especially important when total nitrogen requirement is high and to avoid leaching loss on permeable sandy soils.

Timing of application of nitrogen fertilizer and method are important to reduce losses of nitrogen and improve efficiency of uptake by the crop - currently often below 50 percent. The basal application should be worked into the soil as ammonium nitrogen or urea, to avoid volatilization losses from ammonia going into solution in the floodwater. Similarly, top-dressings of ammonium or urea nitrogen should if possible be applied into the reduced soil horizon - broadcasting on the floodwater is likely to result in high losses. Nitrate-containing fertilizers such as ammonium nitrate or CAN are often less satisfactory for rice; if used, application as a top-dressing when plant uptake of nutrients is proceeding rapidly will minimize losses.

iii. Phosphorus fertilizer. While soil phosphorus availability is improved by flooding, many old rice soils have a low phosphorus content because of continued removal in the crop. This, together with the greater demand for phosphorus by improved varieties makes adequate use of phosphorus fertilizer important. Rice takes up about 8 kg P_2O_5 per tonne of grain produced. Optimum rates vary with local conditions, but 40 kg/ha P_2O_5 will usually be enough for traditional methods and 60-80 kg/ha for improved varieties. Phosphorus should be applied as a basal dressing. Water-soluble phosphorus, or a combination of water and citrate soluble, is normally most efficient for rice production. Rock phosphate may be used on acid soils.

iv. Potassium fertilizer. The total uptake of potassium by rice is much greater than that of phosphorus, but most of this remains in the straw. In traditional rice varieties responses to potassium fertilizer have usually been small. However, improved varieties usually respond to potassium, especially when given adequate nitrogen and phosphorus. Responses are greater on sandy soils. For traditional varieties, if potassium is applied, 20-40 kg/ha is sufficient, but improved varieties justify an application of 60-120 kg/ha. On most soils, potassium fertilizer should be applied as a basal dressing, but on free-draining sandy soils where leaching may occur, half should be basal and half top-dressed.

v. Secondary and micronutrients. Rice is unusual in responding to applications of the element silicon in the form of soluble silicates, and waste products containing this element are applied in some Asian countries. Silicon promotes growth of rice, it is thought by making soil phosphorus more readily available to the plants and by protecting them from iron and manganese toxicity.

Sulphur deficiency is becoming more widespread in rice, because of higher yields, reduced use of organic matter and use of sulphur-free fertilizers. Zinc, manganese and iron deficiencies occur fairly widely, especially on high pH soils.

Because of the intensification of rice production, secondary and micronutrient deficiencies are becoming more common, and it is important to identify and correct them wherever they occur.

vi. Upland rice. Because upland rice relies entirely on rainfall and soil moisture reserves, yields are lower than for wetland rice. Since the soil is not flooded, soil nutrient behaviour is akin to that in other cereal crops. Upland rice can justify 50 to perhaps 120 kg/ha of nitrogen, depending on yield potential, split between seedbed and top-dressing. Many upland rice soils are low in available phosphorus and moderate fertilizer applications are usually required. Potassium fertilizer is important for high yielding crops and on sandy soils.

16.1.3 Maize

High yield in maize is closely associated with nitrogen fertilizer use, but only when other inputs and management are in order. Nitrogen interacts positively with plant population, with earliness of sowing, with varietal potential, with weed control and moisture supply. An example of the mutual benefit from nitrogen fertilizer and enhanced population is shown in Figure 32. However, it must be recognized that neither increased plant population nor high levels of nitrogen fertilizer will improve yields where a third factor is limiting. In particular, where moisture supply is inadequate or uncertain, optimum levels of fertilizer as well as plant population will be below those required where highest yields are expected. Fertilizer can improve utilization of soil water by increasing rooting depth, but the best returns from nitrogen fertilizer are only obtained where water supply, either natural or supplemented by irrigation, is adequate for full crop growth. Under good growing conditions, the response per kilogram of nitrogen applied can be over 30 kg of grain.

In almost all soils and conditions, nitrogen fertilizer increases the yield of maize. Soils may vary in the amount of nitrogen they supply to the crop, due for example to use of organic manures and to previous cropping, but the range of variation is small relative to the large quantity of nitrogen required by the maize crop. For example, a 10 tonne crop will take up over 200 kg/ha of nitrogen. Fertilizer requirement in relation to yield level cannot be calculated directly from crop uptake of nitrogen because of the variations in soil nitrogen supply and the rather unpredictable efficiency of fertilizer uptake by the crop. However, nitrogen fertilizer requirement may be about 50 kg/ha with unimproved varieties and uncertain rainfall, rising with yield potential to 250-300 kg/ha where yields of 12 t/ha or more can be expected. Local recommendations on amounts should, as always, be based on local experimentation under the prevailing growing conditions. Nitrogen fertilizer improves grain protein content (but has little effect on protein quality) and thus has a real effect on the nutritive value of maize in the human diet and in that of livestock.

Maize takes up nitrogen slowly in the early stages of growth, but the rate of uptake increases rapidly to a maximum before and after tasselling, when it can be over 4 kg/ha per day. Nitrogen fertilizer application is best scheduled in accordance with this pattern of uptake, to avoid serious losses by volatilization or leaching and to ensure that nitrogen levels are high in the soil when the crop's demand is high. An application to the seedbed followed by a side-dressing when the crop is knee-high, or for very high application rates two top-dressings, the second at tasselling, are usually recommended.

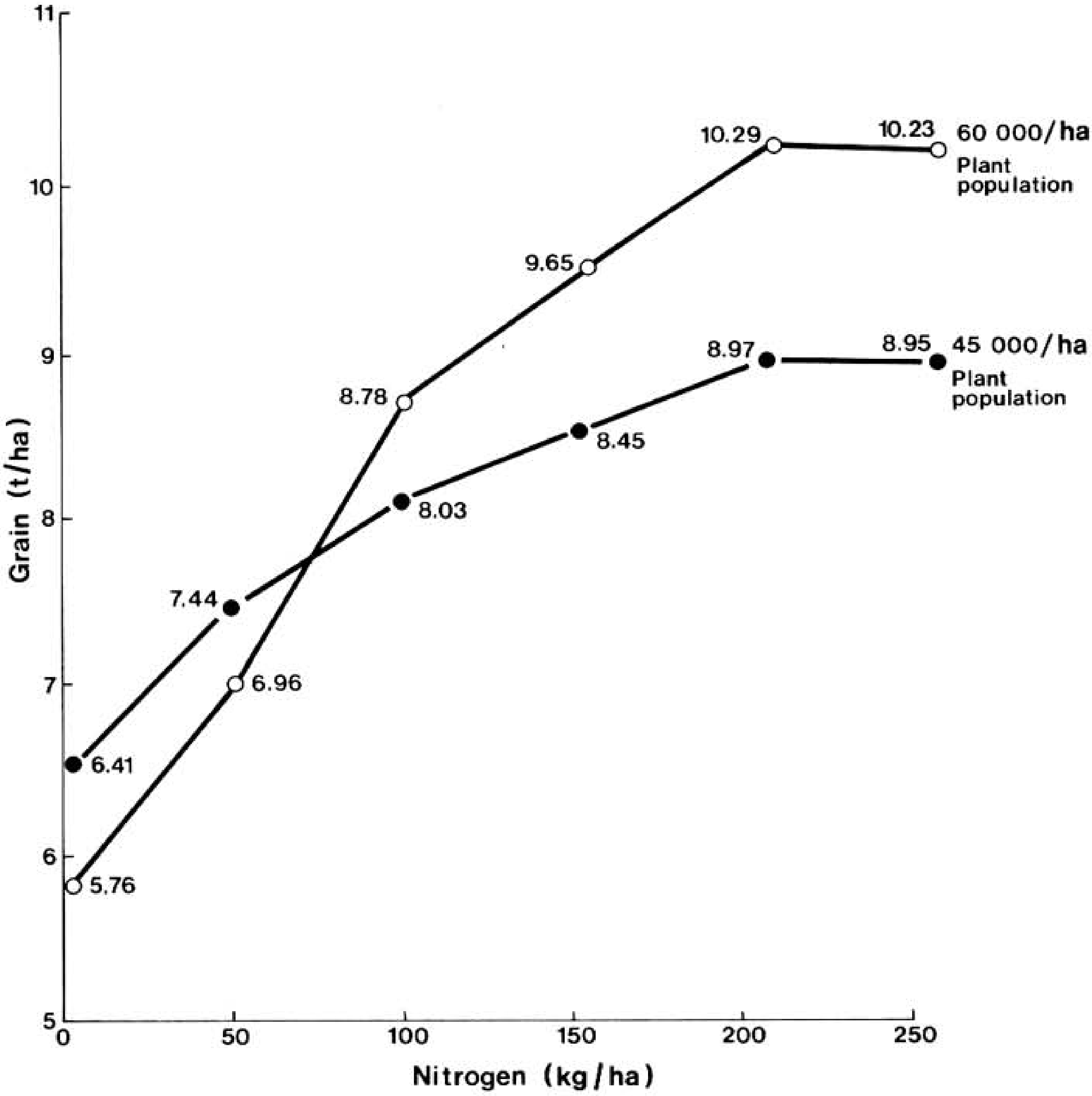


Fig. 32 Effect of nitrogen fertilizer on maize in relation to plant population

Source: Gros A. Engrais. Guide Pratique de la Fertilisation. La Maison Rustique, Paris (1967)

Phosphorus is important for maize, since the crop cannot readily take up soil phosphorus in the large amounts needed for optimum growth and high yield. Best results from nitrogen fertilizer and other inputs will not be obtained without an adequate phosphorus supply. It should be applied in water-soluble or mainly water-soluble form. Rates of application should be varied according to soil analytical values for phosphorus and in relation to yield potential, in the range 30-100 kg/ha P_2O_5. Where a major objective is the longer term maintenance of soil phosphorus levels, it may be noted that maize removes about 8 kg/ha of P_2O_5 per tonne of grain.

Potassium is taken up in large quantities by maize but only a small proportion of total uptake - about 5 kg K_2O per tonne of grain - is removed in the harvest. While maize can in most conditions obtain appreciable amounts of soil potassium, it is important to ensure that the overall supply is large enough. Use of potassium fertilizer is especially important where high rates of nitrogen fertilizer are used and high yield expected. Rates of application should be in the range 30-100 kg/ha K_2O, depending on soil analysis and yield potential.

Both phosphorus and potassium are most effective when applied to the seedbed. Where suitable equipment is available, sideband application together with a moderate rate of nitrogen will improve effectiveness on many soils.

Maize may suffer from a number of micronutrient deficiencies. Perhaps the most widespread problem is zinc deficiency. It is associated with calcareous soils and soils of low organic matter content and may be intensified by a high level of phosphorus supply from the soil or fertilizer or the two together. Local experience and soil and plant analysis can be used as a basis for zinc sulphate application.

16.1.4 Sorghum

Traditional varieties are very tall, with a low harvest index (grain as percentage of total dry matter) and low yielding. When irrigated, very high yields of grain are obtainable from short strawed, high yielding varieties, which also usually give higher yields than traditional varieties at low input levels. As with the other major cereal crops, therefore, fertilizer requirements and recommendations vary widely according to the degree of improvement and the yield obtainable. In many African countries sorghum is grown in rotation with cotton or groundnuts and can utilize the residues of nutrients left in the soil by these crops.

In the past, the use of nitrogen fertilizer has been limited in local varieties because of the risk of lodging and yield depression when there is excessive vegetative growth. In very low rainfall conditions, when soil nitrogen supplies are sufficient for the low yields obtainable, no fertilizer nitrogen is needed. However, most local varieties will respond to 20-40 kg/ha of nitrogen. Improved local varieties or hybrids in limited rainfall areas, e.g. in west Africa or parts of India, justify the use of 50-100 kg/ha, while irrigated crops yielding 10 t/ha or more may need up to 300 kg/ha. Applications up to about 70 kg/ha can be applied to the seedbed but larger dressings are most effective applied partly in the seedbed and partly as early top-dressing.

Phosphorus is an important nutrient for sorghum. Much of the rainfed sorghum is grown on soils poorly supplied with phosphorus and 20-50 kg/ha of P_2O_5, mainly watersoluble, is needed for optimum yield and effective response to nitrogen fertilizer. In high yielding irrigated crops the need for fertilizer phosphorus to support optimum growth is vital and 50-80 kg/ha is justified.

Sorghum makes good use of soil potassium, and potassium fertilizer is required only on low potassium soils or where high yields result in a heavy demand by the crop. High yielding crops of hybrid sorghum need up to 100 kg/ha K_2O.

Sorghum is very sensitive to iron deficiency which can occur widely on calcareous soils, causing chlorotic striping of the leaves. It can be controlled by foliar application of ferrous sulphate or by soil application of an iron chelate.

16.1.5 Pearl Millet

Response to nitrogen in millet is less than in other cereals, being in the range of 10 to 20 kg of grain per kilogram of nitrogen applied to hybrid varieties, and less for unimproved varieties. Recommended fertilizer nitrogen rates are about 20 kg/ha for local varieties under low rainfall conditions, ranging up to 120 kg/ha or more for the hybrid varieties under irrigation, the higher rates being split between seedbed and topdressing.

Phosphorus requirements are variable, depending on soil analysis and yield level, and are in the range of 20-50 kg/ha P_2O_5. Millet is likely to respond to potash only on low potash soils or at high yield levels.

16.2 ROOTCROPS

16.2.1 Potatoes

Nutrition of a potato crop is dominated by its shallow rooting habit and rapid growth rate, so that high yields necessitate a good supply of nutrients throughout the growth period. Potatoes are tolerant of a wide pH range but grow best on slightly to moderately acid soils.

Nitrogen results in early development of the foliage, and therefore of photosynthetic capacity, and maintains active photosynthesis for the required growth period. However, an excess may delay tuber initiation and therefore reduce yield. Nitrogen requirement depends on many factors including soil type and previous cropping. A preceding legume or another crop with high residual effects, or an application of organic manure, can reduce fertilizer nitrogen requirement by 40-50 kg/ha. High yielding, rainfed or irrigated potatoes in temperate regions, with a growing period of 150 to 170 days, respond to as much as 200-300 kg/ha fertilizer nitrogen. Most recommendations for potatoes in tropical and subtropical areas are in the range 80-150 kg/ha of nitrogen, recommendations for particular regions and conditions depending on soil type, cropping system and variety. Potatoes utilize both ammonium and nitrate nitrogen, but especially in the early stages of growth show a preference for the ammonium form. Usually, all the nitrogen fertilizer is applied to the seedbed, but in high rainfall conditions a split application may reduce losses of nitrogen. However, applications after tuber development has started may delay crop maturity.

Potatoes need a good supply of readily available phosphorus, since their root system is not extensive and does not readily utilize less available forms. Also many tropical potato growing soils are rather acid and immobilize phosphorus fertilizer rapidly. Because of low efficiency of uptake by potatoes, phosphorus fertilizer applications need to be considerably higher than the 30-50 kg/ha of P_2O_5 taken up by the crop. Phosphorus fertilizer recommendations are therefore high in most situations, ranging from 100 to over 200 kg/ha P_2O_5 for most tropical potato crops. In temperate regions, phosphorus requirement is in the range 100-300 kg/ha P_2O_5, depending on soil analysis values. Phosphorus fertilizer is used more efficiently by potatoes if sideband placed, and this is especially so at low or moderate application rates. Water-soluble phosphorus is the most efficient source for potatoes.

Potassium plays a large role in photosynthesis and starch production by the potato crop. High yielding crops can remove 300 kg/ha or more of K_2O in the tubers alone. Fertilizer potassium requirement depends on soil supplies and organic manure application. Irrigation can improve availability of soil potassium, and there can be varietal differences in susceptibility to deficiency. Recommendations may be from 60 to 300 kg/ha of K_2O according to circumstances, but in most developing countries are between 60 and 180 kg/ha.

The source of potassium influences potato quality in that potatoes are sensitive to chloride. Thus, potassium sulphate usually gives higher starch production and higher tuber dry matter content than potassium chloride, though the difference in tuber yields is often small. Potassium sulphate can therefore be recommended where the value of the greater starch production exceeds the, usually, greater cost.

Potato quality is also influenced by nutritional imbalance. Excess nitrogen fertilizer can reduce tuber dry matter and cooking quality, while deficiency of potassium can cause blackening of the tubers.

Potatoes are sensitive to a number of secondary and micronutrient deficiencies. Magnesium deficiency can occur on leached, sandy soils and may be intensified by large potassium fertilizer applications; it can be controlled by magnesium applied in amendments such as dolomite or by magnesium-containing fertilizer materials. Copper and manganese deficiency may also occur and are controllable by foliar sprays.

16.2.2 Sweet Potato

The interest in increasing productivity by using fertilizer on sweet potatoes has occurred later than for many staple crops. On most soils, tuber yield is increased by nitrogen fertilizer. However, an excess of nitrogen can stimulate foliage production at the expense of tubers and may also lead to tuber cracking. Full benefit from nitrogen application is only obtained when sufficient potassium is given. It is usual to recommend about 50 kg/ha of nitrogen for this crop, but less on soils well supplied with nitrogen.

A sweet potato crop removes more potassium than phosphorus from the soil and fertilizer potassium has a greater effect on yield than phosphorus. For average conditions about 50 kg/ha P_2O_5 should be applied, but soils of low phosphorus status can justify an application of 70-90 kg/ha. The crop needs a good supply of potassium and a wide N : K_2O ratio of the order of 1 : 1.5 to 1 : 2. Potassium fertilizer usually gives a substantial yield increase and most recommendations are to apply 80-120 kg/ha K_2O. Potassium chloride can depress tuber dry matter content and where this has been found the use of potassium sulphate or a mixture of the two sources is recommended.

Sweet potatoes can suffer from deficiencies of magnesium, sulphur and boron, and corrective control measures may be necessary.

16.2.3 Cassava

Cassava is grown at low levels of fertility and withstands drought conditions; it is often grown as the last crop in an exhaustive rotation. In these circumstances, yields may be very low, but the crop responds well to a satisfactory level of soil fertility, to fertilizer use and to a good moisture regime. While average tuber yields are often around 10-15 t/ha, modern varieties grown under good conditions are capable of yielding well over 50 t/ha. Cassava removes rather large amounts of nutrients in the harvested crop; a 25 t/ha crop will remove about 60 kg/ha of nitrogen, 40 kg/ha of P_2O_5 and 136 kg/ha of K_2O. Correct fertilizer use can be expected to increase yield by 50 to 100 percent.

Cassava responds well to nitrogen fertilizer, with an expected yield increase of 50 kg or more of tubers per kilogram of nitrogen applied. With insufficient nitrogen, individual tubers are poor and thin. Too much nitrogen may, however, result in an excess of vegetative growth at the expense of tuber yield. A reasonable recommendation is to use 40-80 kg/ha of nitrogen, depending on circumstances, with the proviso that on exhausted soils where other growing conditions are good up to 120 kg/ha can be needed.

Many soils on which cassava is grown are poorly supplied with phosphorus and in trials and demonstrations the crop has consistently shown considerable benefit from phosphorus fertilizer - even though cassava makes better use of soil phosphorus than potatoes. Under most conditions 40-80 kg/ha of P_2O_5 should be applied.

A good supply of potassium is essential for cassava, giving a benefit of up to 100 kg of tubers per kilogram of K_2O and helping to offset the very large removal of potassium in the tubers of high yielding crops. Potassium increases yield primarily by increasing tuber size. Potassium deficient crops can contain toxic levels of hydrocyanic acid in the tubers. On soils of moderate potassium status, 100-130 kg/ha of K_2O is recommended, with adjustments for other soil potassium levels. All the fertilizer may be applied at planting, but too close contact with the sets should be avoided as this may affect establishment. Alternatively, the nitrogen component may be split between a basal application and top-dressing.

16.3 LEGUMINOUS CROPS

16.3.1 Soybean

Soybean is a leguminous crop and requires a pH of 6.0 or above for optimum activity of the associated nitrogen fixing bacterium, *Rhizobium japonicum*. Rhizobial bacteria will provide much of the nitrogen requirement of the soybean crop. However, it is usually necessary to treat the seed with bacterial inoculant, as the correct rhizobial strain may not be present in the soil. Strains of the bacterium differ in their ability to stimulate root nodule formation and to fix nitrogen. There is thus considerable scope for enhancement of nitrogen fixation by selecting efficient strains as inoculant. In good conditions, the soybean crop will fix 100 kg/ha or more of nitrogen. On many soils the crop cannot, however, be grown entirely on rhizobial nitrogen fixation, as it takes some weeks for the nodules to develop and the rate of fixation to meet crop need. An application of 20-30 kg/ha of nitrogen as a starter dose in the seedbed closes this gap. Large applications of nitrogen are not desirable since they inhibit the nitrogen fixation process.

Phosphorus and potassium requirements of soybean are related to soil analytical values. While adequate amounts of these nutrients are important, the crop is less responsive to them than, for example, maize, and the amounts removed in the harvested crop are moderate rather than high. Typical phosphorus and potassium rates for soils of medium nutrient status are 50-70 kg/ha of P_2O_5 and 60-100 kg/ha of K_2O. On soils of low nutrient status benefit can often be obtained from applying fertilizer (particularly phosphorus) as a sideband application.

Soybean may be subject to a number of secondary and micronutrient deficiencies. Depending on soil status and conditions, responses have been found to most of the essential elements, in particular magnesium, sulphur, zinc and manganese. Appropriate control measures may be needed to forestall damage from these deficiencies.

16.3.2 Groundnut

As with soybean, most of the nitrogen requirement of a groundnut crop is provided by fixation in the root nodules by symbiotic *Rhizobium* bacteria. Unless soil fertility is high or an organic manure has been applied, a starter dressing of 20-30 kg/ha nitrogen is needed to feed the crop until the nodule bacteria are fully established. In many conditions, and particularly where groundnuts have not been grown for several years, inoculation of the seed with a rhizobial strain is essential.

Groundnut needs phosphorus fertilizer for optimum yield and also for optimum development of nodules and rhizobial nitrogen fixation. However, requirements are not normally large and 40-70 kg/ha P_2O_5 will usually be sufficient. Similarly, potassium requirements are not heavy and may to a large extent be supplied by residues from previous crops and organic manure. Recommendations range from 20 to 70 kg/ha of K_2O. Fertilizers can often be sideband placed with advantage.

The nutrition of groundnut requires attention and action on a much wider front than just nitrogen, phosphorus and potassium. The crop frequently requires supplementary applications of sulphur and calcium and may also suffer from deficiencies of magnesium, manganese, boron and molybdenum. Sulphur requirement depends on input level in rainfall, which is low for example in many west African countries. It can be met by using ammonium sulphate, single superphosphate or low concentration compound fertilizers. Indigenous sources like gypsum, phosphogypsum and pyrites could also be advantageously used.

Groundnuts are unusual in showing calcium deficiency so widely. Essentially, this deficiency is caused by immobility of calcium in the groundnut plant so that too little reaches the fruiting organs, resulting in poor kernel development. Calcium deficiency can usually be overcome by liming to pH 6.0. In some varieties, however, it is necessary to apply additional calcium in the form of gypsum (calcium sulphate) at the flowering stage; a foliar spray of a soluble calcium salt can also be effective. Calcium deficiency can be accentuated by use of potassium fertilizer, so that an adequate calcium supply is particularly important when a large potassium application is needed.

Sandy soils may be deficient in magnesium, which can be supplied by liming with dolomitic materials. However, excess magnesium has the same effect on calcium availability as excess potassium and should therefore be avoided. Boron deficiency, which causes internal damage to the kernels, may also occur on sandy soils, especially in dry conditions, but can be controlled by soil or foliar application of sodium borate. Manganese deficiency, causing poor, chlorotic growth, is usually attributable to overliming and is controllable by a manganese sulphate spray. Molybdenum deficiency inhibits proper rhizobial activity, but the very small amount required can be supplied as a seed treatment.

16.4 CASH CROPS

16.4.1 Sugarcane

Sugarcane is grown on a variety of soils but is best suited to well drained loams and clay loams. It is tolerant of a wide pH range, from 5.0 to 8.0. Under more acid conditions, however, high aluminium solubility can cause toxicity, so that liming is necessary. Since sugarcane has a long life cycle and successive harvests are taken, its fertility requirements are more complex than those of annual crops.

Nitrogen fertilizer has a considerable effect on cane yields, following the usual pattern of diminishing returns to successive increments. In some situations and with some varieties excess nitrogen depresses cane yield. Sugar content of the cane decreases with increasing nitrogen supply and the optimum rate is, more or less, that which maximizes sugar yield (the resultant of cane yield x sugar content). Excess nitrogen may also affect juice quality and ease of sugar recovery. Depressions in yield and quality at high nitrogen rates can be minimized by suitable water management in the final stages of growth.

The requirement for nitrogen fertilizer varies with yield potential and, particularly in plant cane, with the soil nitrogen supply. Plant cane is able to draw on mineralized nitrogen in the soil, which can vary in amount from about 50 to 150 kg/ha, and as an approximate guide it requires 1 kg fertilizer nitrogen per tonne of expected yield. For ratoon cane, the soil nitrogen supply is lower and the rule-of-thumb is 1.5 kg of fertilizer nitrogen per tonne of cane. Thus, for example, a plant cane yield of 100 t/ha would require 100 kg/ha of nitrogen and a 140 t/ha ratoon cane yield 210 kg/ha. Much more may be used in intensively grown crops. Of course, more specific recommendations can be derived from local experimentation and experience. Various systems of foliar diagnosis have also been developed, providing guidance on fertilizer requirements (phosphorus and potassium as well as nitrogen) from analysis of specified leaves or other organs at specified growth stages.

Nitrogen fertilizer for plant cane is usually split applied. The first application of one quarter to one half of the total is made in the planting furrow or broadcast a week or two after planting. The second application should be during the period of rapid growth and nutrient uptake one to three months after planting. Later applications are often less efficient and may reduce sugar content. For the ratoon crop, nitrogen should be applied immediately or within two months or so after cutting the previous crop.

Phosphorus fertilizer stimulates root growth and tillering in the early stages, and it is therefore correct to apply it at planting; placing it in the planting furrow increases efficiency of uptake, especially on the less fertile soils. However, many sugarcane soils fix phosphorus rather rapidly, so that availability of this initial application can be low for the ratoon crop. Ratoon crops benefit from an initial application of phosphorus fertilizer immediately after cutting the previous crop. For soils of medium phosphorus status, an application for the plant crop of 100-120 kg/ha of P_2O_5 is frequently recommended, and 200 kg/ha on phosphorus-deficient soils. For the ratoon crop, 60 kg/ha of P_2O_5 will usually provide enough to stimulate regrowth.

Sugarcane needs a good level of potassium nutrition, for a number of reasons. The harvested crop removes very large amounts of potassium from the soil - high yields can remove as much as 400 kg/ha. Cane and sugar yields are increased, in most circumstances, by potassium fertilizer. Adequate potassium counteracts the adverse effects of high rates of nitrogen fertilizer on cane sugar content and juice quality. Typically, potassium applications are in the range of 80-200 kg/ha per annum of K_2O, but considerably more may be used on irrigated, high yielding crops. Potassium nutrition can be monitored by soil and plant analysis and supplementary applications made where plant potassium content is below a specified level.

Sugarcane is sensitive to deficiencies of secondary and micronutrients, and in addition to monitoring by visual symptoms considerable information is available on plant nutrient contents as indices of adequacy. As well as deficiencies of sulphur, copper, manganese and zinc, lime-induced iron deficiency readily occurs in sugarcane and can be controlled by application of an iron chelate. Magnesium deficiencies can occur where soil magnesium status is low. Conversely, on soils extremely high in magnesium, excessive uptake of this nutrient may, by suppressing potassium uptake, induce potassium deficiency. Finally, sugarcane, like rice, reacts favourably on some soils to soluble silicates, which probably act by the same mechanisms of releasing soil phosphate and controlling manganese toxicity.

16.4.2 Cotton

Cotton requires a warm growing season and grows best on well drained soils with good physical structure. Very acid soils must be limed. An adequate moisture supply is essential, especially during flowering and boll development. Satisfactory rainfed crops are grown in many countries. Cotton is also well suited to irrigated conditions, and the highest yields are obtained when grown under irrigation. Good management including timely sowing and effective weed and pest control are necessary for high yields and for best response to fertilizers. In FAO trials between 1961 and 1977 fertilizer increased yield, on a regional basis, by 40 to 100 percent.

Nitrogen fertilizer increases yield of cotton by increasing the number and length of branches, and therefore the number of flowers. However, the amount to be applied depends very much on circumstances. Excess nitrogen should be avoided as it may reduce yield and quality by stimulating too much vegetative growth and delaying maturity. The rate of fertilizer required is related to water supply. Recommended rates for rainfed cotton are usually between 50 and 100 kg/ha while most irrigated crops need 120 kg/ha or more. In some intensively cropped, irrigated cotton-growing regions, applications are as high as 300 kg/ha. Soil and plant nitrate analyses can be used to monitor crop nitrogen nutrition, and may be useful in deciding how much nitrogen fertilizer to give as top-dressing.

It is usual to split the nitrogen application, part being applied to the seedbed and part as a top-dressing at the start of flowering. Irrigated crops with high yield potential may receive two or three top-dressings.

Phosphorus requirements of cotton are related to soil analytical levels. Phosphorus has particular value in cotton for promoting establishment and early growth. Recommended rates vary from 30 to 100 kg/ha of P_2O_5. The higher rates can be important on newly broken up soils.

About 30 kg/ha of K_2O is removed by the cotton crop per 1000 kg of lint. Many moderately yielding crops have been grown without potassium fertilizer, but it should be applied for higher yielding crops, where cotton is grown sequentially and where soil potassium contents are moderate or low. Recommended rates are similar to those for phosphorus, 30 to 100 kg/ha of K_2O.

Cotton is subject to a number of secondary and micronutrient problems. Magnesium deficiency can occur on sandy soils and can be avoided by liming with dolomitic materials. Sulphur deficiency occurs fairly widely in North and South America and in Africa. As little as 10 kg/ha of sulphur is required to overcome it; sulphur-containing fertilizers or gypsum are suitable sources. Boron deficiency has been reported in a number of countries, and iron and zinc deficiencies also occur; all are controllable by well proven foliar or soil applications.

16.4.3 Citrus

Citrus crops - orange, lemon, grapefruit, etc. - are grown on a variety of soils, good drainage being a prime requirement. They have a special need for correct nutrient balance, are very sensitive to an unbalanced nutrient supply and are subject to deficiencies of secondary and micronutrients, which occur very widely. In addition to yield of fruit, quality is much affected by nutrition, and both amounts and timing of nutrient applications can be critical in this respect. The fertilizer requirements of citrus crops are further complicated by their perennial nature, with separate establishment and fruiting periods, each having specific fertilizer needs. In most conditions citrus crops make growth, and therefore require nutrients, throughout the year though the rate of growth varies with season.

Quality in citrus for the market relates to external appearance - size, colour, skin and rind thickness and texture - and to internal qualities, in particular juiciness and low acidity. For processing, high juice content, soluble solids and juiciness are needed. Nitrogen and potassium nutrition have considerable effects on quality, as does the balance between them.

Nitrogen gives large increases in tree growth and in yield but in excessive amounts can have adverse effects on quality unless correctly balanced with other nutrients. Phosphorus is important in establishment and in early growth; levels in the soil are often built up by applications in the establishment phase, so that only maintenance applications are needed later in the life of the crop. Excess phosphorus can reduce quality and affect copper and zinc availability. Potassium influences fruit setting and development, but the amount given must be related to nitrogen applications to ensure good quality. The effects of deficiencies of secondary and micronutrients are well known in citrus and it is desirable to monitor their status in the crop by leaf analysis. Remedial applications are needed very frequently.

Leaf analysis is a valuable aid to correct fertilizer practice and standards for major, secondary and micronutrients have been established in many growing regions. Together with soil analysis, observations on growth and visual symptoms and quality considerations can provide a good guide to fertilizer requirements.

In making fertilizer recommendations for citrus, there are alternative approaches based on rates of nutrient per tree or on expected yield per tree as well as on rate per hectare, all of which have advantages in particular situations. Recommended rates vary widely according to conditions and local experience. Typical application rates for fruiting trees are about 200 kg/ha of nitrogen, 80 kg/ha of P_2O_5 and 150 kg/ha of K_2O. Timing of application is not very critical; two or three applications per year are usual. Foliar sprays of micronutrients and of nitrogen as urea are common in some growing areas because of the speed with which crop nutrient status can be manipulated in this way.

16.5 GRASSLAND

In principle, the use of fertilizer on grassland can result in very high levels of herbage production. Table 22 gives an example of the yield of grass dry matter obtainable in Puerto Rico at high rates of fertilizer use. However, the yields of herbage, and associated livestock productivity, that can be obtained in practice are frequently restricted by soil and climatic potential, by farming system and social structure, by the management difficulties in converting high yields of herbage production into animal production and by the lack of sufficient livestock and associated facilities to utilize the greater herbage production effectively. In planning to increase grassland productivity by the use of fertilizers it is essential to ensure that these limitations are removed.

The level of intensity of grassland and animal production thus ranges from very low to very high. Low-intensity grassland composed of native species is usually limited in potential by rainfall, temperature or altitude. Modest improvements in productivity may be possible by use of phosphorus fertilizer, which can encourage development of legumes and therefore supply an input of nitrogen by fixation. Under very acid soil conditions liming may also be necessary to encourage legumes. Much low

Table 22 EFFECT OF NITROGEN FERTILIZER ON HERBAGE DRY MATTER PRODUCTION FROM NAPIER GRASS IN PUERTO RICO

Nitrogen kg/ha per year	Herbage yield (t/ha/year)		
	Cutting interval (days)		
	40	60	90
0	10.7	17.0	34.1
225	17.0	27.6	47.8
450	22.7	41.1	63.3
900	27.5	49.9	84.7

Source: Vicente-Chandler J. *et al.* J. Agric. Univ. Puerto Rico, 45:37-45 (1961).

intensity grassland also requires sulphur application for improvement to be effected, and often molybdenum to support rhizobial activity.

More intensive grassland requires an appreciable input of nitrogen, which may be from legumes or from fertilizer, and supporting applications of phosphorus and potassium fertilizers. Increased productivity is also dependent on an adequate rainfall regime or on irrigation. Legumes can provide considerable quantities of nitrogen to a grass/legume mixture - about 100 kg/ha in cool temperate climates and up to 200 kg/ha or more in warm temperate and tropical climates. They can therefore support good levels of herbage production, but not the highest potential yields. While in some countries grass/legume swards receive fertilizer nitrogen, this usually encourages the grass component at the expense of the legume and therefore reduces the nitrogen contribution from the legume. Legumes such as *Centrosema, Desmodium* or *Stylosanthes* species in association with tropical grasses can give moderate to high production levels. Usually, it is necessary to inoculate the legume seed with the appropriate *Rhizobium* bacterium and, as with arable legumes, there is considerable scope for the selection of improved bacterial strains.

Very high grassland production depends on the use of high rates of nitrogen fertilizer, supported by phosphorus and potassium. Nitrogen fertilizer rates up to 400-500 kg/ha per annum applied up to six times during the six-month growing season to maintain herbage growth are used successfully.

For intensive grassland production, whether based on legumes or on nitrogen fertilizer, adequate phosphorus must be used. Phosphorus fertilizer has a major effect at the establishment stage, especially for legumes, and especially on tropical soils of low phosphorus status and high phosphorus fixing capacity. High yields of grass take up 100 kg/ha or more of P_2O_5 per annum. Where the grass is grazed, most of this phosphorus is returned in dung and urine but where grass is cut and removed from the field considerable depletion can take place. Regular applications of 50-100 kg/ha of P_2O_5 per annum are needed.

Potassium fertilizer is required by legumes and grasses at establishment, but more particularly at all stages by legumes to enable them to compete successfully with grasses in mixed swards. It is also needed to replace the large amounts of potassium removed in herbage, which can be as high as 400 kg/ha of K_2O per annum. Under grazing management most of this is returned to the soil but when herbage is cut and removed from the field there can be a serious drain on soil potassium reserves.

Potassium can be taken up in "luxury" amounts by grassland, resulting in inefficient utilization for herbage production. High potassium contents in the herbage may also affect magnesium nutrition of the sward and of grazing livestock, causing the condition known as hypomagnesaemia (grass tetany or staggers). To avoid this, the overall potassium requirement should be split into a number of moderate applications throughout the growing season.

Successful grassland production will also, according to circumstances, necessitate attention to requirements of sulphur, molybdenum and other nutrients. A number of nutrient deficiencies can be important in the nutrition of grazing livestock; deficiencies of phosphorus, magnesium, copper and cobalt are the most common.

16.6 FAO TRIALS AND DEMONSTRATIONS

The number of trials and demonstrations conducted by FAO on the above crops and others is very large. The effect of fertilizer on yield is summarized in Table 23, and it will be seen that increases in yield, regionally and by crop, were from 41 to 171 percent, showing the prime place that fertilizer has in increasing productivity of foodgrains and other major crops.

Table 23 RESPONSE TO FERTILIZER IN SOME MAJOR CROPS IN THE FAO FERTILIZER PROGRAMME, 1961-1977

Region	Average best yield increase from fertilizers	Region	Average best yield increase from fertilizers
Near East and North Africa		Latin America	
Wheat (8)	60	Rice (8)	101
Rice (3)	38	Maize (11)	84
Maize (3)	61	Potatoes (7)	150
Potatoes (5)	58	Groundnuts (5)	97
Groundnuts (5)	56	Cotton (3)	83
Cotton (4)	41	Eastern and Southern Africa	
		Maize (4)	62
		Sorghum (4)	114
		Millet (2)	107
West Africa		Groundnuts (2)	51
Rice (11)	48	South and Southeast Asia	
Maize (8)	71		
Sorghum	8		
Millet (5)	69	Wheat (2)	171
Cassava (2)	48	Rice (5)	63
Groundnuts (11)	54	Maize (3)	75
Cotton (5)	98	Groundnuts (2)	52

Source: Richards I.R. Phosphorus in Agriculture No. 76, p. 147-156 (1979).

Note: Number of countries shown in brackets.

17. FERTILIZER AND WATER USE

17.1 WATER AND CROP NUTRITION

The relationship between water in the soil and the uptake and use of plant nutrients is very complex, since the water status in the soil and changes in soil water conditions have major effects on availability of soil nutrients, on losses of nutrients from the soil and on the way and extent to which plants take up nutrients and use them for growth and yield.

17.1.1 Nutrient Availability

Water content of the soil affects the availability of all nutrients. A prime example is nitrogen which is affected in a number of ways. In dry soil conditions, biological activity in the soil is restricted, so that breakdown of organic matter slows down and stops, and with it mineralization of organic forms of nitrogen to plant-available mineral forms also ceases. At the same time, mineralization of other nutrients such as phosphorus and sulphur is also inhibited. Thus, in periods of dry soil conditions, e.g. in dry seasons, little accumulation of mineral nitrogen occurs, but when the rains come there can be a very considerable flush of mineralization providing nitrogen and other nutrients for plant growth.

Dry periods during crop growth also affect mineralization and may lead to a temporary shortage of nitrogen in the soil. The use of irrigation can avoid such fluctuations in soil biological activity during crop growth, and one of the effects of irrigation is to increase soil nutrient supply from organic sources - though the increases will seldom be sufficient to offset the additional demand for nutrients resulting from greater plant growth and production.

Availability of many nutrients already in mineral form, e.g. potassium and other cations, is improved by a satisfactory soil moisture status. In dry soil conditions, cations are more tightly bound to soil colloids and therefore less available to plants. Also, since the volume of soil solution is smaller, the amount of sparingly soluble nutrients, such as phosphorus, is reduced and plants will not be able to absorb sufficient.

In waterlogged soil, the concentrations of ammonium ions, iron, phosphorus and manganese increase, but nitrate content falls because of denitrification. The uptake by rice of many nutrients - nitrogen, phosphorus, manganese and iron - is increased under waterlogged conditions but the uptake of other cations may be reduced.

17.1.2 Nutrient Losses

There are three main ways in which water status and water management may influence loss of nutrients from the soil-plant system.

i. Excessive rainfall or excessive irrigation resulting in the passage of water through the soil profile will carry with it soluble nutrients, particularly nitrate, sulphate and boron. The implication of this for irrigation management is clear. Also, in temperate climates with moderate or high rainfall, the amount of rainfall during winter is usually sufficient to cause appreciable loss by leaching of these nutrients, which may be present in quantity in the soil at the beginning of winter through breakdown of crop residues at the end of the growing season. The amount of loss depends on how much rain falls. Since this often varies from year to year, it is necessary to take it into account in deciding how much fertilizer to apply.

ii. Waterlogging causes denitrification of nitrate. In rice soils, nitrate levels are kept low by correct water management and losses are normally small. However, in upland soils nitrate levels are often quite high so that periodic waterlogging by heavy rainfall or excess irrigation can cause a large loss. Free-draining soils become waterlogged less readily, so that it is on the heavier-textured soils that this risk is greatest.

iii. Ammonia volatilization from urea and some ammonium-containing fertilizers is influenced by soil water status. Under very dry conditions, little loss occurs and in stable wet soil conditions ammonium is held in solution in the soil. However, where soil moisture status is intermediate, or where the soil or flood water is losing water rapidly by evaporation, volatilization of ammonia can be appreciable.

17.1.3 Nutrient Uptake and Use

The uptake of nutrients by crops is also influenced by the effect of water supplied to the crop on crop growth and metabolism. If water uptake is restricted by dry soil conditions, the rate of root extension is reduced and the plant is less able to draw on moist horizons in the soil. Furthermore, in most soils the highest nutrient status is in the topsoil (plough layer), and it is this horizon that dries out first. Even though the plant is able to obtain water from the subsoil, it may not in these conditions be able to obtain adequate nutrients for continued full growth.

Efficient use of nutrients after uptake depends on a satisfactory continuing supply of water. If sufficient water is not available, transport of nutrients within the plant can be restricted, and their use for metabolic activities and plant biomass production will also be limited.

17.1.4 Water and Fertilizer Response

The growth and yield responses of the crop to fertilizer are very much influenced by the level of water supplied. Their response is a synthesis of the various factors affecting crop growth, nutrient availability and nutrient uptake discussed above. Two examples(Figures 33 and 34) show the much better use that crops make of fertilizer when water supply is improved. Figure 33 shows the greater response to nitrogen fertilizer, as well as higher yield level, with increasing soil contribution to crop water supply and Figure 34 shows the effect of irrigation on response to fertilizer.

The need to ensure that sufficient fertilizer is supplied in association with irrigation is clear.

17.2 WATER AND NUTRIENT USE EFFICIENCY

17.2.1 Water Requirement of Crops

The estimation of crop water requirement underlies effective planning of crop production at farm level. Water requirement is the quantity of water needed to raise a full crop without any harmful residual effect on the soil. It thus includes the quantity of water needed to meet the evapotranspirational needs of the crop, losses during application and any special operations such as land preparation, puddling, flooding rice, or leaching of salt-affected soils.

Water requirement (WR) is met from a number of sources, the principal ones being soil profile water (S), rainfall (R) and irrigation (IR):

$$WR = R + IR + S$$

The irrigation requirement of a crop is therefore its total water requirement less effective rainfall and soil profile water, i.e.:

$$IR = WR - (R + S)$$

17.2.2 Nutrient Use Efficiency

Nutrient use efficiency (NUE) has two connotations. Soil scientists generally equate it with the percentage of the applied nutrients utilized by a crop, but in agronomic terms it can be looked upon as the amount of produce per unit of applied nutrient. It is thus obtained by subtracting the yield of the unfertilized control (Y_o) from that of the fertilized treatment (Y_F) and dividing by the amount of nutrients applied (N):

$$NUE = \frac{Y_F - Y_o}{N}$$

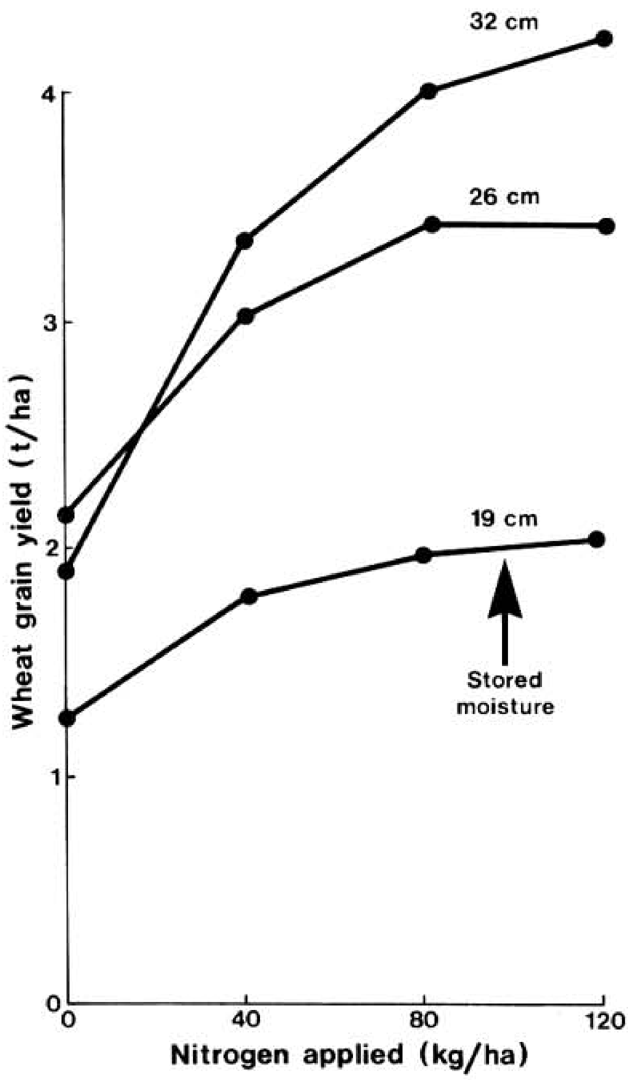


Fig. 33 Response of rainfed wheat to nitrogen in soils with different stored moisture

Source: Tandon H.L.S. Fertilizer News 25: 45-78 (1980)

The actual yield level and the response to fertilizer application will be influenced by many aspects of crop management. In relation to water supply and management, NUE may be improved by minimizing the fertilizer losses from the soil by leaching or denitrification that poor water management may induce, and by ensuring that lack of water does not at any stage appreciably retard growth or nutrient uptake. Clearly, excess water can be a cause of losses of nitrogen and insufficient irrigation at a critical stage can limit growth and yield. It is also important that all other management factors and crop requirements should be adequately supplied.

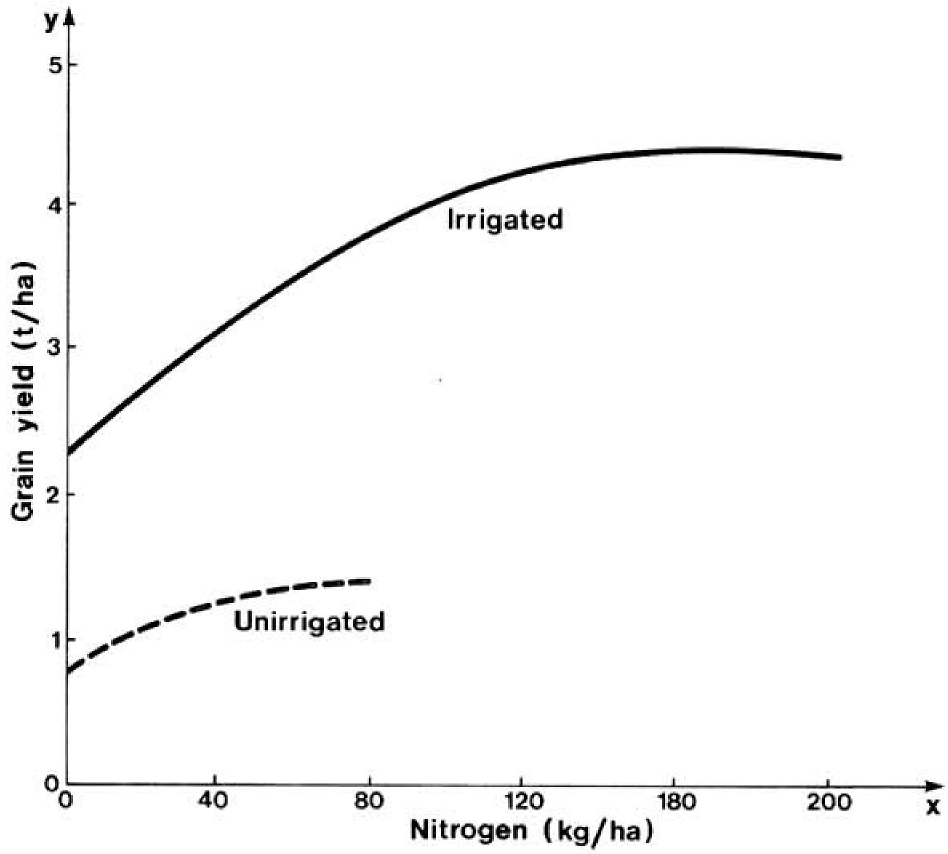


Fig. 34 Response of irrigated and unirrigated wheat to nitrogen application

Source: Singh N.P. and Rai R.K. Fertilizer News 24: 34-38 (1979)

Table 24 SENSITIVE GROWTH PERIODS FOR WATER DEFICIT IN IMPORTANT CROPS

Crop	Growth period
Rice	Head development and flowering > vegetative period > ripening
Wheat	Flowering > yield formation > vegetative period
Sorghum	Flowering and yield formation > vegetative period
Maize	Flowering > grain filling > vegetative period
Groundnut	Flowering and yield formation particularly pod setting
Safflower	Seed filling and flowering > vegetative period
Peas	Flowering and yield formation > vegetative period
Cotton	Flowering and boll formation
Potato	Stolonization and tuber initiation > yield formation > early vegetative and ripening
Sugarcane	Period of tillering and stem elongation > yield formation

Source: Doorenbos J. and Kassam A.H. FAO Irrigation and Drainage Paper 33, FAO, Rome (1979)

The time of water application greatly influences NUE through its effect on crop yield, which can be substantially reduced by omitting irrigation at the most moistureresponsive growth stages. In most crops the reproductive growth stage has been found to be most critically affected by moisture deficiency (Table 24).

17.2.3 Water Use Efficiency

Water use efficiency (WUE) is defined as the economic crop yield (Y) per unit of water used by the crop for evapotranspiration (ET):

$$WUE = Y/ET$$

Since water supply is often a limiting factor in crop production and irrigation is expensive and finite in quantity, any practice that increases yield per unit of water used is important. Once full crop cover is achieved, water use (ET), is controlled, with certain provisos, by incoming solar energy and not by further increases in crop density or height. In these circumstances, any input factor that increases economic yield will improve water use efficiency. The effect of fertilizer in doing so is illustrated in Figure 35.

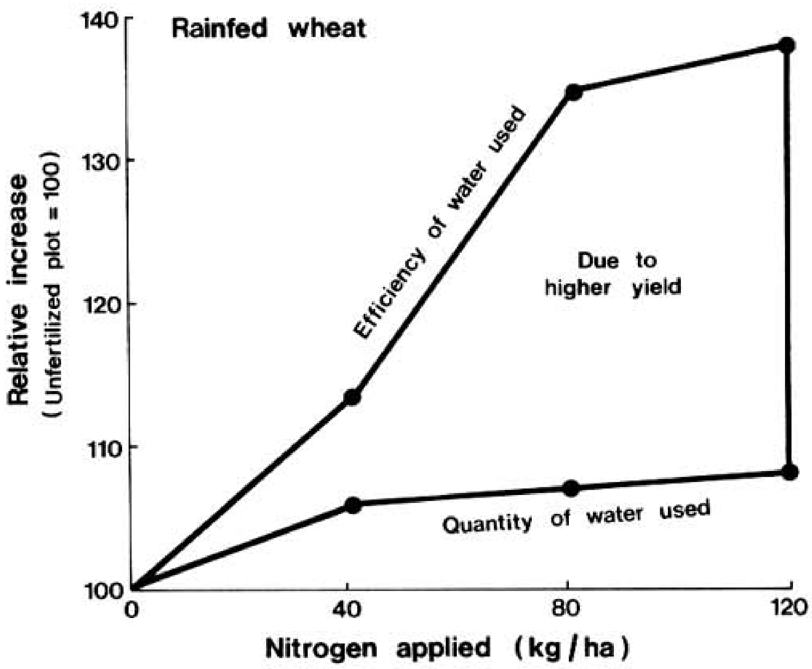


Fig. 35 Water use and its efficiency for rainfed wheat as influenced by increasing levels of N fertilizer

Source: Tandon H.L.S. Fertilizer News 25:45-78 (1980)

17.3 FERTILIZER USE IN RELATION TO WATER SUPPLY

Policy on fertilizer use should therefore be to maximize both efficiency of nutrient use and water use efficiency. The way in which this should be done depends on the water regime.

i. For non-irrigated, dryland crops, the crop often has to face moisture stress at some stage and whatever the level of fertilizer used, the limiting factor on production is water supply. Fertilizer rates must be decided in relation to the level of water supply from stored soil moisture and rainfall, which determine the expected level of yield. Both expected yield and optimum fertilizer levels are likely to be moderate. For crop production in rather arid zones, too much fertilizer may adversely affect yield and water use efficiency by stimulating vegetative growth so that the limited water supplies are used up before grain formation and filling is complete.

ii. For irrigated upland crops, fertilizer requirement is normally high. It can be decided in relation to expected yield level, and calibrated by the results of field trials on the local soils and under local management practices. Both fertilizer use efficiency and water use efficiency will be maximized by providing adequate amounts of both inputs for full growth and yield, and by timing applications so that crop nutrient and water needs are met at all times.

iii. In wetland rice, provided water management is good, yield levels are determined by climate and season, by variety and management and by fertilizer use. Amount of fertilizer, method of application and timing are all important. Phosphorus and potassium, together with some nitrogen, are required before transplanting and should be worked into the soil. Loss of nitrogen by denitrification will be minimized if the soil is kept flooded. Subsequent nitrogen applications should be made during growth to provide for the crop's continuing requirement. Efficiency of fertilizer nitrogen use on rice is often low because of volatile losses of ammonia and it is important to apply appropriate fertilizer products in appropriate methods that will reduce these losses.

18. ECONOMICS OF FERTILIZER USE

Before a farmer can be convinced that he should apply a purchased input such as fertilizer, he needs to have a knowledge about fertilizers and their effect on crop yield. However, his decision on whether or not to use fertilizer on a particular crop is generally based on economics.

18.1 FACTORS AFFECTING DECISION-MAKING

The principal elements of production economics as applied to fertilizer use consist of physical yield response to fertilizers applied, prices of fertilizer and crop, the influence of time, and the individual farmer's attitude toward decisionmaking. The publication "Economic, Financial and Budget Aspects of Fertilizer Use Development" (FAO/FIAC 1983) identified the following economic and institutional factors as important considerations influencing the economics of fertilizer use:

i. the price relationship between fertilizers and the crops to which they are applied together with the market outlook for these crops, which largely determine the profitability and incentive for using fertilizers;

ii. the level of farmers' incomes and the availability and cost of credit, which largely determine whether farmers can afford the initial outlay for fertilizers;

iii. conditions of land tenure which, if unfavourable, may greatly reduce the incentive for farmers to use fertilizers;

iv. adequate supplies and distribution facilities to ensure that the right kinds of fertilizers are available to farmers at the right place and time.

The relative importance of these factors varies depending on circumstances and they are to a considerable extent interdependent. Each of them can be influenced by the government which is therefore easily able to stimulate the use of fertilizers if this is national policy.

18.2 RESPONSE FUNCTION

The response function to fertilizer use is a basic concept which relates the amount of crop capable of being produced and the amount of fertilizers and other farm inputs applied. In other words, there will be a maximum obtainable amount of crop produce for any given amount of fertilizers and other farm inputs used.

In theory, the determination of the response function should take into account all variables, such as use of other farm inputs, which logically influence yield of crop.

The theoretical presentation of response function is:

$$Y = f(X_1, X_2 \ldots . X_n)$$

where: Y = crop yield

$(X_1, X_2 \ldots . X_n)$ = inputs included within the response function as having the major influence on production

Normal practice for fertilizer functions, however, is to restrict the variable inputs to the level of fertilizer applied.

The average relationship between the amount of fertilizer applied and the increase in crop yield has been investigated by a number of workers. Table 25 shows a few examples of estimates and of research findings which indicate that it is reasonable to assume that 1 kg nutrient ($N+P_2O_5+K_2O$) produces around 10 kg cereal grains.

Table 25 RESPONSE RATIOS OF CEREALS TO FERTILIZER APPLICATION

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

Source: FAO Fertilizer and Plant Nutrition Bulletin 2, FAO, Rome (1981)

The important information supplied by the response function is the increment of crop product obtainable from an increased level of fertilizer use at each level of fertilizer application. This information is essential for the determination of the optimum fertilizer application level (i.e. the most profitable level of fertilizer use).

The classical production function or complete response relationship normally exhibits stages of increasing, diminishing, and negative returns corresponding to more than proportional, less than proportional, and negative increases in crop produce per unit of fertilizer applied. The farmer is obviously interested only in the first and second stages of the function and his specific interest depends on whether his main consideration is maximization of profit of the return to the money spent on fertilizer. This attitude is conditioned by the resources available to him and by his views on risk and uncertainty.

18.3 ECONOMIC OPTIMUM

In analysing the economics of fertilizer use, the principal considerations are the production increase attributed to fertilizer (or physical response), and the relationships between the cost of fertilizers and the price of crops. If the objective of the farmer is to obtain the economic optimum value from the use of fertilizer, his concern is to operate within the second stage of the response function wherein the yield obtained from a unit of fertilizer (the marginal yield) is increasing but at a decreasing rate. As the number of units of fertilizers increase (Table 26), the total crop yield increases as well, while the marginal yield per unit of fertilizer applied (fourth column), which is actually the incremental yield consequent on the unit increase of fertilizer applied, declines.

It is apparent in Table 26 that the most profitable level of fertilizer application is one increment below the amount required to

Table 26

EXAMPLE OF ECONOMIC OPTIMUM APPLICATION OF FERTILIZERS[1]

Units of fertilizer applied per ha	Total crop yield kg/ha	Increase in crop yield over control kg/ha	Marginal yield for each unit of fertilizer applied kg/ha	Value of additional fertilizer applied Rs 46/unit[2]	Marginal return of additional crop Rs 0.76/kg	Net economic return Rs	Value-Cost Ratio[3] VCR
0	3 844			-	-	2 921	-
1	4 356	512	512	46	389	3 265	8.4
2	4 818	974	462	46	351	3 566	8.0
3	5 230	1 386	412	46	313	3 838	7.6
4	5 592	1 748	362	46	275	4 067	7.2
5	5 904	2 060	312	46	237	4 258	6.8
6	6 166	2 322	262	46	199	4 411	6.4
7	6 377	2 533	211	46	160	4 526	5.9
8	6 539	2 695	162	46	123	4 604	5.6
9	6 651	2 807	112	46	85	4 623	5.1
10	6 712	2 868	61	46	46	4 643	4.7
11	6 724	2 880	12	46	9	4 606	4.3
12	6 685	2 841	-39	46	-30	4 531	3.9

1 Based on high yielding variety wheat experiments in India.

2 Rs 10.50 = US$ 1 (approx).

3 The value of the yield increase divided by the cost of the fertilizer applied.

Source: FAO/FIAC. Economic, Financial and Budget Aspects of Fertilizer Use Development. FAO, Rome (1983) produce the highest yield. In this case, the application of 10 units of fertilizer gives the highest net return of Rs 4643. In other words, while the highest yield is obtained with 11 units of fertilizer, the maximum economic return is obtained with 10 units, i.e. where the cost of the additional unit of fertilizer equals the value of the additional yield: Rs 46 = Rs 46. If an eleventh unit of fertilizer is applied the cost of the additional unit is more than the value of the additional yield: Rs 46 vs. Rs 9. As the ratio of crop and fertilizer prices changes, the amount of fertilizer applied must also change to maintain optimum economic returns per hectare. The extent of the change depends on the shape of the response curve. This concept of economic optimum is further illustrated in Figure 36. It is, therefore, important that information on marginal yield and the relationship of prices of fertilizer and crop are available.

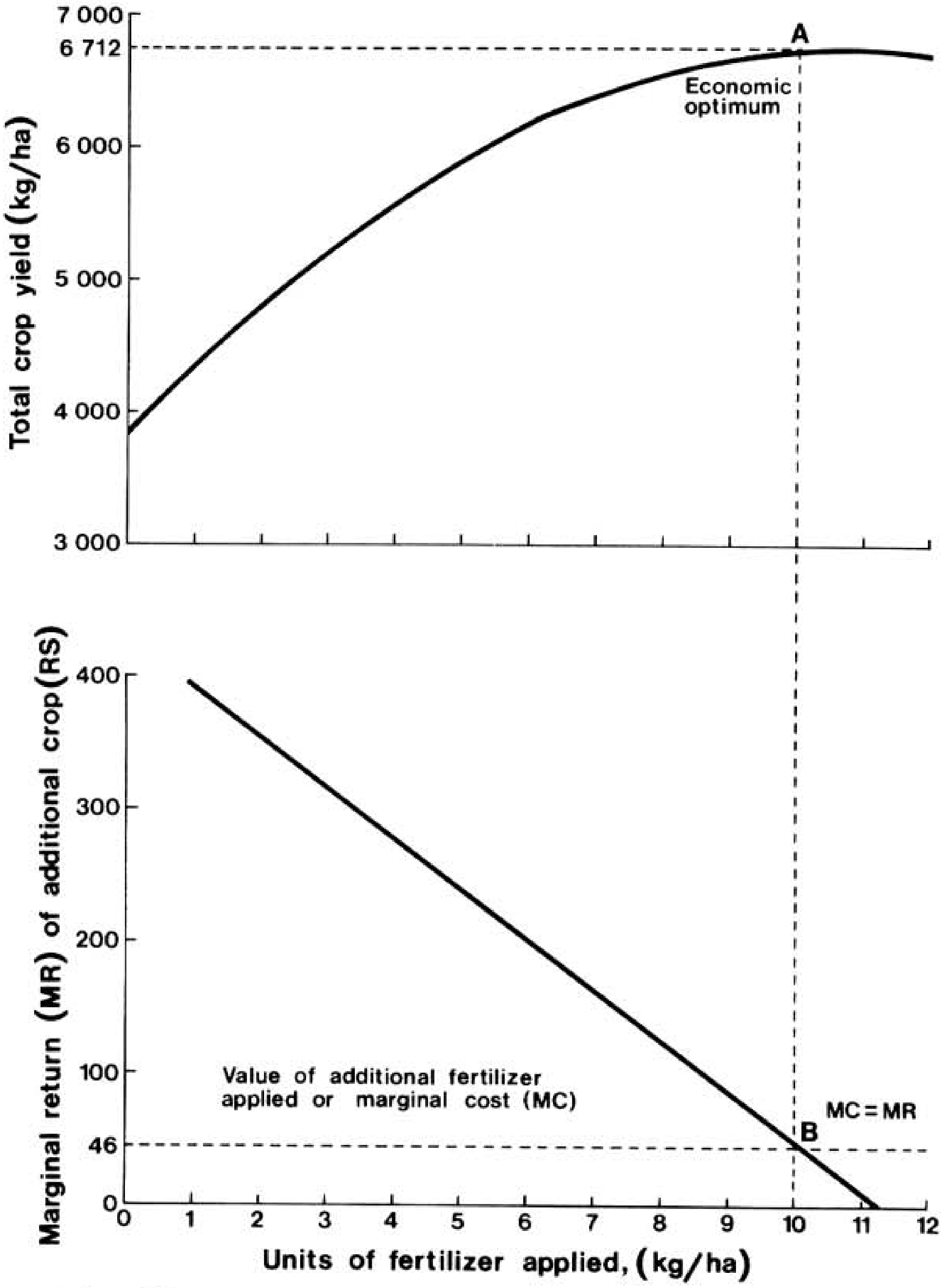


Fig. 36 Crop response and profit relationship

Note: RS = Rupees, RS 10.50 = US$ 1 (approx)

Generally, farmers with sufficient resources use fertilizer rates which are at or near the optimum economic return per unit of land. At this point, an additional unit of fertilizer produces 61 kg of additional crop worth an additional Rs 46 which just equals the value of the additional fertilizer applied.

On the other hand, the rates of fertilizer application of interest to small-scale farmers with limited resources, who are concerned with the economic return on the money they spend on fertilizers, are those on the steeper part of the response curve, where the value-cost ratios (VCRs), the concept to be discussed later, are higher.

18.4 NET RETURN AND VALUE-COST RATIO

It is natural for the farmer to compare the expected value of the additional crop yield obtained by the application of fertilizers with the cost of the fertilizers that brought about the increased yield. The additional value is obtained by multiplying the additional amount of crop expected to be harvested by the prevailing unit price of the crop. On the other hand, the cost of fertilizer is derived by multiplying the amount of fertilizer applied by the unit price paid by the farmer. The difference between the added value of the crop and the cost of fertilizer is known as the "Net Return".

The profitability of fertilizer use can also be determined by using an indicator called "Value-Cost Ratio" (VCR) - the quotient obtained by dividing the expected value of the yield increase by the cost of the fertilizer applied.

The profitability indicators may be computed as follows:

$$\text{Net Return} = (C \times P_1) - (F \times P_2)$$

$$\text{Value-Cost Ratio} = \frac{(C \times P_2)}{(F \times P_2)}$$

where: C = number of units of additional yield attributed to fertilizer application

P_1 = unit price of crop

F = number of units of fertilizers applied

P_2 = unit price of fertilizer

$(C \times P_1)$ = total value of additional crop yield attributed to fertilizers applied

$(F \times P_2)$ = total cost of fertilizers applied

Results of fertilizer trials-cum-demonstrations usually do not permit the calculation of the response curve to the different nutrients owing to the design used. Nevertheless, if the range of treatments is great enough, the net return and value-cost ratio (VCR) can be determined. The example given in Table 27 based on FAO Fertilizer Programme data illustrates this.

From the example, the lowest N, P_2O_5, K_2O treatment (40-40-40) gave the highest response and net return with a good VCR. On the other hand, the highest N, P_2O_5, K_2O treatment (80-80-80) gave the least response and economic return. The highest VCR was obtained from the 40-0-0 treatment and its economic return was only slightly less than from the 40-40-0 treatment. Assuming these results to be economically representative, the 40-40-40 treatment could be recommended for use by the better-off farmers and the 40-0-0 treatment by those with limited resources to purchase fertilizers.

Table 27 EXAMPLE OF NET RETURN AND VALUE-COST RATIO DETERMINATION FROM TRIAL-CUM-DEMONSTRATION RESULTS

Treatment $N-P_2O_5-K_2O$ (kg/ha)	Yield increase kg/ha	%	Gross Return ($/ha)	Cost of fertilizers ($/ha)	Net Return ($/ha)	VCR
Control	3 000	-	-	-	-	-
40-0-0	890	29	122.82	16.80	106	7.3
40-40-0	1 090	36	150.42	30.30	120	5.0
40-40-40	1 455	49	200.79	47.10	154	4.3
80-80-80	910	30	125.58	94.20	31	1.3

The decision of the farmer to use fertilizer based on the VCR level depends on his own standard of profitability. However, the general rule of thumb is that a VCR of at least 2, i.e. a return above the cost of fertilizer treatment of at least 100 percent would be attractive to the farmer. The net return, however, should also be considered because at low application rates of fertilizers, the VCR may be 2 or more owing to the small cost of the treatment, but the net return would also be small and unattractive to the farmer. In addition, other factors should also be taken into account, including the likelihood of the expected yield being obtained, an assured market for the crop and the assured availability of the fertilizers to the farmer.

Farmers usually use less than the recommended fertilizer rates because of a number of factors. These include the anticipated yield increase, expected crop prices, cost and availability of fertilizers, level of financial resources and credit availability, land tenure considerations, the degree of risk and uncertainty and the farmers' ability to bear them. It is, therefore, natural for the farmer to be cautious and build in a fair safety margin when deciding the level of fertilizer to apply, taking into account the factors enumerated.

19. FERTILIZER SUPPLY, DISTRIBUTION AND CREDIT

In the preceding chapter it was noted that the economics of fertilizer use is greatly modified by changes in the external circumstances. In particular, any deterioration in the marketing infrastructure or emergence of transport bottlenecks can be expected to discourage higher levels of fertilizer consumption.

The use of fertilizer by the farmer is largely contingent upon its timely availability in adequate quantities. Any interruption in the smooth flow of this vital input from factories or ports to farmers' fields is bound to have an adverse effect on fertilizer use. Distribution, therefore, must be geared towards ensuring an uninterrupted and timely supply of fertilizers to the end users. Credit is another integral component of the whole package of fertilizer supply arrangements. Adequate availability of finance is an essential for the efficient passage of fertilizer through the distribution channels to the farmer.

In describing the fertilizer supply system in totality, it is necessary to discuss a whole range of interrelated aspects including procurement, logistics of distribution, distribution channels, quality control, credit and government policy. It is necessary to analyse these operations simultaneously to ensure a comprehensive understanding of the whole system. Underlying and interrelating with the requirements for the distribution system are the constraints under which the fertilizer production and consumption activities operate.

19.1 PRODUCTION AND CONSUMPTION DISCREPANCIES

There are two fundamental factors common to most countries, especially the developing countries. First, fertilizer factories are generally located near the sources of raw material, supplies of energy and transport facilities such as ports, rivers and railways. In many cases, fertilizer plants are situated far away from the main fertilizer consumption areas which are usually very widely dispersed throughout the country. For instance in a developing country of the size of India, there are millions of farmers spread widely throughout the length and breadth of the country mostly requiring fertilizers in small quantities. Fertilizer produced in the factories has, therefore, to be moved over long distances before reaching the ultimate consumer.

Secondly, seasonality of demand for fertilizer has a fundamental effect on the whole distribution system. Whereas fertilizer production takes place throughout the year, its consumption is concentrated in peak seasons which may last for a few weeks only. This imbalance between demand and supply necessitates storage of fertilizers on a more or less continuous basis.

Regardless of these geographical and temporal imbalances, the fertilizer has in any event to be procured, stored, transported and distributed. These operations and their interdependence are discussed in the following sections.

19.2 PROCUREMENT

Procurement constitutes the first step in the entire fertilizer distribution chain. The level of reliance on imports depends on the amount of domestic production capability, which may be small, or may be sufficient for national consumption.

Importation may be by government, a government agency, an association or an individual. Theoretically, a centralized agency as a bulk buyer is favourably placed to obtain better terms. Whatever the system, appropriate arrangements have to be made to procure fertilizers from the most economic sources of supply.

Once the fertilizer material is available either through imports or from domestic production it is first likely to be stored in either factory stores or a port or field warehouse. The emphasis in the developing countries should always be to move as much fertilizer as possible to the field warehouses as soon as possible, away from factory stores and ports. This enables optimum utilization to be made of limited transportation capability. No transportation system, particularly in developing countries, is geared to supplying the whole peak season requirement during the actual peak season.

A variety of patterns prevails for movement of fertilizer to the ultimate consumer. Figure 37 illustrates the pattern of flow of material from factories and ports to the farmer in most of the developing countries. Whereas domestic production may be handled only by manufacturers and established channels of distribution, the imports may in addition be handled by specialized government agencies.

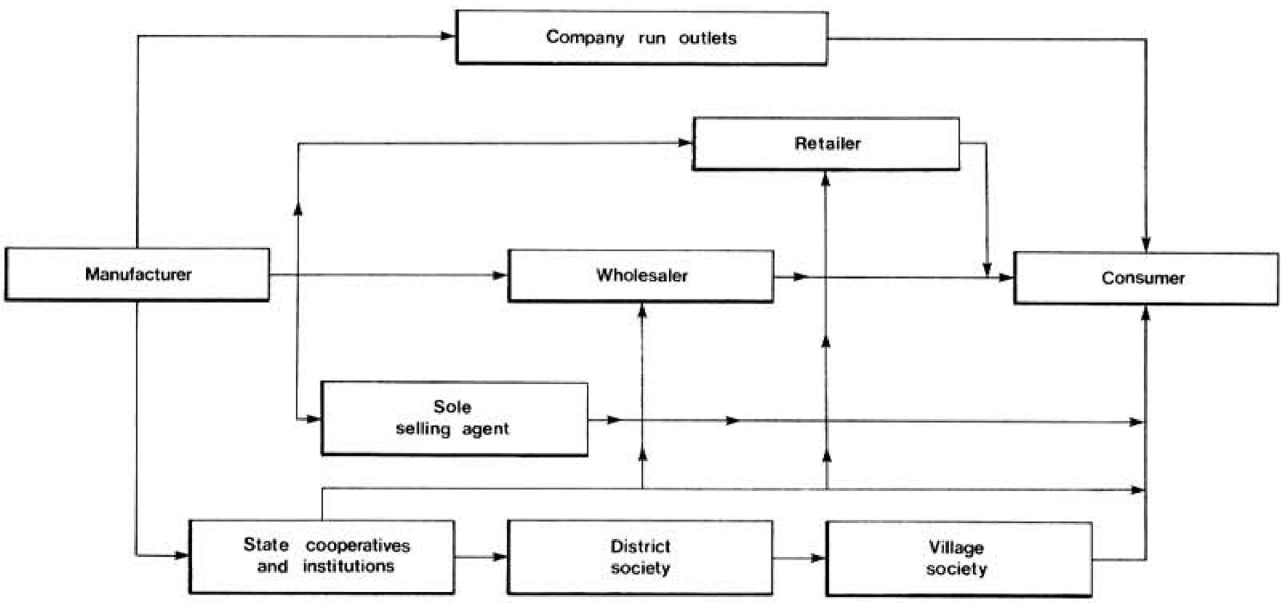


Fig. 37 Marketing channels

19.3 DISTRIBUTION CHANNELS

The main channels of distribution in developing countries are: cooperatives, private traders and state boards or other public sector agricultural agencies.

Most of the distribution is, however, handled by cooperatives and the private sector, which in India, for example, have an approximately equal share in the distribution of 16 million tonnes of fertilizer. In many developing countries the role of the private trade is minimal. It may be relevant to mention here that the phenomenal increase in fertilizer use in India over the years is in no small measure due to the multichannel approach in fertilizer distribution.

19.4 LOGISTICS OF DISTRIBUTION

The logistics of fertilizer distribution cover a very broad and comprehensive range of operations including packaging, transport, storage, handling and general administration. In a large number of developing countries, these account for as much as 25 to 35 percent of the retail price of the product. The distribution costs assume special significance in view of the rising cost of fertilizers, whether imported or domestic production, and the need to sell it at as low a price as possible to the farmer. Measures aimed at reducing distribution costs are of high priority. It is, therefore, most essential to have a clear perception of the manner in which various components contribute to the total distribution cost.

The nature of the existing transport and storage infrastructure broadly determines the total cost, which is modified by the nature of marketing arrangements. It is very difficult to improve upon and reduce costs in the existing infrastructural facilities in the short-run. Nevertheless, cost reductions can certainly be achieved by choosing an efficient marketing system, and this is where the developing countries have enormous potential for effecting improvements in the overall fertilizer supply system.

19.5 TRANSPORTATION

Given the large distances between the location of factories and the farmers' fields, movement of fertilizer is naturally of great importance. Transport is an important cost item amounting in many developing countries to between one quarter and one half of the total marketing cost, or 10 to 20 percent of the retail price of fertilizer. It is therefore imperative to select the optimum mode of transport. The question relates not only to the choice between available alternative means of transport such as rail, road and water, but equally to the manner in which the most efficient utilization of a particular transport method can be achieved. The latter is particularly important in situations where rail or road infrastructures are not fully developed and the existing resource constraint prevents expansion of these facilities on any significant scale.

A full comparative evaluation of rail versus road transport is not necessary here but there is no ambiguity concerning the fact that road transport is very often more expensive than rail. This follows clearly from the inherent advantages of the economies of scale in rail transport and the sliding scale of freight tariffs. Movement by road is generally preferred for relatively short distances, because (i) the difference in road and rail freight is not substantial; (ii) transit loss is minimal; (iii) road transport avoids intermediate handlings at railway stations. Road transport takes the material direct to the dealer or the farmer.

The pattern of movement of fertilizer by various means of transport differs widely between developing countries. For example in India, Bangladesh and Korea from 75 to 80 percent of the fertilizer is moved by rail, and in many other countries transportation by truck has a predominant role. As mentioned earlier, there is often considerable scope for optimizing utilization of the existing capability. The rationalization includes the following components:

i. in the case of rail transport, movement of material by single destination full train loads rather than piecemeal movement;

ii. avoidance of criss-cross movement of the same material;

iii. avoidance of transhipment points when moving by rail;

iv. arranging return use of rail transport - fertilizer one way, foodgrains the other.

Productivity can also be improved through operational efficiency, better management control and closer monitoring of the system.

19.6 STORAGE

The continuity of the fertilizer production process contrasted with the seasonality of demand make regional and district storage essential to avoid strain on the transport system. Storage can be on farm, by dealers or where large quantities are involved by manufacturers. There is a need for good storage, to keep the material in good condition, and specialized agencies have therefore developed to carry out this function. These agencies may be in the public or private sector. Manufacturers sometimes tend to depend more and more on these specialized agencies who in addition to storing the material render, at a cost, the service of receiving the material through rail and road transport and also despatching the material to different destinations according to the despatch plans of the manufacturers. Most frequently these specialized agencies warehouse a variety of products besides fertilizers. Cooperatives in India have undertaken a massive programme of field warehouse establishment, as far as village level. Farmers and retail outlets have hardly any specialized storage capacity.

In practice, a great variety of warehouses owned by different agencies are made use of to store fertilizer material, the overall objective being to ensure timely availability of the material nearer to the point of consumption.

19.7 FERTILIZER QUALITY CONTROL

Best results are obtained from the application of fertilizer only when it has the requisite chemical composition and acceptable physical characteristics in terms of product shape, size, crushing strength, moisture content and storage characteristics. Any deviation from these standard norms will jeopardize realization of the potential increase in yield levels from fertilizer use. In extreme cases, if fertilizer is adulterated or deviation from the norm is substantial, application of this potentially beneficial input may even lead to deterioration in the crop or in soil conditions. Availability of fertilizers of the right quality is, therefore, as vital as its timely and uninterrupted movement.

In a number of countries of the developing world, small farmers with marginal holdings of land predominate, not only in terms of number, but also in their share of total agricultural output. Given the overall resource limitation of farmers and their lack of knowledge relating to the quality of fertilizer bought, it becomes absolutely essential to have some sort of regulatory system through which quality of fertilizers can be fully guaranteed. Once substandard fertilizer has been applied, the damage is done.

The need to enforce a system of quality control is found not only at manufacturer level, but also throughout the fertilizer distribution chain.

As discussed earlier, transport, storage and handling are essential components of the overall fertilizer supply operation and there is every possibility of deterioration in the quality of fertilizers if adequate care is not taken at all stages. Unsuitable handling may lead to loss of important physical and chemical caracteristics. There is also, in the absence of regulatory machinery, the risk of adulteration.

This monitoring system takes the shape in many countries of comprehensive legislation backed up by a suitable administrative infrastructure. The regulations prescribe certain standards with regard to both physical and chemical properties of fertilizer including specification of minimum tolerance limits in departures from declared nutrient content. All those operating in the field of fertilizer production and distribution must adhere to these standards. Any infringement of the regulations invites punitive action, the nature and extent of which is prescribed by law.

Almost all the developed countries of the world have comprehensive legislation on fertilizer quality control, but many developing countries have yet to make a significant advance in providing an effective surveillance system. The need to enact legislation controlling fertilizer quality is being increasingly felt because of the unprecedented increase in fertilizer consumption in most of the developing countries. It is, therefore, quite reasonable to expect that more and more countries of the developing world will have systems monitoring fertilizer control in the near future.

An effective quality control system requires the setting up of quality control laboratories to provide regular checks on the quality of the material at different levels. Manufacturers invariably have such laboratories in their manufacturing units and a system exists for checking nutrient content and other aspects of quality at regular intervals. There is, therefore, little scope for fertilizer to be below standard up to the time it leaves the factory. Problems may, however, arise during the movement of the material from the factory to the farmer. The industry (including distributors) as well as the state provincial authorities have the responsibility of ensuring quality control right up to the time the material reaches the farmer. Random checks are therefore essential.

Fertilizers are stored for long periods, and have a long storage life if kept under ideal conditions. However, conditions are frequently far from ideal. While every effort is needed to maintain good storage conditions and to use fertilizer before any deterioration takes place, it is also desirable to establish a procedure for returning any that has deteriorated to the factory for reprocessing.

19.8 DISTRIBUTION MARGIN

Fertilizer marketing in many of the developing countries is not competitive but is largely a government controlled and operated business. The private trade has a very limited role to play in such countries.

The distribution margin is the cost of all the functions involved in transferring fertilizer from place of manufacture to point of use. The components as well as the actual costs vary widely in different developing countries. Basically, the distribution margin has to cover wholesale and retail components of the following functions, from factory gate or port of entry to farm: transport; storage; blending or packaging (if needed); handling; losses (product wastage); selling and promotion; finance.

In countries where the maximum selling price to the farmer is controlled, the level of distribution margin is also fixed by the government. As a matter of principle, fertilizer business should provide of the developing countries. This discrepancy still persists in spite of substantial growth in the volume of credit extended by governments. For short term production loans, which also include loans for fertilizer purchase, the share of cooperatives is found to be quite significant in many developing countries. However, their share has tended to fall in recent years.

There is a growing realization in many developing countries that the effectiveness of credit could be enhanced by augmenting the flow of money through agencies maintaining close links with the ultimate consumers, i.e. with farmers. This clearly suggests the importance of distribution credit. If the resource position of the dealer is improved by giving him greater loans on favourable terms he in turn is able to assist the farmer. The dealer is in a better position than most to assess a farmer's requirements for credit and can also more readily bring about an improvement in the overall loan recovery rate. It may be noted that, in many cases, viability of the institutional credit system is much undermined by the large volume of outstanding debts. A variety of factors is responsible for this problem, but the most important of these is outside interference in the functioning of the institutions.

A variety of experiments have been made in different developing countries on the disbursement of credit, with varying results. An experiment which has been carried out with considerable success in Inia is given as an example. The credit requirement of the farmer is worked out by crop and season and is allowed to stand for a period of two or three years - unless there are violent changes in his cropping pattern or in fertilizer prices. The participating farmer is provided with a passbook containing all the details of his title to the land, cropping pattern, and credit requirement. It also includes his photograph. The farmer is also provided with a cheque book with a limited amount of cheques capable of encashment in different seasons. The farmer simply needs to present a cheque to the identified fertilizer depot to obtain in return the corresponding quantity of fertilizer. The credit supplied is endorsed in the passbook so that he is not able to claim credit from any other institution. The farmer is satisfied because he is able to get his requirement of fertilizers whenever he wants. He takes care not to lose this particular cheque facility by repaying loans at the due time.

An arrangement that can result in great improvement in efficiency of credit utilization links fertilizer distribution with the marketing of the farmer's produce. Currently, credit in most of the developing countries is provided by various types of government-financed agricultural banks and cooperatives which are separated from fertilizer distribution agencies. So long as the two functions are performed in isolation the problems of non-return of outstanding dues and efficient utilization of credit in general are likely to remain.

In some countries, however, government-sponsored bodies do take the responsibility of ensuring proper coordination of the credit disbursement and fertilizer distribution functions. In the Republic of Korea such an integration is accomplished through an agency called the National Agricultural Cooperative Federation, which is solely responsible for fertilizer and pesticide distribution, agricultural credit disbursement and marketing of agricultural products. In Thailand, the linkage is being established under the Marketing Organisation for Farmers and Agricultural Cooperative Federation of Thailand. In India, the Food Corporation of India handles imported fertilizers besides conducting its normal food procurement operations. Lately, there has been some useful progress on the need to co-ordinate disbursement and food procurement operations on a much wider scale.

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19.10 PRICING POLICIES AND SUBSIDIES

The expected increase in fertilizer consumption in developing countries will only materialize if the input/output price relationship is favourable to farmers. The cost of fertilizer production has, for a variety of reasons, been rising in developing countries over the years. If fertilizers are sold to the farmer at prices determined on a costplus basis, then it is very unlikely that the farmer will be willing to use fertilizers. The available evidence clearly demonstrates that the profitability of fertilizer use has a direct bearing on fertilizer consumption.

From the analysis of the economics of fertilizer use and particularly the value-cost ratio, it is obvious that fertilizer needs to be made available to the farmer at prices which, in a number of cases, must be considerably lower than its ex-factory cost. This essentially amounts to subsidizing the farmer to the extent of the difference. Prices and subsidies are interrelated questions and assume special significance in government-controlled economies. The selling prices of fertilizers in these economies are generally statutorily controlled and are fixed after carefully assessing the amount the farmer can afford to pay. Prices are, therefore, only need-based and have no relation to the free market price. The manufacturers or suppliers in such situations are directed to sell fertilizers at controlled maximum selling prices and are in turn compensated by government in accordance with set formulae. This compensation may in some ways seem to be a subsidy to fertilizer manufacturers, but in fact it is a subsidy to the farmer.

The system outlined above operates in most of the developing countries of South Asia including Pakistan, Sri Lanka, Bangladesh and India. India provides a classic example of the manner in which the system works. The recently constituted Fertilizer Industry Coordination Committee (FICC), a price administering body at the national level, fixes the so-called 'retention' price for individual manufacturers. The retention price seeks to ensure a return of 12 percent on net worth to the manufacturer at 80 percent capacity utilization and under stringent norms of consumption of raw materials and utilities. If the retention price per unit is higher than the statutorily fixed maximum selling price, the difference is reimbursed to the manufacturers by government, and *vice versa*. The Ministry of Chemicals and Fertilizers operates a Fertilizer Price Fund Account which carries the responsibility for all such subsidization operations.

Given the existing unprofitability of fertilizer use at free market prices and the high cost of producing fertilizers in developing countries, subsidies on fertilizers seem unavoidable. The value of the subsidy continues to grow with the increase in the volume of consumption, and of course also increases with any increase in the cost of production. At the same time, the need for increased use of fertilizers, even though they are subsidized, to augment a country's own foodgrain production rather than depend on imports has been universally appreciated. A situation of excessive foodgrain imports cannot be allowed to continue for long since it puts an enormous burden on the national exchequer.

In view of the mounting burden of foodgrain and fertilizer subsidies and the extremely vulnerable resource position of many developing countries, their governments have taken serious steps to arrest further growth in the cost of subsidies. These include not only introduction of cost-reducing technolgical and other innovations but also cover measures aimed at improving efficiency of fertilizer use. In some countries, such as India and Pakistan, increases in the selling prices of fertilizers have also been resorted to as a short term paliative.

19.11 FAO PILOT SCHEMES ON DISTRIBUTION AND CREDIT

The experience gained during 23 years of implementing the FAO Fertilizer Programme in the field of development of fertilizer use, under varying local farming conditions in more than 50 developing countries, has demonstrated not only the ways to increase yields due to the rational use of fertilizers, but also the obstacles at national, regional and individual level to such utilization. At farmers' level these are, among others: absence of improved agricultural techniques; weakness of extension services; limited availability of credit; inadequacy of storage and distribution facilities; and short supplies of fertilizers; and constraints in the marketing of agricultural products.

Once the demand for fertilizer and related inputs has been created in a given area or region, these inputs must be made available for farmers in sufficient quantities, at the right time and place. There are usually difficulties in finding and appointing a reliable distributor in a place where the use of fertilizers has only recently been developed, and where their total consumption is small to begin with. This distributor has to be prepared to supply farmers, often in remote places, with small quantities, perhaps on credit, drawing on his own resources, which are themselves limited. These conditions mean that distributors have no desire to engage in such an enterprise.

Distribution at farm level may be undertaken by the traditional village retailers. However, these local dealers have no experience with fertilizers and they need to be taught how to make a trade out of them, and to be provided with adequate agricultural information on their use, so that they are in a position to advise their farmer clients properly. The financial resources of these local traders are limited and, if they are to add fertilizers to their already existing range of products, they need sufficient credit to cover purchase from the wholesaler, transport and storage of these fertilizers. But the farmers' resources are also very limited. In many cases they are unable to purchase even a tiny quantity of fertilizer. This is why access to credit for the farmers is a crucial point in the development of the use of fertilizers and, consequently, in increased crop production and farm income.

In many developing countries, although there are various sources of credit available such as local money-lenders, retailers, various kinds of banks, marketing offices and agricultural development organizations, the terms are often very unfavourable. Sometimes there are no local representatives of the credit institutions, or the necessary steps to obtain credit are too complicated and take too long for the small farmer, who needs this credit before sowing time. And even when these sources of credit are apparently all available, it is possible that the majority of small peasant farmers do not have access to them for lack of a land title or other valid guarantee. The FAO Fertilizer Programme, with the aid of its pilot schemes for the distribution of fertilizers on credit for small-scale farmers, is endeavouring to find solutions to the different problems of distribution and credit.

The finances to implement these schemes generally come from the International Fertilizer Supply Scheme (IFS) and grants from bilateral assistance channels.

The schemes include credit in kind for a given crop covering limited areas on the basis of a revolving fund; the marketing of fertilizers by an official organization; the management of the fund by a public institution; and the assistance of the extension service and other related organizations associated with the scheme.

The scheme is aimed at the establishment of improved marketing and credit facilities for fertilizer procurement and is based on the establishment of self-managed groups of farmers at village level.

The success of a pilot scheme with a village group depends:

i. for the extension service, on the contact with the group to build up and ensure the most efficient use of the fertilizers;

ii. for the distribution system, on timely delivery, not after sowings, of inputs, right to the central site of the group;

iii. for the credit system, on the formalities of granting and repaying credit being reduced to the minimum and taking place, at least to begin with, in the relevant villages themselves (for example, through a mobile bank);

iv. for the group itself, on preparation of fertilizer orders several months before they are needed, and a determined will to repay, with elimination of bad payers.

The Fertilizer Programme assumes the coordinating role.

To give illustrations of a few success stories, in Upper Volta, the introduction of pilot schemes for the distribution of fertilizer on credit has led to the establishment of an agricultural credit system, which is in closer contact with the farmer. The success of a similar scheme in Zaire has prompted the World Bank to take over the infrastructure created by the project in eastern Kasai and incorporate it in a project for intensification of maize production. In Tanzania, where inadequate availability and lack of advisory and credit facilities has been identified as a major constraint to increased fertilizer consumption, the FAO pilot distribution and credit activities since 1978 have provided about 2000 tonnes of fertilizer for 3000 farmers. The repayment rate during 1981-82 is reported to have exceeded 90 percent, thus giving the pilot scheme a sound basis for expansion.

In addition to direct involvement in improving the profitable use and the distribution of fertilizers at all levels, the FAO Fertilizer Programme also contributes by organizing meetings, seminars and preparing documents.

20. FERTILIZER PROMOTION

20.1 PROMOTIONAL OBJECTIVES

Fertilizer promotion is an important aspect of any fertilizer marketing activity. It motivates and stimulates customer buying, increases trading effectiveness and provides short and long term benefits to supplier and farmer. The essence of the marketing approach is that the customer, in this case the farmer, becomes the pivot around which the entire operation of a business revolves. Customer satisfaction becomes an all-important goal of the business enterprise. The fertilizer industry is well aware of the fact that merely making fertilizer available to the farmer, though important, is not enough to increase fertilizer use. It is equally important to convince him of the effectiveness of fertilizers and of their economic value in helping him to make farming into a profitable venture and not merely a means of subsistence. With this end in view, the world fertilizer industry has been playing a vital role in propagating the scientific use of fertilizers and the other inputs required for higher crop production.

Fertilizer promotion broadly falls into two parts. The first is primary promotion, aimed at creating basic awareness among farmers about the need to use fertilizers and other improved farm practices in order to obtain higher yields of good quality produce. The basic responsibility for this is with the government and its various agencies, including the agricultural departments and extension wings of agricultural universities. National organizations such as the fertilizer industry associations and institutes in many countries also assist in this basic promotional effort through their publication services and training programmes, and by collection, analysis and interpretation of data. They sometimes participate directly in area development programmes. The second aspect of fertilizer promotion is undertaken by the fertilizer manufacturers or suppliers and is more concerned with popularizing the product or products of individual suppliers.

Both these aspects of fertilizer promotion have the common objective of persuading farmers to adopt scientific farming methods and have, therefore, to be based on persuasive communication. For this purpose, the message has to be designed clearly and in the best possible manner and steps are required to ensure that the message is properly received by the recipient.

20.1.1 Promotional Methods

In promoting fertilizer use and shaping an effective promotional framework it is necessary to take into account farmers' psychology, their educational status, financial position and receptivity. In the developing countries, where the educational level of cultivators is low, their outlook is limited and the general level of farming practices is still traditional, a different approach to promotion is necessary to that in developed countries, where literacy is high, farm holdings are large, farming practices are highly sophisticated and financial investment is readily available.

The various approaches to promotion of fertilizers can be broadly classifed as advertising, publicity and public relations, personal selling and sales promotion. All these should be covered in varying degrees in a promotional programme designed to convey the total message to the target audience. The emphasis will vary from area to area.

The media available for fertilizer promotion are very numerous. They include demonstrations, field days and fertilizer festivals, farmer meetings, puppet shows, exhibitions, farm advisory and information services, films, filmstrips and slides, the press, cinema advertising, radio programmes and advertising, television, literature services of various natures, outdoor displays such as boardings, wall paintings, display at dealers' premises, and training programmes for farmers and suppliers.

It is also possible to categorize the various approaches as primary or secondary promotion. In the category of primary promotion, generally undertaken by state agencies, is included technical advice, area development programmes or pilot schemes, farmers' meetings, and training programmes. In the secondary category, more associated with individual products, are demonstrations, personal selling, field days and festivals, advertising, audio-visual methods and display outside and on dealers' premises.

In most cases, an appropriate media mix is adopted to suit local conditions depending on effectiveness, cost involved and practicalities.

20.1.2 Fertilizer Demonstrations

Farmers in all countries quickly accept what they see and are much more impressed with the display of a package of practices under their own farm conditions than with remote results from laboratories or experimental farms. Demonstration of fertilizer use has been perhaps the most popular and effective method of convincing farmers that they should adopt improved crop production technology. In areas where the educational level of farmers is poor and their outlook is limited, demonstrations carry much more weight than any other promotional media.

In conducting successful demonstrations there are certain essential steps. These are: (i) selection of a suitable farmer; (ii) correct location of the demonstration plot; (iii) active involvement of and proper technical guidance to the farmer; (iv) active participation of local agents; (v) adoption of the required package of inputs and methods rather than a single input; (vi) appropriate publicity before and after laying down the demonstration.

The chosen farmer should invariably be a prominent and well-liked person of integrity in the area and in good relation with the local extension officer. He can be encouraged to participate by the benefits that will accrue to him from adopting the new methods and inputs. He should have a farm which is representative of the area and has reasonably fertile land and, if needed, good water availability. The location of the demonstration field should be as near to the main road or approach road to the village as possible so that it is easy to organize field days around it. After establishment of the demonstration, it is necessary to keep in close touch to ensure that the package of practices is followed.

20.1.3 Meetings and Field Days

The field days and meetings associated with the demonstration should be planned as a coherent programme at or before the start of the cropping season. Visits to the site by groups of farmers should take place when the crop is well advanced and can be seen to best advantage, and can also coincide with harvesting the crop so that the benefit in terms of yield and quality can be seen. Follow-up meetings can be held in a local meeting room where the results of the demonstration can be given on charts or by other visual methods. Meetings should take place at a time when farmers are free to attend and should be conducted simply and in language that they can understand.

20.1.4 Fertilizer Dealers

The fertilizer dealer is a vital link between the manufacturer, supplier and farmer. He is generally the person in closest contact with the farmer. He belongs to the area, has a close association with the farmer and his family and is familiar with the surroundings. The farmer trusts him, accepts him as a guide and friend. His business contact with the community can prove to be of special advantage in acting as an agent of change, accelerating the adoption of new technology. Considerable emphasis is now being laid on the training of dealers on a group basis by the fertilizer industry itself. The dealer training programmes include discussions on product knowledge, relative merits and de-merits of different fertilizers, soils of the area, salient features of the package of practices recommended for crop production locally, operation of legislation and controls, accounting, and availability of soil or seed testing facilities. A brief idea about the complementaty role of crop varieties and agrochemicals in enhancing crop yields is also given. Guidance in business skills can be particularly important. The intention of this programme is not to make the dealer act as an agronomist but to inculcate in him the attitude of rendering service to the farming community by way of guidance additional to his activity in selling his products. Training of this nature helps in broadening the outlook of dealers and also in improving their relationship with farmers.

20.1.5 Promotional Innovation

The methods of promotion used are constantly changing and improving as agronomic information becomes available and as experience and new initiatives lead to the development and adoption of methods better suited to local conditions.

An important basis for improved promotional methods has resulted from the coordination of strategy between the main agencies involved - the fertilizer industry, the commercial banks, government agricultural departments and the universities and research institutions. As a result of the professional approach of these organizations, assessments and surveys have been made of the effectiveness of different promotional methods, so that the most rewarding combination of media can be deployed according to local circumstances.

The development of agronomic research and the accumulation of information on fertilizer requirements and associated improvements in inputs and cultural techniques have enabled much more detailed advice to be given and provided a sound and broad technical basis for the marketing programmes of the fertilizer suppliers. To be effective in the longer term, marketing programmes should emphasize not only the best way to use fertilizers but also how to combine their use with the overall package of improved varieties, pest and disease control, effective water management and other cultural practices.

The introduction of high yielding varieties had considerable impact on the promotional methods used. A useful innovation in some countries has been that of the village adoption programme, which sets out to plan the development of a village systematically over a period of a number of years. The aim is to increase fertilizer use and to introduce the overall package of improved inputs and techniques and ways of conserving and utilizing natural resources. These villages can also be used as focal points for promotion of improved methods among farmers from the surrounding area.

20.2 FAO FERTILIZER PROGRAMME

The FAO Fertilizer Programme was initiated in 1961 with the following broad objectives:

i. to increase food supplies, supply of the feed for animal production and farmers' income generally;

ii. to assist to develop national programmes of fertilizer use and production;

iii. to assist in disseminating effectively information on fertilizer requirements and use; and

iv. to develop guidelines regarding fertilizer in foreign aid programmes.

20.2.1 Mode of Functioning

Like other FAO projects, the Fertilizer Programme is organized on the basis of fullest cooperation with and by the countries that agree to take part in it. This means that all of the fertilizer demonstrations and trials are established on the fields of ordinary farmers, by field staff of the Ministry of Agriculture in each country. The supervisory staff are also Ministry officials. The function of the specialist appointed by FAO is to act as an adviser on technical matters, working through a counterpart officer appointed by the Ministry. In actual practice the FAO specialist usually takes a more active part because of his great experience in fertilizer and field work.

20.2.2 Field Programme

The Field Programme constitutes the core of the Fertilizer Programme. The objective of the field programme is to indicate fertilizer requirements for major soils and crops and to increase rapidly the use of fertilizer. In order to achieve this goal, very extensive fertilizer demonstrations, fertilizer trials and soil testing programmes have been employed. The Field Programme aims to carry out very large numbers of fertilizer demonstrations with two to four plots each on the fields of ordinary farmers. It also aims to conduct a number of simple field trials with six to ten plots each, also on farmers' fields, in order to get more information about fertilizer responses and nutrient deficiencies of local soils. Farmers' field days are held in order to make sure that the results of the demonstrations are understood and appreciated.

In addition, training courses in fertilizer field work and the use of fertilizers are provided by the FAO specialists for the benefit of the government officials taking part in the Programme. Regional fertilizer meetings are organized by FAO in which the governments of the region participate. In addition, close informal contact and cooperation is maintained with other agricultural development work in each country.

By now FAO Fertilizer Programmes have carried out thousands of demonstrations and field trials in a large number of the developing countries of the world. The Programme is also promoting fertilizer use on a world scale through publication of numerous Technical Bulletins on fertilizer use, crops and soils, and related subjects.

20.2.3 Recent Developments

The FAO Fertilizer Programme aims to increase agricultural production through the efficient use of mineral fertilizers and other inputs and by improved crop production techniques. In view, however, of the present energy crisis, emphasis is being given to the use of alternatives, such as renewable sources of plant nutrients, to complement mineral fertilizers and enhance their efficiency of use, within the framework of Integrated Plant Nutrition Systems (IPNS).

The FAO Fertilizer Programme is oriented to carry out on-farm adaptive trials of the proven technologies from the research institutes and subsequently to demonstrate the viable technologies to small farmers. Only those components which are within the reach of small farmers need to be integrated initially. Other developments in production techniques that need extra facilities can subsequently be included in the project activities.

A simplified broad outline on IPNS suited to various economic and agro-ecological situations for inclusion in FAO Fertilizer Programme activities has been prepared and work has already been initiated in this direction in some developing countries.

21. FERTILIZER USE AND ENVIRONMENTAL QUALITY

Fertilizer has played a key role in achieving higher agricultural production in both the developed and developing countries. The increasing use of fertilizer has, however, recently caused some alarm concerning possible side effects in relation to environmental pollution. This is a very important subject and has to be considered carefully from different angles, including the fertilizer needs of modern agriculture, the relevant fertilizer-soil-plant interactions and the possible effects on the human environment.

An ever-growing world population requires increasing amounts of food, fodder, fibre and fuel, thereby putting more and more pressure on local agriculture to meet this demand. It has been well demonstrated in developing countries that the output of consumable nitrogen (i.e. the production of nitrogen in foods and feeds) is positively correlated with the total input of nitrogen. The total farm input of nitrogen includes: (i) fertilizer nitrogen; (ii) nitrogen fixed by soil micro-organisms; (iii) nitrogen in organic manure; (iv) nitrogen in precipitation and irrigation water. A higher output of nitrogen, however, also results in higher offtake of phosphorus, potassium and other plant nutrients, so that more phosphorus and potassium in fertilizers and organic manures have to accompany the increased input of nitrogen. Of the different components of input, fertilizer use is being increased because its use alone can quickly and easily give higher agricultural production. No other sources of nitrogen, phosphate and potash are available in sufficient quantities to satisfy total world requirements for plant nutrients. Increasing use of fertilizer is, therefore, essential to satisfy worldwide demands for food.

Judicious use of fertilizer meets crop needs, but not all the nutrients applied are used by crops within one season; some of the fertilizer nutrient application remains in the soil. In the developed countries where fertilizer use has been common practice for many decades, questions are being asked about the side effects on the human environment of larger inputs of fertilizers.

Soil types vary from region to region, and climates and cropping differ between tropical, subtropical and temperate zones. Likewise, the effects of fertilizers on the soil and on the environment of these regions also differ.

21.1 SOIL AND CLIMATE

21.1.1 Tropical Soils

Tropical soils are generally low in organic matter and nutrient retention capacity. The texture of the soils is generally coarse and consequently percolation rates are higher leading to greater nutrient losses. Rainfall in the tropics is often too high or too low. High total rainfall with high intensity in a short period causes surface runoff as well as leaching, and heavy losses of soil and plant nutrients occur as a result. The uniformly high temperatures that prevail speed up the mineralization rate of soil organic matter and nitrification rate of applied ammoniacal N fertilizers, thus increasing the risk of nitrate being leached.

On the other hand, fertilizer use is very low in both low and high rainfall areas so that the pollution hazard through fertilizer use is only likely to be minimal. The potential problem of environmental pollution by fertilizer use is basically limited to areas with moderate rainfall and assured irrigation where fertilizer use is on the increase.

21.1.2 Temperate and Cold Climate Soils

Temperate and cold climate soils are relatively rich in organic matter and also have higher nutrient retention capacity. Organic matter is also better retained than in tropical soils. Rainfall is generally less intensive than in the tropics, so that runoff and leaching losses of soil and plant nutrients are less. Because of the lower temperatures, the mineralization rate of organic matter and nitrification rate of applied ammoniacal nitrogen fertilizers is also relatively low.

Fertilizer use in these areas has been practised continuously for a longer period than in the tropics, and application rates are higher. For these reasons the question of environmental pollution through fertilizer use in temperate and cold regions calls for more critical examination than in those tropical areas where fertilizer use is still at a very low level.

21.2 CROP AND CROPPING PATTERN

The major influence on the level of available nutrients, particularly nitrogen, present in the soil and at risk to various loss mechanisms at any one time is whether or not a growing crop is present. Crops take up nutrients rapidly, particularly under tropical conditions, and thus reduce soil nutrient levels. In the absence of a crop, soil nutrient levels can rise due to mineralization from soil organic matter and plant residues.

21.2.1 Tropical Crops

In high rainfall tropical areas with two or three crops a year, opportunity for nutrient loss affecting the environment is restricted, but can still occur when rainfall is excessive. Wetland rice occupies a large area of tropical soils but is a special case in that nitrogen is present in these soils predominantly in the ammonium form. Any nitrate loss will tend to be by gaseous routes, not by leaching.

Tree crops in the tropics maintain to some extent a closed cycle of nutrients, but losses are more likely when yield is increased by the introduction of fertilizer nutrients.

In regions with wet and dry seasons, loss of nutrients to the environment may occur because the soil wetting and drying cycles can enable nutrients to build up when the crop is not present or when its nutrient demands are small.

21.2.2 Temperate and Cold Climate Crops

In temperate and cold climates, actively growing arable crops, mainly wheat and other cereals, occupy the land area for only part of the year, so that the opportunity for loss of residual nutrients or nutrients mineralized from organic form is greater. Typically, excess rainfall causes nutrient (mainly nitrate) losses outside the growing season, while the evapotranspirational demand for water during active growth utilizes much or all of the rainfall. In arable cropping losses of nitrogen can be appreciable, but grassland and forestry carry a crop throughout the year and nutrient losses are small.

21.3 FERTILIZER USE

21.3.1 Tropical and Subtropical Zones

Fertilizer use in the tropics first began on plantation crops, and the introduction of high yielding varieties of cereals in the mid-sixties helped to extend it to these crops. The rate of fertilizer use on arable land in most of the tropical and subtropical countries is lower than the world average (78 kg/ha); it is much less than in some of the developed countries. There are also wide variations in fertilizer use within a particular country. For example, fertilizer consumption during 1981-82 in the major states of India ranged from 3 to 123 kg/ha. Crop productivity is directly related to fertilizer consumption. Egypt, with high fertilizer consumption produces very high crop yields, while in other countries, with moderate fertilizer use, productivity is at an intermediate level.

Even though high rainfall and high temperatures prevail in these areas, there is unlikely to be any environmental pollution problems concerned with fertilizer use because it is still at a relatively low level. The most recent research on the subject does not indicate any evidence that fertilizer has enriched groundwater beyond the limit prescribed by the World Health Organization. There is little likelihood of any future threat to environmental pollution by fertilizer use in these areas provided sound agronomic measures are followed when using fertilizers. In the limited areas in these regions where fertilizer use is relatively high, or likely to be increased, care should be taken to avoid situations developing which could result in environmental problems arising. This can be done by following the best agronomic advice available and also by monitoring the effects of intensification of cropping on environmental quality.

21.3.2 Temperate and Cold Climatic Zones

Fertilizer use in temperate zones and cold climatic zones is much higher than in the tropics and subtropics (Table 29). The average consumption in Europe is 139 kg/ha of nutrients over the whole agricultural area, and much higher in some countries and in particular on arable and intensive grass. The question of fertilizer use and environmental quality is more crucial in these areas of the world than in tropical areas where fertilizer use is still at a low level.

Table 29 FERTILIZER CONSUMPTION IN TEMPERATE AND COLD CLIMATIC ZONES, 1982

Country	Fertilizer consumption ($N + P_2O_5 + K_2O$ kg/ha of agricultural area)
Japan	367
Netherlands	317
Belgium	286
Norway	284
Korea (Republic of)	275
FR Germany	268
Czechoslovakia	255
Denmark	225
France	178
UK	139
Austria	96
USA	39
Europe (Average)	139

Source: FAO Fertilizer Yearbook, Vol. 33, 1983.

A higher nitrogen input in arable crops results in a higher consumable output (i.e. taken up in crop) of nitrogen, phosphorus and potassium. On average, consumable output of nitrogen ranges from 70 percent to 60 percent between the 100 and 300 kg/ha levels of nitrogen application.

For grassland, the offtake of nutrients from the farm as a whole is low, because a high proportion of the mineral nutrients consumed by grazing livestock is returned to the soil in dung and urine. This can lead to a build-up in nutrient status in the soil, but much of this is in organic form in the grass plants and the active soil biomass. Only in extreme cases, at very high fertilizer input rates, is there a risk that loss of nutrients will cause an environmental problem while the grass crop remains. However, change of use from grass to arable can release large quantities of nutrients, particularly nitrogen, even at low levels of fertilizer use.

21.4 ENVIRONMENTAL SIGNIFICANCE OF NUTRIENT LOSSES

21.4.1 Nitrogen

In summary, nitrogen is lost to the environment as nitrate in drainage water and surface runoff, and to the atmosphere as nitrogen and nitrogen oxides following denitrification of nitrate and as volatilized ammonia.

i. Nitrate leaching and runoff losses are of significance because they contribute to the nitrate content of surface and underground waters, and therefore of water supplies. High levels of nitrate in drinking water can cause medical problems. Methaemoglobinaemia (blue baby disease) in infants is associated with a high nitrate intake, and there is an unproven suggestion of a link between level of nitrate intake and the formation in the human body of possibly carcinogenetic nitrosamines. For this reason the World Health Organization recommends that drinking water should not contain more than 11.3 mg/l N as nitrate, up to 22.6 mg/l being acceptable in some circumstances.

   Some water resources in some productive agricultural areas with moderate rainfall are at times around or above these limits. Much can be done to reduce nitrate to a satisfactory or acceptable level by management or treatment of water supplies. However, it is also important in such areas that agricultural practices and fertilizer use should wherever practicable take account of the need to minimize nitrate loss.

ii. Nitrogen and nitrogen oxide loss to the atmosphere is not of established environmental significance, though there have been unconfirmed suggestions that emission of large quantities of nitrogen oxides might affect the stratospheric ozone layer. This effect is not now considered to be of any significance.

iii. Ammonia volatilization is not an environmental problem since the ammonia is dissipated in the atmosphere at very low concentration.

21.4.2 Phosphorus

Because of the low solubility of calcium phosphates, the concentration of phosphorus in leaching water is very low and amounts lost to underground water by this route are insignificant (0 to 2 kg/ha P_2O_5 per year). However, when soil is eroded by surface runoff, the soil particles carry with them phosphorus in adsorbed or insoluble form which can later be released into rivers, lakes or reservoirs.

The significance of elevated phosphorus content in surface waters is that it can, together with other nutrients and organic matter, cause eutrophication, i.e. excessive growth of algae which can result in oxygen depletion, fish mortality and amenity problems.

Phosphorus from fertilizer is very rarely of significance as a cause of eutrophication, but anti-erosion measures may help to reduce amounts of soil phosphorus reaching surface waters. Eutrophication is primarily a result of nutrient input to water from sources such as farm wastes and, most important, human wastes including sewage.

21.4.3 Potassium

Potassium is leached at very low concentrations but does not cause environmental problems in water, or indeed in any other way.

21.5 CONCLUSIONS

In some agricultural systems, particularly in intensive, highly fertilized temperate cropping, attention has to be paid to using fertilizers efficiently and to monitoring the effects of farming systems, including biological nitrogen fixation, on environmental quality.

22. PLANT NUTRITION AND PRODUCT QUALITY

Optimum use of fertilizer results in higher yield and better crop quality. For example, the protein content of cereals can be increased by proper management of nitrogen, in particular by providing adequate for full growth and nitrogen uptake and applying at the best time or times - often some in the early stages of growth and some just before ear emergence. Similarly, a proper supply of phosphorus and potassium increases the sugar and starch contents of crops, and secondary and micronutrients also play important roles in improving crop quality.

Crop quality can be related to the nutritive value of the produce and to the commercial or market value, which often depends on features such as appearance, taste, smell and keeping quality. Where crops are to be processed, either for food production or industrial use, the quality requirements depend essentially on the needs of the processor, in terms of both quantity and specifications of output from the processing plant.

22.1 FACTORS AFFECTING QUALITY

The quality of crop products depends on inherited genetic make-up and on environmental (external) factors. The inherited factors determine the basic quality specific to the crop and variety while the environmental factors affect the realization of the inherited potential, by regulating it in different ways. The external factors include plant nutrients, soil, climate and management. Balanced use of plant nutrients plays a vital role in determining the quality of the produce. Frequently, quality is improved by fertilizer application up to an optimum level, while applications well in excess of this may lead to lower quality, either because of a straightforward nutrient excess or because of imbalance between nutrients.

22.2 NITROGEN FERTILIZER AND PRODUCT QUALITY

Nitrogen is the nutrient that has the greatest effect on plant growth and metabolism and therefore the largest effect on product quality. Increased nitrogen supply changes plant composition mainly by increasing the protein content and often by decreasing the contents of carbohydrates and oils - since a part of the products of photosynthesis has been diverted to protein production. Some examples are given of crops in which nitrogen fertilizer (and other sources of nitrogen) influence quality.

i. Cereals

Nitrogen increases the protein content of grain, which is advantageous in a number of ways. It increases the protein contribution to the diet from foodgrains, and in particular improves the bread-making potential of wheat - because flour from high-protein wheat makes a loaf of better texture and appearance. The higher protein content in cereals for use as animal feed is also beneficial. Excess nitrogen may, however, adversely affect the quality of barley used for production of malt, since the quality and quantity of malt extract depends on the starch content of the grain and is inversely related to protein content.

ii. Forage crops

Nitrogen application increases the protein content of forage crops, which is normally beneficial because, owing to cost or limited availability of protein supplements, the diet of livestock often contains insufficient protein. Both true protein and non-protein nitrogen contents are increased, and both components are used by ruminant livestock.

iii. Oil and sugar crops

While nitrogen increases total yields of oil and sugar, it usually depresses oil and sugar contents when applied beyond the optimum rate. For these crops, therefore, correct use of nitrogen fertilizer is important.

iv. Vegetables

By deepening the green colour of the crop, nitrogen makes many leafy vegetables such as spinach or cabbage more attractive.

22.3 PHOSPHORUS FERTILIZER AND PRODUCT QUALITY

Phosphorus plays a significant role in the formation of many important plant components including phosphoric acid esters, phytin, phosphatides, phosphoprotein, and nucleoproteins. These compounds play an important role in plant growth and development and in quality of the produce. Plant health and seed quality are also influenced by phosphorus content in the plant. Increasing phosphorus supply increases crude protein content of the plant and in particular increases the content of essential amino-acids. Controlling phosphorus deficiency also increases starch and sugar contents to normal levels and the contents of some vitamins are increased.

The phosphorus nutrition of grassland and other crops for forage and grazing is also important, since low phosphorus content in the diet leads to aphosphorosis, a serious disease in grazing livestock. At less extreme levels of deficiency the fertility of livestock may be quite severely affected. It is therefore important for these crops to receive adequate phosphorus fertilizer, and this may be particularly relevant in practice on extensive (range) grassland to which little fertilizer has previously been applied.

22.4 POTASSIUM FERTILIZER AND PRODUCT QUALITY

Potassium activates many enzyme systems and in particular is generally considered to improve the energy status of plants and the metabolism of carbohydrates, as well as improving tolerance to stress. A satisfactory level of potassium nutrition has a wide range of effects on crop quality and behaviour:

i. it increases carbohydrate content (sugar, starch, fibre) and thus improve quality of crops such as sugarcane, potatoes and jute;

ii. it increases the content of a number of vitamins, important in fruit and vegetable crops for fresh consumption;

iii. correct potassium nutrition prevents certain forms of blackening in potato tubers;

iv. in cereals, the grain filling period is extended and grain size is increased by an adequate potassium supply, and the degree of lodging can be reduced;

v. resistance to frost, drought, diseases and pests are all improved by a satisfactory potassium supply.

The content of potassium in food crops, both for man and for livestock, is not in itself important since a dietary deficiency of potassium is rare and an excess, within reason, is not harmful. However, high levels of potassium nutrition of crops can reduce the uptake of magnesium and calcium. A low level of magnesium relative to potassium in the diet of ruminant livestock can cause hypomagnesaemia, a complex magnesium deficiency state.

22.5 EFFECTS OF SECONDARY AND MICRONUTRIENTS ON QUALITY

A number of secondary and micronutrients have important effects on quality, of which some of the more common are mentioned below. Calcium deficiency causes a number of problems in various crops, mainly vegetables and fruits, especially when other growing conditions - temperature, water supply, nutrients - are good. Its deficiency conditions include bitter pit in apples and empty shells in groundnuts. Sulphur is an important constituent of a number of essential amino-acids, so its deficiency lowers protein quality. Crops such as mustard and onions rely for pungency on sulphurcontaining compounds, so that deficiency adversely affects flavour. Copper deficiency can adversely affect the formation and filling of cereal grain, leading to production of small or shrivelled grain. Molybdenum deficiency can affect the formation and appearance of the inflorescence of cauliflowers. An excess of chlorine, either in saline soil or from fertilizer, can reduce the starch content of potato tubers and adversely affect the burning characteristics of tobacco.

22.6 BALANCED USE OF PLANT NUTRIENTS AND QUALITY

Optimum quality of produce is achieved through the balanced application of all the required plant nutrients, and not just by application of one nutrient. Fertilization matched to crop requirement ensures optimum produce quality while excess improves quality components only in exceptional cases - for example, intensive fertilization of cereals with nitrogen improves the baking quality of wheat flour.

Awareness of the need for micronutrients in relation to quality as well as yield has increased *pro rata* as NPK fertilizer use has raised crop yields and crop need for other nutrients. Provided soil and other supplies of micronutrients are adequate, the use of fertilizers usually increases crop content of micronutrients, which can be a beneficial factor in the diet of man and animals.

Fertilizer and other environmental growth factors affect plant growth, yield formation and produce quality in a most complex way. Among these factors plant nutrients occupy a vital position and any deficiency in supply from the soil should be properly made up by suitable fertilizer use to ensure high quality products. Micronutrients may have great influence on plant production and quality even though the quantities required are small.

Without fertilizer use, human beings and animals would have to exist on food materials poor in quality as well as inadequate in quantity. Proper use of fertilizer improves the quality of produce by enabling crops to fulfil their normal growth potential, and thus contributes to the health of man and animals by providing a good quality diet.

APPENDIX 1

GLOSSARY OF TERMS ON FERTILIZER AND PLANT NUTRITION

ACID-FORMING FERTILIZER: A fertilizer capable of increasing the residual acidity or reducing the residual alkalinity of the soil.

ADDITIVE: Substance intended to improve the properties of a fertilizer or soil conditioner.

AGGREGATE SAMPLE: A combination of all increments from the sampling unit.

AGRICULTURAL LIMING MATERIAL: Material containing oxides, hydroxides and/or carbonates of calcium and/or magnesium, used for neutralizing the acidity of the soil.

ALKALINE (OR BASIC) FERTILIZER: A fertilizer capable of increasing the residual alkalinity or reducing the residual acidity of the soil.

AMMONIA (LIQUID ANHYDROUS): A material mostly produced by the synthetic process and obtained in the liquid form. It is used in the fertilizer industry for ammoniation of superphosphate, in making base mixtures, in making mixed fertilizers, or for conversion into salts such as sulphate, phosphate, chloride, nitrate, etc. It is also applied directly into the soil by suitable mechanical means. Fertilizer grade anhydrous ammonia contains about 82 percent of nitrogen.

AMMONIATED SUPERPHOSPHATE: A product obtained from superphosphate when it is treated with ammonia or solutions containing free ammonia.

AMMONIATING SOLUTION (NITROGEN SOLUTION): A solution used for ammoniating superphosphate or a mixture of superphosphate with other fertilizers. This solution may be liquor ammonia itself or a solution of ammonium nitrate or urea in liquor ammonia.

AMMONIUM CHLORIDE (SAL AMMONIA OR MURIATE OF AMMONIA) (NH_4Cl): Ammonium salt of hydrochloric acid containing 25 percent of nitrogen in ammoniacal form.

AMMONIUM CITRATE: A term used to express the soluble phosphate content of fertilizers, to describe various extraction solutions of given concentrations of ammonium citrate and aqueous ammonia.

AMMONIUM NITRATE (NH_4NO_3): A product obtained by neutralizing nitric acid with gaseous ammonia. It is usually in a granular or prilled form, and coated with a suitable material to prevent absorption of moisture and caking in storage. Fertilizer grade ammonium nitrate has a total nitrogen content of 33-34.5 percent, of which one-half is present as ammoniacal nitrogen and the other half as nitrate nitrogen.

AMMONIUM PHOSPHATE: Two important ammonium phosphates are: (a) mono-ammonium phosphate ($NH_4H_2PO_4$) containing about 11 percent of nitrogen and about 53 percent of P_2O_5: (b) diammonium phosphate [$(NH_4)_2HPO_4$], fertilizer grade phosphate contains about 18 percent of nitrogen and 46 percent of P_2O_5.

AMMONIUM PHOSPHATE SULPHATE: A material produced by neutralizing a mixture of phosphoric acid and sulphuric acid with ammonia.

AMMONIUM SULPHATE (SULPHATE OF AMMONIA) [$(NH_4)_2SO_4$]: Ammonium salt of sulphuric acid containing 20.6 percent of nitrogen in ammoniacal form.

AMMONIUM SULPHATE NITRATE: A double salt of ammonium sulphate and ammonium nitrate containing 26 percent of nitrogen of which about one-fourth is in the nitrate form and three-fourths in the ammoniacal form.

ANALYSIS: As applied to fertilizers, it designates the percentage composition of the product expressed in terms which the existing trade practice and law require and permit.

AQUEOUS AMMONIA: A solution containing water and ammonia in any proportion, usually qualified by a reference to ammonia vapour pressure.

APPLICATION: General term for all processes of administering fertilizers and soil conditioners to a crop or soil or both.

ASH: The mineral residue remaining after the destruction of organic material by burning.

BATCH: A definite quantity of material manufactured or produced under conditions which are presumed to be uniform.

BASIC SLAG: A by-product in the manufacture of steel from phosphorus-containing iron ores, containing 8 to 18 percent P_2O_5.

BLOOD, DRIED BLOOD, BLOOD MEAL: Blood which has been dried and to which no other material has been added.

BONE: Hard tissue forming the skeletal structure of animals and containing salts of calcium, chiefly phosphate and carbonate.

BONE ASH: A product obtained by burning bones to ash. The material contains 30 to 40 percent P_2O_5.

BONE BLACK (BONE CHAR): A product obtained by heating bones in closed retorts. This is used for clarifying sugarcane juice and the spent material used as phosphorus fertilizer. It may contain 1 to 2 percent of nitrogen and 30 to 35 percent P_2O_5.

BONE MEAL, RAW: A by-product of the bone-crushing industry, consisting of ground bones without any of the gelatine or glue removed. It contains at least 3 percent nitrogen, and about 22 percent P_2O_5 of which about 8 percent is citratesoluble.

BONE MEAL, STEAMED: A product obtained by subjecting bones to the action of steam under pressure to dissolve part of the gelatine and grinding the residue. It contains about 28 percent of P_2O_5 of which about 16 percent is citratesoluble.

BULK DENSITY (LOOSE): The mass per unit volume of a material after it has been tipped freely into a container under clearly specified conditions.

BULK DENSITY (TAMPED): The mass per unit volume of a material tipped into a container and then compacted under clearly specified conditions.

BULK FERTILIZER: Commercial fertilizer delivered to the purchaser, in solid or liquid form in a non-packed form (to which a label cannot be attached).

CAKING: The formation of a coherent mass from individual particles.

CALCIUM AMMONIUM NITRATE: A mixture of ammonium nitrate and finely pulverized limestone or dolomite, granulated together. It contains 21 to 26 percent of nitrogen, half of which is in the form of ammoniacal nitrogen and the other half in the form of nitrate nitrogen.

CALCIUM CYANAMIDE (CYANAMIDE) ($CaCN_2$): A commercial product consisting principally of calcium cyanamide and carbon. It contains not less than 20 percent of nitrogen which is not immediately plant-available.

CALCIUM METAPHOSPHATE [$Ca(PO_3)_2$]: A product obained by treating phosphate rock with gaseous phosphorus pentoxide (P_2O_5) at high temperature.

CALCIUM NITRATE [$Ca(NO_3)_2$]: The calcium salt of nitric acid. It is an excellent source of the nitrate form of nitrogen and of water-soluble calcium. The commercial product contains about 15 percent nitrogen and 28 percent CaO.

CHILEAN NITRATE OF SODA (CHILE SALTPETRE): A product obtained by refining the crude nitrate deposits found in Chile and containing about 99 percent sodium nitrate (see also Nitrate of Soda).

c.i.f.: Cost, insurance and freight.

c. & f.: Cost and freight.

CITRATE-SOLUBLE P_2O_5: That part of the total P_2O_5 in a fertilizer that is insoluble in water but soluble in neutral or alkaline ammonium citrate solution.

CITRIC ACID-SOLUBLE P_2O_5: That part of the total P_2O_5 particularly in basic slag and bone meal that is insoluble in water but soluble in 2 percent citric acid solution.

CLAY: A group of hydrated aluminium silicates of microcrystalline structure and a constituent of soils.

COATED FERTILIZER: Fertilizer, the granules of which are covered with a thin layer of a different material in order to improve the behaviour and/or modify the characteristics of the fertilizer.

COMPLETE FERTILIZER: A product obtained by mixing different fertilizer stock materials, containing three major plant nutrients, namely, nitrogen, phosphorus and potassium (see also Fertilizer Mixture).

COMPLEX FERTILIZER: Fertilizers which contain two or more major nutrients made by a chemical reaction between the nutrient-containing raw materials.

COMPOST: A product obtained by the controlled decomposition of organic wastes.

COMPOUND FERTILIZER: Fertilizer having a declarable content of at least two of the nutrients nitrogen, phosphorus, and potassium, obtained chemically or by mixing, or both.

CONTAINER: A closed receptacle directly in contact with a fertilizer or soil conditioner whereby it may be transported or stored in unit quantities (for example a bag, bottle, tank, barrel).

CRUSHING STRENGTH: The minimum force required to crush individual particles.

DECLARABLE CONTENT: The content of a nutrient which, according to national legislation, may be given on a label or document associated with a fertilizer or soil conditioner.

DELIVERY: A quantity of material transferred at one time.

DICALCIUM PHOSPHATE ($CaHPO_4$): A product containing not less than 34 percent of P_2O_5 in citrate-soluble form, which is considered available to plants.

DISSOLVED BONE: Ground bone or bone meal that has been treated with sulphuric acid. It is commonly known as 'Bone Superphosphate' and contains 1 to 2 percent nitrogen and 16 percent total P_2O_5 of which about 8 percent is water-soluble.

DOLOMITE: A mineral composed chiefly of carbonates of calcium and magnesium in substantially equi-molar proportions.

DUNG: The semi-solid excrement of animals used as a manure and soil conditioner.

EQUIVALENT ACIDITY: The number of parts by weight of calcium carbonate (as $CaCO_3$) required to neutralize the acidity resulting from the use of 100 parts by weight of a fertilizer.

EQUIVALENT BASICITY: The number of parts by weight of calcium carbonate (as $CaCO_3$) that corresponds in acid neutralizing capacity to 100 parts by weight of the fertilizer.

f.a.s.: Free along side.

FERTILIZATION: The use of mineral fertilizers for plant nutrition.

FERTILIZER: A material in which declared nutrients are in the form of inorganic salts obtained by extraction and/or by physical and/or chemical industrial processes (also termed Mineral Fertilizers).

FERTILIZER FORMULA: The quantity and grade of the stock materials used in making a fertilizer mixture, for example, 400 kg of ammonium sulphate containing 20.6 percent nitrogen, 400 kg of superphosphate containing 16 percent soluble P_2O_5 and 200 kg of potassium sulphate containing 48 percent K_2O.

FERTILIZER GRADE: The legal guarantee of its available plant food content expressed in terms of percentage of N, P_2O_5 and K_2O, or in other forms of expression (e.g. elemental) as required by national legislation.

FERTILIZER MIXTURE: A product obtained by mixing different fertilizer intermediates and containing more than one of the three fertilizer nutrients, nitrogen, phosphorus and potassium (see also Complete Fertilizer).

FILLER: Any material mixed with fertilizers for any purpose other than the addition of available nutrients, such as for conditioning to give anti-caking properties, and for increasing the weight to bring the percentage of nutrients to desired values.

FINAL SAMPLE, LABORATORY SAMPLE: A representative part of the reduced sample or, where no intermediate reduction is required, of the aggregate sample.

FISH GUANO: A material consisting essentially of fresh by-products of the fishing industry and produced by grinding and composting.

FISH MEAL: A product obtained by drying and grinding, or otherwise treating, fish or fish waste and to which no addition has been made.

f.i.o.: Free in and out.

f.o.b.: Free on board.

f.o.r.: Free on rail.

FUSED CALCIUM AND MAGNESIUM PHOSPHATE: A product derived from the fusion of rock phosphate with approximately 30 percent of magnesium oxide as such or as a mineral silicate.

FUSED TRICALCIUM PHOSPHATE: A product composed chiefly of the alpha form of the compound represented by the formula $Ca_3(PO_4)_2$. It is obtained when rock phosphate containing 5 to 10 percent silica is fused and the melt quenched.

GRAIN SIZE: The dimension which corresponds to the smallest sieve aperture through which a particle will pass if presented in the most favourable attitude.

GRANULAR FERTILIZER: Solid material formed into particles of a predetermined mean size.

GRANULATION: Techniques using a process such as agglomeration, accretion or crushing, to make a granular fertilizer.

GROUND PHOSPHATE ROCK: Material obtained by grinding naturally occurring phosphate rock to a fineness meeting relevent legislation or accepted custom.

GROWTH MEDIUM: Any material such as soil, peat, etc. used as a support for plant roots, that has a capacity for water retention and which may contain added or naturally occurring nutrients.

GUANO: Includes many materials which vary in source, composition and readiness for use. It may be (a) bat guano - found in caves; (b) Peruvian guano - the accumulated excrement of sea birds found in Peru; (c) fish guano, whale guano, sheep guano, goat guano; and (d) phosphatic guano of various kinds. The nitrogen content varies from 0.4 to 9.0 percent and total P_2O_5 from 12 to 26 percent.

GUARANTEE (OF COMPOSITION): Quantitative and/or qualitative characteristics with which a marketed product must comply for contractual or legal reguirements.

GYPSUM: A hydrated calcium sulphate ($CaSO_4$, $2H_2O$): The commercial material contains varying amounts of impurities and is used as a soil amendment.

HIGH ANALYSIS FERTILIZER: A fertilizer containing not less than 25 percent of the major plant nutrients, namely, nitrogen, phosphorus (as P_2O_5) and potassium (as K_2O).

HOOF AND HORN MEAL: A product resulting from processing, drying and grinding of hooves and horns and containing 13 to 15 percent nitrogen.

HUMUS: Term used in agronomy for defining certain fractions of the soil evolved from organic materials therein.

INCREMENT: A representative quantity of material taken from a sampling unit.

KAINITE: A mineral composed of potassium chloride and magnesium sulphate ($KCl.MgSO_4.\ 3H_2O$). The crude potash ore sold as kainite has varying contents of sodium chloride, and contains not less than 12 percent K_2O.

KIESERITE: Magnesium sulphate ($MgSO_4.H_2O$) containing 27 percent MgO and 22 percent S.

KOTKA PHOSPHATE: A product obtained by partial acidulation of ground rock phosphate with sulphuric acid and containing not less than 16 percent of available P_2O_5 of which at least 6 percent is water-soluble.

LABEL: Paper or plastic label or a printed area of a package or container marked with the information required by national legislation.

LIQUID FERTILIZER: This term includes anhydrous ammonia, ammoniating solutions, other nitrogenous solutions and liquid mixed fertilizers. The principal materials used in making liquid fertilizers are ammonia, urea, phosphoric acid and potassium chloride.

LIQUID MANURE: Liquid resulting from animal urine and litter juices or from a dung heap.

LIMING MATERIAL: Product containing one or both of the elements calcium and magnesium, generally in the form of an oxide, hydroxide or carbonate, principally intended to maintain or raise the pH of soil.

MAGNESIA (MAGNESIUM OXIDE): A product consisting chiefly of the oxide of magnesium.

MAGNESIUM SULPHATE: Usually the product known as kieserite ($MgSO_4.H_2O$). The highly hydrated form Epsom salts ($MgSO_4.7H_2O$) is suitable for foliar application.

MANURES: See Organic Manures.

MINERAL FERTILIZER: See Fertilizer.

NITRATE OF SODA AND POTASH: Chiefly the sodium and potassium salt of nitric acid containing not less than 15 percent of nitrate nitrogen and 10 percent of potash (as K_2O) (see also Potassium Nitrate).

NITROPHOSPHATES: Products obtained by treatment of phosphate rock with nitric acid alone or in admixture with sulphuric or phosphoric acid, with or without subsequent treatment with ammonia.

NON-ACID-FORMING FERTILIZER: A fertilizer not capable of increasing the acidity or reducing the alkalinity of the soil.

OIL CAKE: The residue left after extraction of fatty oil from different oil seeds employed for industrial purposes, chiefly valued for its nitrogen content and also containing phosphorus, potassium and other elements in small proportions.

ORGANIC MANURES: Carbonaceous materials mainly of vegetable and/or animal origin added to the soil specifically for the nutrition of plants.

ORGANIC NITROGEN FERTILIZER: Fertilizer containing nitrogen associated with carbon in organic combination.

OVERSIZE: That portion of a batch or sample which does not pass through a sieve of specified aperture size.

PARTIAL SAMPLE: A quantity of material taken at a point from a sampling unit.

PARTICLE SIZE ANALYSIS (GRANULOMETRY) BY SIEVING: The division of a sample by sieving into size fractions.

PEAT: Residual matter from plants grown and decayed in almost permanently waterlogged conditions and which may contain a limited quantity of naturally occurring mineral material.

PHOSPHATE ROCK: A natural rock containing one or more calcium phosphate minerals of sufficient purity and quantity to permit its use directly or after concentration in the manufacture of commercial phosphorus fertilizers.

PLANT FOOD RATIO: The ratio of the numbers of fertilizer units in a given mass of fertilizer expressed in the order N-P-K.

PLANT NUTRIENT: A chemical element essential for plant growth.

POTASSIUM CHLORIDE (KCl): A potassium fertilizer containing 60 percent K_2O.

POTASSIUM METAPHOSPHATE (KPO_3): A product composed chiefly of the crystalline compound represented by the formula KPO_3.

POTASSIUM NITRATE (KNO_3): A nitrogen-potassium fertilizer containing 13 percent N and 44 percent K_2O.

POTASSIUM MAGNESIUM SULPHATE: A double salt of potassium and magnesium containing about 21 percent K_2O.

POTASSIUM SULPHATE (K_2SO_4): A potassium fertilizer containing 48 percent K_2O and also supplying 17-20 percent of sulphur.

POWDER: Solid substance in the form of fine particles.

PRECIPITATED BONE PHOSPHATE: A by-product from the manufacture of glue from bones obtained by neutralizing the hydrochloric acid solution of processed bone with lime. The phosphorus is chiefly present as dicalcium phosphate.

PRILL: Particle obtained by solidification of falling droplets of fertilizer.

REDUCED SAMPLE: A representative part of the aggregate sample obtained by a process of reduction in such a manner that the mass approximates to that of the final (laboratory) sample.

REVERTED PHOSPHORIC ACID: The part of the water-soluble P_2O_5 in a fertilizer which as a result of some reaction has become insoluble in water.

SAMPLING UNIT: A defined quantity of material having a boundary which may be physical, for example a container, or hypothetical, for example a particular time or time interval in the case of a flow of material.

SECONDARY FERTILIZER ELEMENTS: Calcium, magnesium and sulphur.

SEMI-ORGANIC FERTILIZER: Product in which declared nutrients are of both organic and inorganic origin obtained by mixing and/or chemical combination of organic and inorganic (mineral) fertilizers.

SIEVING: The process of separating a mixture of particles according to their sizes by one or more sieves.

SLOW RELEASE FERTILIZER: Fertilizer whose nutrients are present as a chemical compound or in a physical state such that their availability to plants is spread over a period of time.

SLURRY: Semi-liquid effluent from livestock, consisting of urine and faeces, possibly diluted with water.

SOIL AMENDMENT: Any substance that is added to the soil for the purpose of improving its physical or chemical character, enhancing soil productivity or promoting the growth of crops but excluding commercial fertilizers and organic manure.

SOIL CONDITIONER: Material added to soil mainly to improve its physical and, as a consequence, its chemical and biological properties.

SOIL FERTILITY: The ability of a soil to support satisfactory plant growth.

SOLUBILITY OF A FERTILIZER NUTRIENT: The quantity of a given nutrient which will be extracted in a specific medium under specified conditions, expressed as a percentage by mass of the fertilizer.

SOLUTION FERTILIZER: Liquid fertilizer free of solid particles.

STRAIGHT FERTILIZER: Qualification generally given to a nitrogen, phosphorus or potassium fertilizer having a declarable content of one primary nutrient only.

SULPHATE OF POTASH (K_2SO_4): See Potassium Sulphate.

SUPERPHOSPHATE (SINGLE SUPERPHOSPHATE): A commercial product obtained by treating phosphate rock with sulphuric acid and containing about 18 percent of P_2O_5, mainly water-soluble, along with calcium sulphate and other products of reaction (contains 16 percent S).

SUSPENSION FERTILIZER: A two-phase fertilizer in which solid particles are maintained in suspension in the aqueous phase.

TEST SAMPLE: A representative part of the final sample prepared by an appropriate method for a particular test.

TEST SIEVING: Sieving with one or more test sieves.

TRACE ELEMENTS (MICRONUTRIENTS): Elements which are essential to plants in very small quantities for completion of their normal life cycle (B, Cl, Cu, Fe, Mn, Mo, Zn).

TRIPLE SUPERPHOSPHATE: A commercial product obtained by treating phosphate rock with phosphoric acid and containing about 46 percent P_2O_5, mainly water-soluble.

TRUE DENSITY: The mass per unit volume of the particles of a material.

UNDERSIZE: That portion of the batch or sample which passes through a sieve of specified aperture size.

UREA $[CO(NH_2)_2]$: A synthetic, non-protein organic compound, crystalline or made into granules or prills for fertilizer use and containing 46 percent nitrogen.

UREAFORMALDEHYDE: Slow release nitrogen fertilizer produced by reaction between urea and formaldehyde.

WASTE-LIME (BY-PRODUCT LIME): An industrial waste or by-product containing calcium or calcium and magnesium in forms that will neutralize acids. It may be designated by prefixing the name of the industry or process by which it is produced; for example gas lime, tanners' lime, lime kiln ash.

APPENDIX 2

WEIGHTS, MEASURES AND CONVERSION FACTORS AND TABLES

Weights

1 gram	=	15.4323	grains troy
1 kilogram	=	2.20462	pounds
1 metric ton	=	0.98421	long ton (20 hundredweights)
	=	1.10231	short tons (2000 pounds)
1 quintal (= 100 kg)	=	1.9684	hundredweights (cwt.)
	=	220.46	pounds
1 ounce (avoirdupois)	=	28.3495	grams
1 pound	=	0.45359	kilogram
1 hundredweight	=	50.8023	kilograms
1 long ton	=	1.01605	metric tons
1 short ton	=	0.90718	metric ton

Linear measures

1 centimetre	=	0.39370	inch
1 metre	=	3.28084	feet
	=	1.09361	yards
1 kilometre	=	0.62137	mile
1 inch	=	2.54000	centimetres
1 foot (12 inches)	=	30.4801	centimetres
1 yard (3 feet = 36 inches)	=	91.4402	centimetres
1 mile (statute mile) = 1,760 yards)	=	1,609.34	metres
1 nautical mile (6,080 feet)	=	1,853.2	metres

Square measures

1 square centimetre	=	0.155	square inch
1 square metre	=	10.763865	square feet
	=	1.195985	square yards
1 hectare	=	2.47109	acres
1 square kilometre	=	0.38610	square mile
1 square inch	=	6.451626	square centimetres
1 square foot (144 square inches)	=	0.092903	square metre
1 square yard (9 square feet)	=	0.836127	square metre
1 acre (4,840 square yards)	=	0.404687	hectare
1 square mile (640 acres)	=	2.5899	square kilometres
		(258.998 hectares)	

Fertilizers

SYMBOLS AND RELATIVE ATOMIC MASSES ("ATOMIC WEIGHTS") OF SOME ELEMENTS

Symbol	Element	Relative atomic mass
Al	aluminium	27
B	boron	10.8
C	carbon	12
Ca	calcium	40.1
Cl	chlorine	35.5
Co	cobalt	58.9
Cu	copper	63.5
Fe	iron	55.9
H	hydrogen	1
K	potassium	39.1
Mg	magnesium	24.3
Mn	manganese	54.9
Mo	molybdenum	95.9
N	nitrogen	14
Na	sodium	23
O	oxygen	16
P	phosphorus	31
S	sulphur	32.1
Si	silicon	28.1
Zn	zinc	65.4

Conversion factors

$$P \underset{\times\, 0.436}{\overset{\times\, 2.29}{\rightleftarrows}} P_2O_5 \qquad Ca \underset{\times\, 0.715}{\overset{\times\, 1.40}{\rightleftarrows}} CaO \underset{\times\, 0.56}{\overset{\times\, 1.79}{\rightleftarrows}} CaCO_3$$

$$K \underset{\times\, 0.83}{\overset{\times\, 1.20}{\rightleftarrows}} K_2O \qquad Mg \underset{\times\, 0.60}{\overset{\times\, 1.66}{\rightleftarrows}} MgO \underset{\times\, 0.48}{\overset{\times\, 2.09}{\rightleftarrows}} MgCO_3$$

UNIT WEIGHT OF SELECTED COMMODITIES BY COUNTRIES

Wheat

United States, Australia, Canada, New Zealand	= 1 bushel	=	27.215 kg	=	60	lb.
South Africa, Rhodesia, Zambia, Kenya	= 1 bag	=	90.718 kg	=	200	lb.
United Arab Republic	= 1 ardeb	=	150 kg	=	330.693	lb.
Sudan	= 1 ardeb	=	162 kg	=	357.148	lb.

Maize

United States, Canada, Australia, New Zealand	= 1 bushel	=	25.410 kg	=	56	lb.
United Arab Republic	= 1 ardeb	=	140 kg	=	308.647	lb.

Paddy rice

United States	=	1 bushel	=	20.412 kg	=	45	lb.
United States	=	1 bag	=	45.359 kg	=	100	lb.
United Arab Republic	=	1 daribah	=	945 kg	=	2038.366	lb
Thailand (for export)	=	1 kwein	=	1010 kg	=	2226.67	lb.
Philippines	=	1 cavan	=	44 kg	=	97.003	lb.
Japan (brown)	=	1 koku	=	150 kg	=	330.693	lb.
Burma	=	1 basket	=	20.865 kg	=	46	lb.
Sri Lanka	=	1 bushel	=	20.865 kg	=	46	lb.
Australia	=	1 bushel	=	19.051 kg	=	42	lb.

Cotton (lint)

India (raw)	=	1 maund	=	37.324 kg	=	82.286	lb.
India (raw)	=	1 bale	=	177.807 kg	=	392	lb.
Pakistan (raw)	=	1 bale	=	177.807 kg	=	392	lb.
United States (net)	=	1 bale	=	217.723 kg	=	480	lb.
United Arab Republic	=	1 kantar	=	50.000 kg	=	110.232	lb.
Sudan	=	1 kantar	=	45.000 kg	=	100	lb.

IMPERIAL TO METRIC CONVERSIONS

Weights	Multiply by	
troy ounces	31.104	grams
pounds (lb.)	0.454	kilograms
UK hundredweights	0.508	quintals
short tons	0.907	metric tons
long tons	1.016	metric tons

Square measures

acres	0.405	hectares (ha)
square feet	0.093	square metres
square yards	0.836	square metres
square miles	2.590	square kilometres

Concentrations

ounces per Imp. gallon	6.236	grams per litre
ounces per US gallon	7.490	grams per litre

Yields

pounds per acre (lb. per acre)	1.121	kilograms per hectare
pounds per acre (lb. per acre)	0.011	quintals per hectare
hundredweights per acre	125.54	kilograms per hectare
long tons per acre	25.11	quintals per hectare
short tons per acre	22.42	quintals per hectare
bushels per acre (wheat)	0.672	quintals per hectare
bushels per acre (maize or corn)	0.627	quintals per hectare
bushels per acre (barley)	0.538	quintals per hectare

METRIC TO IMPERIAL CONVERSIONS

Weights	Multiply by	
grams	0.032	troy ounces
kilograms	2.205	pounds (lb.)
quintals	1.968	UK hundredweights
metric tons	1.102	short tons
	0.984	long tons

Square measures		
hectares	2.471	acres
square metres	10.764	square feet
	1.196	square yards
square kilometres	0.386	square miles

Concentrations		
grams per litre	0.160	ounces per Imp. gallon
grams per litre	0.134	ounces per US gallon

Yields		
kilograms per hectare	0.892	pounds per acre (lb. per acre)
quintals per hectare	89.218	pounds per acre (lb. per acre)
kilograms per hectare	0.008	hundredweights per acre (cwt. per acre)
quintals per hectare	0.796	hundredweights per acre (cwt. per acre)
quintals per hectare	0.040	long tons per acre
	0.045	short tons per acre
quintals per hectare	1.487	bushels per acre (wheat)
quintals per hectare	1.549	bushels per acre (maize or corn)
quintals per hectare	1.859	bushels per acre (barley)

IMPERIAL TO METRIC CONVERSION TABLE

WEIGHT												
Tons (long) to metric tons												
Tons (long)	1	2	3	4	5	6	7	8	9	10		
Metric tons	1.02	2.03	3.05	4.06	5.08	6.10	7.11	8.13	9.14	10.16		
Pounds to kilogrammes												
Pounds	1	2	3	4	5	6	7	8	9	10		
Kilogrammes	0.45	0.91	1.36	1.81	2.27	2.72	3.18	3.63	4.18	4.54		
LENGTH												
Miles to kilometres												
Miles	1	2	3	4	5	6	7	8	9	10		
Kilometres	1.61	3.22	4.83	6.44	8.05	9.66	11.29	12.87	14.43	16.09		
Yards to metres												
Yard	1	2	3	4	5	6	7	8	9	10		
Metres	0.91	1.83	2.74	3.36	4.57	5.49	6.40	7.32	8.23	9.14		
Inches to millimetres												
Inches	1	2	3	4	5	6	7	8	9	10	11	12
Millimetres	25.40	50.80	76.20	101.60	127.00	152.40	177.80	203.60	228.60	254.00	279.40	304.80
AREA												
Acres to hectares												
Acres	1	2	3	4	5	6	7	8	9	10		
Hectares	0.40	0.81	1.21	1.62	2.02	2.43	2.83	3.24	3.64	4.05		
Sq. yards to sq. kilometres												
Square yards	1	2	3	4	5	6	7	8	9	10		
Square metres	0.84	1.67	2.51	3.34	4.18	5.02	5.85	6.69	7.53	8.36		
CAPACITY												
Gallon (Imperial) to litres												
Gallons	1	2	3	4	5	6	7	8	9	10		
Litres	4.56	9.09	13.64	18.18	22.23	27.28	31.82	36.37	40.22	45.46		

CONVERSION OF UNITS OF NITROGEN (N) INTO UNITS OF NITROGENOUS AND COMPLEX FERTILIZER MATERIALS

lb/kg N to be applied	Amm. sulphate (21% N)	Amm. sulphate nitrate (26% N)	Calcium amm. nitrate/Amm. chloride (25% N)	Amm. nitrate (34% N)	Calcium nitrate (15.5%N)	Sodium nitrate/ Amm. phosphate sulphate 16-20-0 (16% N)	Urea (46% N)	Urea amm. phosphate 28-28-0 (28% N)	Diammonium phosphate 18-46-0 (18% N)
					lb/kg				
10	48	38	40	29	65	63	22	36	56
20	95	77	80	59	129	125	43	71	111
30	143	115	120	88	194	188	65	107	167
40	190	154	160	118	258	250	87	143	222
50	238	192	200	147	323	313	109	179	278
60	286	231	240	176	387	375	130	214	333
70	334	269	280	206	452	438	152	250	389
80	380	308	320	235	516	500	174	286	444
90	428	346	360	265	581	563	196	321	500
100	476	385	400	294	645	625	217	357	556
110	524	423	440	324	710	688	239	393	611
120	571	462	480	353	774	750	261	429	667
130	619	500	520	382	839	813	283	464	722
140	666	538	560	412	903	875	304	500	778
150	714	577	600	441	968	938	326	536	833

CONVERSION OF UNITS OF PHOSPHATE (P_2O_5) INTO UNITS OF PHOSPHORUS AND COMPLEX FERTILIZER MATERIALS

lb/kg phosphate (P_2O_5) to be applied	Single super-phosphate (14% P_2O_5)	Single super-phosphate (18% P_2O_5)	Triple super-phosphate/ Diammonium phosphate (46% P_2O_5)	Urea ammonium phosphate 28-28-0 (28% P_2O_5)	Ammonium phosphate sulphate 16-20-0 (20% P_2O_5)
			lb/kg		
10	56	71	22	36	50
15	83	107	33	54	75
20	111	143	43	71	100
30	167	214	65	107	150
40	222	286	87	143	200
50	278	357	109	179	250
60	333	429	130	214	300
70	389	500	152	250	350
80	444	571	174	286	400
90	500	643	196	321	450
100	556	714	217	357	500

CONVERSION OF UNITS OF POTASH (K_2O) INTO POTASSIUM AND COMPLEX FERTILIZER MATERIALS

lb/kg potassium (K_2O) to be applied	Potassium chloride (Muriate of potash) (60% K_2O)	Sulphate of potash (48% K_2O)
	lb/kg	
10	17	21
20	33	42
30	50	63
40	67	83
50	83	104
60	100	125
70	117	146
80	133	167
90	150	188
100	167	208

APPENDIX 3

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