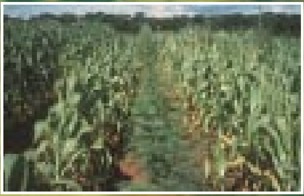
Guide to efficient plant nutrition management

challenges

sources of plant nutrients



management of plant nutrients

environmental issues

policies

Food and Agriculture Organization of the United Nations

Guide to efficient plant nutrition management

LAND AND WATER DEVELOPMENT DIVISION
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1998

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations

Foreword

Plant nutrients are essential for producing sufficient and healthy food for the world's expanding population. Plant nutrients are therefore a vital component of any system of sustainable agriculture. Moreover, agricultural intensification requires increased flows of plant nutrients to crops and higher uptake of those nutrients by crops. The depletion of nutrient stocks in the soil, which is occurring in many developing countries, is a major but often hidden form of land degradation. On the other hand, excessive applications of nutrients, or inefficient management, can cause environmental problems, especially if large quantities of nutrients are lost from the soil/crop system into water or the air.

The *Guide to efficient plant nutrition management* addresses some major issues related to the agronomic management of plant nutrients in an attempt to ensure both enhanced and sustainable agricultural production and to safeguard the environment.

This guide is intended to promote the assessment of plant nutrient requirements on a farming system basis and monitoring of soil fertility. It will help in the formulation of advice to governments and eventually legislation in the field of fertilizer use and plant nutrition. As the guide emphasizes, plant nutrient management should be a major concern at both the farmer and the national level.

The guide is intended to assist everyone concerned with the manufacture, marketing and use of fertilizers in working towards efficient and sustainable plant nutrition management. The advice it contains should be promoted by governments in regional groupings, by international and national non-governmental organizations, by the fertilizer industry and by United Nations agencies.

All parties addressed by this guide are invited to observe and promote its general principles. The cooperation of the fertilizer industry in observing these principles will be particularly valuable.

As a follow-up, soil fertility status and the evolution of soil fertility should be evaluated and monitored by agro-ecological zone. Particular emphasis should be put on long-term trends in soil fertility so that plant nutrient depletion, wherever observed, can be countered.

Environmental impact assessments should be carried out regularly, especially in zones with intensive use of fertilizers.

Robert Brinkman
Director, Land and Water Development Division

ACKNOWLEDGEMENTS

This document benefited from contributions from FAO's Legal Office. FAO is grateful to the following persons and organizations for their contributions and comments:

R. Dudal (Belgium)
A. Finck (Germany)
C. Hera (FAO/IAEA Joint Division, Austria)
J. Neeteson (The Netherlands)
C. Pieri (World Bank, United States)
D. Powlson (United Kingdom)
N. E. Nielsen (Denmark)
P. Sequi (Italy)
J. P. Pichot (France)
The International Fertilizer Industry Association (France)

Executive summary

Increasing agricultural production by improving plant nutrition management, together with a better use of other production factors, is a complex challenge. Agricultural intensification requires increased flows of plant nutrients to crops, a higher nutrient uptake and higher stocks of plant nutrients in soils. This also results in a higher production of crop residues, manure and organic wastes. Excessive use of nutrients, inefficient management of cropping systems, and the inefficient use of residues and wastes result in losses of plant nutrients, which means an economic loss for the farmer. On the other hand, an inadequate or insufficient use of plant nutrients creates an insidious depletion of the stock of plant nutrients on the farm, which will also mean an economic loss for the farmer. Environmental hazards can be created by applying too much nutrient compared with the uptake capacity of cropping systems, while the depletion of nutrient stocks is a major, but often hidden, form of environmental degradation. Plant nutrition management depends largely on prevailing economic and social conditions. Farmers' decisions depend on their economic situation and their socio-economic environment, on their perception of economic signals and on their acceptance of risks.

The fundamental assumption of this guide is that plant nutrition management can contribute to food security and to the sustainable production of agricultural goods without harm to the environment.

The guide addresses all parties engaged in or influencing the production, distribution and use of plant nutrients: local organic products, mineral fertilizers and biological inoculants. It proposes responsibilities, guidelines and a basis for agreement among the parties concerned to share the promotion and development of intensified plant nutrition management guided by accurate policies through coherent plans for action.

The *Guide* proposes the adoption of Integrated Plant Nutrition Systems (IPNS) which enhance soil productivity through a balanced use of local and external sources of plant nutrients in a way that maintains or improves soil fertility and is environmentally-friendly. In the medium term, IPNS help accumulate plant nutrient stocks (in soils and crop residues) as well as capital for sustainable continuation of the intensification process.

The guide emphasizes the urgent need to identify and develop local technologies and decision-making mechanisms to improve plant nutrition practices. Disseminating information and training small-scale farmers are important ways of promoting the intensified, sustainable and environmentally- friendly farming practices that will increase farmers' incomes.

The essential components of efficient plant nutrition management, which the guide aims at communicating, are described below.

- The sources of plant nutrients are described and information is provided on their efficient use for agricultural intensification and their potential impact on the environment.

- Optimizing the management of plant nutrients, as a part of sound agricultural intensification, results from a balanced supply of plant nutrient sources, maintaining or increasing the capital of plant nutrients on the farm and the efficiency of the nutrients involved in crop production, and maximizing income for farmers within the local economic context.

- Advice on plant nutrition management should include assistance in decision making at plot and at farm level, in order to optimize the use of local resources and the ability of farmers to intensify production within the existing economic environment.

Advice should also be provided at village level or in small watersheds on the management of and investment in local sources of nutrients available from vegetation and livestock. Such advice is most cost-effective if the private and public sectors cooperate in helping the farmers. Information about the potential environmental impact of plant nutrient management should be provided to everyone concerned. Correct research backup is essential.

- The possible environmental impact of the overuse, underuse and misuse of plant nutrient sources is discussed.

- National policies should facilitate the development of sound plant nutrition management and the investments needed to intensify production while conserving the natural resource base.

The major aspects put forward for consideration are:

- assessment of plant nutrient requirements for meeting crop production targets;
- choice of sources and methods of supply;
- determination of the level of domestic fertilizer production required;
- price levels and the issue of subsidies for plant nutrients;
- legislative aspects; and
- support for extension and research.

Policy-making in these areas determines the extent to which farmers have access to plant nutrients and are able to increase their production while maintaining soil fertility. A farmer needs purchasing power to obtain external inputs, as well as advice on how to use them in a balanced way. The guide outlines appropriate policies in the areas of assessment, marketing, transport and storage, training, pricing, legislation, packaging, advice and planning, and financing. It emphasizes that the right balance of government and private participation in the production, importation and distribution of fertilizers needs to be found. In addition, it advocates setting up national plant nutrition focal points to advise on policy and to regulate the availability, quality, production and trade of plant nutrients (in particular fertilizers) in a way that complements the overall plant nutrition strategy of the government, and then to implement that policy.

Contents

Challenges for plant nutrition management

The challenges for plant nutrition management are to maintain (and where possible increase) sustainable crop productivity to meet demands for food and raw materials, and to enhance the quality of land and water resources. There is no contradiction between these challenges. Indeed, environmental hazards can be minimized by matching plant nutrients with crop requirements, and judicious soil and water conservation methods.

Agriculture inevitably removes plant nutrients from the soil and from the farm. Consequently, if a farming system is to be sustainable, these nutrients have to be replaced by whatever sources are available. For the farmer, nutrient losses are money wasted.

In many developing countries, the loss of soil fertility from continual nutrient mining by crop removal without adequate replenishment, combined with imbalanced plant nutrition practices, poses a serious threat to agricultural production. It is already causing yield decreases as large as those caused by other forms of environmental degradation.

While recycling and transfer of nutrients from non-crop areas, crop residues and animal manure can partially make up for exports of nutrients by harvested products, the use of external sources such as mineral fertilizers is essential to meet crop requirements and to increase crop production in many farming systems. Intensification of agriculture by increasing the use of plant nutrients is limited by environmental hazards and economic constraints. In industrialized countries, environmental issues and international trade agreements restricting surplus food production are now the limiting factors on further intensification; in developing countries, the high cost of external sources of nutrients and their inadequate availability limit intensification.

Considering the importance of plant nutrients to

THE OBJECTIVES OF THIS GUIDE

The objectives are to set forth responsibilities and propose guidelines for all parties engaged in or influencing the production, distribution and use of plant nutrients, with special reference to fertilizers.

Reference is made to the shared responsibility of many segments of society, including governments, individually or in regional groupings, industry, trade, international institutions and farmers, to work together with a common aim: an efficient use of plant nutrients that will lead to intensified and sustainable agriculture and protection of the natural resource base.

The guide specifically aims to:

- promote a better understanding of the role of plant nutrients in securing the sustainability of agriculture and in building up and maintaining soil productivity;
- ensure that all sources of plant nutrients, especially fertilizers, are used efficiently for increased agricultural production;
- identify how the application of plant nutrients can affect the environment and point to ways of avoiding negative impacts;
- formulate recommendations for plant nutrition management in a framework of IPNS, taking into account farmers' production goals and strategies within specific agro-ecological, social and economic conditions;
- promote the development of sound advisory services and efficient input supply systems to farmers;
- facilitate the emergence of farmers' associations leading to the adoption of sound plant nutrition practices; and
- provide elements for the design of national strategies and policies for effective plant nutrition in support of agricultural intensification and rural development.

agricultural production, it is imperative to establish the relationships between yield, use of plant nutrients, economic feasibility and environmental quality. What farmers need to know is how much and which plant nutrients they should supply to provide the optimum economic increase in yield without damaging the environment. The answer depends on the ecological, social and economic characteristics of each farming system.

Increased attention is now being paid to developing Integrated Plant Nutrition Systems (IPNS) that maintain or enhance soil productivity through a balanced use of mineral fertilizers combined with organic sources of plant nutrients, including biological nitrogen fixation. IPNS is ecologically, socially and economically viable, and it can increase both soil productivity and crop yields. It focuses first on the seasonal or annual cropping system, rather than on an individual crop; secondly, on the management of plant nutrients in the whole farming system; and, thirdly, on the concept of village or community areas rather than individual fields.

The FAO study *World agriculture: towards 2010* estimates that about two-thirds of the needed increase in crop production in developing countries will have to come from yield increases on land already under cultivation. Plant nutrients are the most important inputs for increasing yields. Over the past three decades, additional nutrients applied as fertilizer have been responsible for 55 percent of the yield increases in developing countries. The development of plant nutrition management to increase the quantity of plant nutrients in farming systems and thus crop productivity is a major challenge for food security and rural development.

This guide promotes the effective management of plant nutrients. It is relevant to farmers, advisory services, research and extension bodies, development agencies, financial institutions, the fertilizer industry and government decision-makers in both developed and developing countries — in fact to all those concerned with sustainable agricultural production and environmental protection.

Sources of plant nutrients

Nature and supply of plant nutrients

Plants build up their biomass using water, carbon dioxide from the air, energy from sunlight and nutrients taken up from the soil and water. For optimum plant growth, nutrients must be available:

- as solutes in the soil water;
- in adequate and balanced amounts, corresponding to the instant demand of the crop;
- in a form which is accessible to the root system (except when provided through foliage).

Plants are supplied with nutrients mainly from:

- soil reserves;
- mineral fertilizers;
- organic sources;
- atmospheric nitrogen through biological fixation;
- aerial deposition caused by wind and rain;
- irrigation, flood or groundwater, and sedimentation from runoff.

These sources are used by farmers according to their availability and affordability. The total amount of plant nutrients available to the crop is a key factor determining yield.

Plant nutrients

These are elements that are essential for plant growth and that are taken up from the soil or from water — irrigation, flood or groundwater — or are supplied via a hydroponic medium. The primary nutrients are nitrogen, phosphorus and potassium which are consumed in relatively large amounts. Three secondary nutrients are taken up in smaller quantities but are essential for plant growth: calcium, magnesium and sulphur. Micronutrients or trace elements are required in very small quantities but are often important for plant or animal metabolism. They include iron, zinc, manganese, boron, copper, molybdenum and chlorine. In addition, some plants benefit from the presence of sodium, cobalt and silicon but these do not rank as essential nutrients.

Soil reserves

Soils contain natural reserves of plant nutrients in quantities that depend on soil composition and stage of weathering. These reserves are often in forms unavailable to plants, and only a minor portion is released each year through biological activity or chemical processes. This release is too slow to compensate for the removal of nutrients from agricultural production, especially in the humid tropics where soils are strongly weathered. The quantities (or stock) of plant nutrients available for a crop are determined by the supply of nutrients to the crop from internal and external sources, the uptake of nutrients by the crop, and losses of plant nutrient to the environment. Thus plant nutrient stock is constantly changing. The capacity of a soil to store easily-available plant nutrients is an important factor in plant nutrition management. Chemical analysis can provide an approximation of the nutrient stock, the accuracy of which is related to soil type, cropping conditions and crop species.

Fertilizers

These are mineral or organic substances, natural or manufactured, that are applied to soil, irrigation water or a hydroponic medium, to supply plants with nutrients. Fertilizers contain at least 5 percent of one or more of the three primary nutrients (N, P_2O_5, K_2O). The term is often used as an abbreviation for mineral fertilizers (see below). Products with less than 5 percent of combined plant nutrients are called plant nutrient sources. The legal definition of a fertilizer varies in different countries.

sources of plant nutrients

Mineral fertilizers

Mineral fertilizers are manufactured in liquid or solid form, usually in an industrial process. They can supply main nutrients, secondary nutrients, micronutrients or mixtures of nutrients. Straight fertilizers supply only one nutrient while complex fertilizers supply several. Compound fertilizers are produced by the blending or chemical linkage of straight fertilizers or nutrients. The terms chemical or artificial fertilizers are often used for these products but are misleading because the nutrients supplied by mineral fertilizers are the same as those supplied by the mineralization of organic material through soil micro-organisms; indeed, some fertilizers are directly derived from natural products such as guano, potassium salts or natural sodium nitrates. Mineral fertilizers have a higher plant nutrient content and a lower bulk than organic sources of plant nutrients. High-grade fertilizers contain more plant nutrients (up to 82 percent) than low-grade fertilizers, producing savings on transport and handling costs.

Organic sources

These nutrients are materials of organic origin, either natural or processed. The term organic fertilizers is often used incorrectly to describe nutrient sources containing less than 5 percent of at least one of the three primary nutrients. In this sense, some organic materials of animal origin — such as guano, bone meal, fishmeal, and blood — are true fertilizers but commonly used organic sources of nutrients, such as manure, slurry, compost and sewage sludge, are not. Organic materials can be used to increase the amount of organic matter in the soil, thus enhancing its water retention and exchange capacity, and its physical condition.

Farmyard or animal manure is a mixture of animal excreta and the litter used for bedding. Green manure is fresh, locally produced plant material that is worked into the soil without composting or digestion by animals. When leguminous crops are used as green manure, the atmospheric nitrogen they have fixed is also added to the soil. Slurry is a mixture of liquid and solid animal excreta, sometimes diluted with water. Sludge is residual organic material derived from sewage. Compost consists of organic materials of animal and plant origin partially decomposed through fermentation; mineral fertilizers are sometimes added to it.

Biological nitrogen fixation

Some micro-organisms are able to convert nitrogen in the air to ammonia for use as their nitrogen source. The conversion is made by bacteria living either on their own in the soil or, on a considerably larger scale, in symbiosis with leguminous plants or trees (*rhizobium*), or other specific trees (*actinomycetes*), or with azolla in aquatic conditions (blue-green algae). Biological nitrogen fixation can be enhanced by inoculation with efficient strains of nitrogen-fixing micro-organisms, part of the fixed nitrogen being directly assimilated by plants. The term biofertilizers is sometimes inappropriately used for these micro-organisms; microbial inoculants is the preferred term.

Aerial deposition

Some nutrients are supplied in small quantities to the soil surface through aerial deposition. These include nitrates in rainwater, ammonia as a gas or dissolved in rainwater, sulphur in acid rain, salts and chlorine in marine spray and calcium in the form of dust.

Irrigation water, floodwater and groundwater

These sources also supply plant nutrients, either naturally or because fertilizers have been added to the irrigation water. While water often contains small amounts of nutrients, irrigation can also result in a loss of nutrients from leaching. Some of the nutrients provided by surface and groundwater originate from plant nutrient losses within the watershed.

Soil amendments

Amendments are substances that are applied to the soil to correct a major constraint other than low nutrient content. Lime, for example, is used to remedy acidity; phosphates are used to reduce phosphorus fixation; gypsum is used to improve sodic (alkali) soils; and peat can be added to the surface layers to increase organic matter content.

Gathering sources of plant nutrients

The natural plant nutrients found in the soil are deposited there either from the air or from water, or result from nitrogen fixation and the weathering of mineral particles in the soil. Vegetation takes up some of these nutrients, some are geographically redistributed by runoff, and some are lost by volatilization, fixation and leaching. Farmers harvest the natural supply of these nutrients for their crops and reorganize their distribution in space and time through their production systems.

On land under natural vegetation, the organic matter that accumulates at the soil surface releases plant nutrients as it decomposes (or when it is burnt in a fire). Nutrients taken up from deeper layers thus eventually become available to plants in the topsoil. Slash-and-burn systems exploit this nutrient management technique. As crops are harvested, the local supply of nutrients is progressively depleted; eventually the land must be left in a prolonged fallow or replenished with external nutrients.

The practice of allowing short fallow periods on arable land is another means of accumulating the natural supply of nutrients for a later cropping period. However, much less nutrients are gathered in a short fallow period than in a long fallow, of ten years or more, in perennial vegetation.

Farming systems redistribute and concentrate natural nutrients in a number of ways. For example:

- some traditional farming systems allow livestock to graze a large non-cropped area and the manure is then collected and spread over a selected cropped area;
- forest litter is collected and used to mulch a cropped area;
- manure from animals kept in corrals and shelters is spread on cropped areas;
- feedstuffs are imported to the farm and fed to livestock whose manure is then spread over cropped areas;
- crop residues are collected and processed (by composting or in biogas plants) and then spread on cropped areas; and
- leguminous crops are grown to supply the plant nutrients that are produced by nitrogen fixation.

Management of plant nutrients

Restoring, maintaining and increasing soil fertility are major agricultural priorities, particularly in the many parts of the developing world where soils are inherently poor in plant nutrients, and the demand for food and raw materials is increasing rapidly. In these areas, there is a need to intensify crop production to meet demand for food without using former land fallow practices. A fertile soil provides a sound basis for flexible food production systems that, within the constraints of soil and climate, can grow a wide range of crops to meet changing needs.

Integrated Plant Nutrition Systems

IPNS associate available, accessible and affordable plant nutrients to increase farm productivity and economic returns.

IPNS operate at plot, farm and village or territory levels. At the plot level, they are designed to optimize the uptake of plant nutrients by the crop and increase the productivity of that uptake (the ratio between harvested products and nutrient uptake) while reducing nutrient losses. The optimal nutrient supply is determined by the production methods used, the prevailing prices of fertilizers, the cost of mobilizing local nutrient sources and the commercial value of the crop. IPNS increases plant nutrient stocks in soils and improves other aspects of soil fertility such as water infiltration and water-holding capacity; it also reduces limitations on crop growth caused by factors such as soil acidity and compaction. IPNS make use of crop rotations to optimize nitrogen fixation, the efficient management of crop residues, exploration of the soil by developing rooting systems, and management methods that limit nutrient losses (by exploiting nutrients that are released slowly from organic and mineral sources).

At farm level, IPNS aim to optimize the productivity of the flows of nutrients passing through the farming system during a crop rotation (see figure on page 11). IPNS improve the production capacity of farmers through application of external plant nutrient sources and amendments, efficient processing, and recycling of crop residues and on-farm organic wastes that limit plant nutrient losses. IPNS empower farmers by increasing their technical know-how and decision-making capacity, and promote changes in land use, crop rotations, and interactions among forestry, livestock and cropping systems in support of agricultural intensification. IPNS require financial and labour investments, generate additional income and promote an increased rate of return from all inputs. IPNS involve risk management and enhance the synergy among crop, water and plant nutrition management.

At the level of the village or farming community, IPNS take into account plant nutrient sources outside the cropped areas. These include plant nutrients in irrigation water and flood sediments, manure produced by livestock grazing, forests and permanent pastures, and forest litter and organic material that is physically transferred from forest and pastures to the cropped area. In

FAO'S IPNS APPROACH

IPNS is used to maintain or adjust soil fertility and plant nutrient supply to achieve a given level of crop production. This is done by optimizing the benefits from all possible sources of plant nutrients.

The main objectives are to:

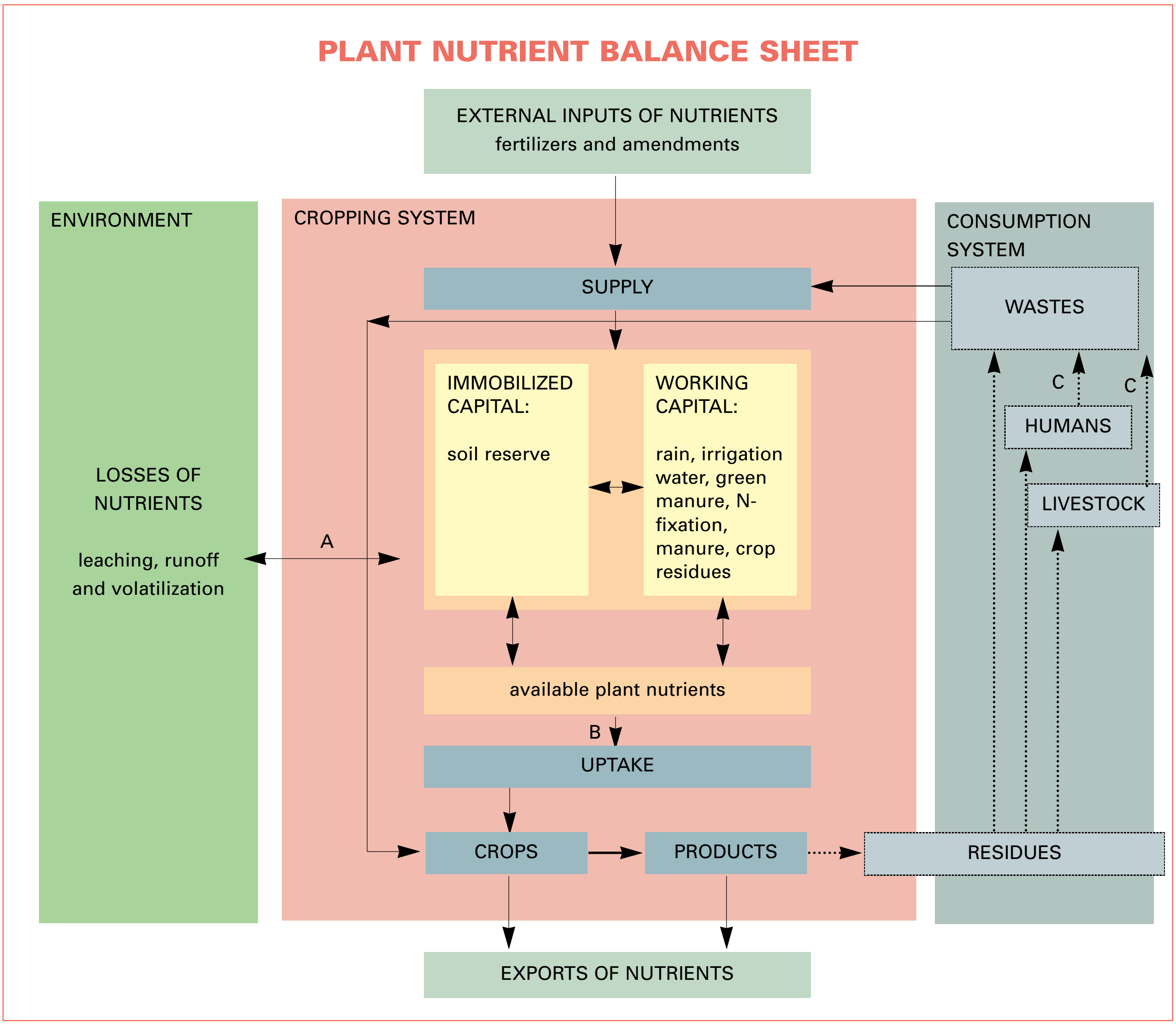
- maintain or enhance soil productivity through a balanced use of mineral fertilizers combined with organic and biological sources of plant nutrients;
- improve the stock of plant nutrients in the soil;
- improve the efficiency of plant nutrients, thus limiting losses to the environment.

peri-urban agriculture, farmers purchase manure from industrial livestock systems and organic wastes from cities. IPNS promote the rationalization of the transfer of organic matter and plant nutrients from non-cropped areas to cropped areas, and the mobilization of unused nutrient resources or the saving of valuable nutrient sources diverted as domestic fuel, raw materials for building or for industrial purposes. At village level, IPNS also involve the development of the financial capacity of farmers for the adoption of change through farmers' associations.

▼ *The following plant nutrient balance sheet highlights three ways in which farmers can improve nutrient use:*
A: reduction of plant nutrient losses by limiting runoff through investment in soil drainage;
B: increase of nitrogen uptake by introducing cover crops;
C: reduction of nitrogen losses from wastes by improving manure management.

Plant nutrient balance

An agricultural ecosystem differs from a natural one in that plant nutrients are constantly being removed and exported, and in that sources of plant nutrients outside the cropped area may be used to increase production. In a natural ecosystem, the supply of nutrients at least compensates losses from runoff, leaching and volatilization and, in favourable conditions, nutrients accumu-



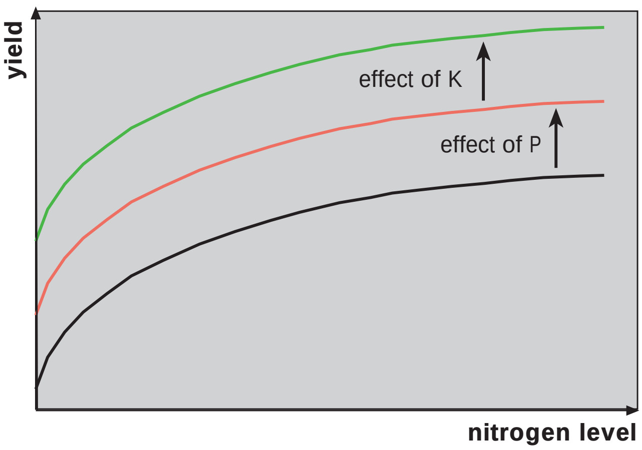
late in the perennial vegetation and in the topsoil. In agricultural systems, farmers intervene at several stages of the plant nutrient cycle in order to optimize crop production and the corresponding export of nutrients (see diagram opposite).

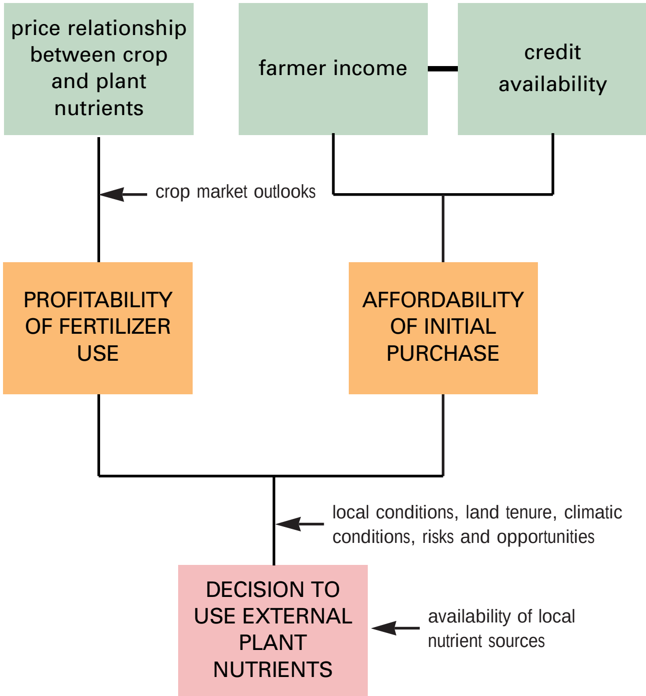
Farmers try to satisfy plant nutrient demand by using the 'immobilized capital' of plant nutrients in the soil and the 'working capital' of plant nutrients from natural and organic sources. They complement these with external nutrients. However, the nutrients stored in the soil should not be depleted beyond a critical level. These nutrients cannot be transferred rapidly from one plot to another. Plant nutrients in crop residues, manure, litter from forests, green manure and domestic wastes compose a 'working capital' because farmers can transfer them and allocate them to a particular crop in a crop rotation and to a particular plot.

A balance sheet can be established for every nutrient. The efficiency of a production system depends on the importance of crop uptake versus the total supply of nutrients. High losses of nutrients limit the efficiency. Plant nutrient stocks can be 'mined' providing this does not affect the annual supply of nutrients or the general status of soil fertility.

Normally, insufficiency of one plant nutrient limits the efficiency with which other plant nutrients are taken up, reducing crop yield (see diagram below). Unbalanced availability of nutrients can lead to mining of soil reserves for nutrients in short supply and to losses of plant nutrients supplied in excess. Lack of balance also encourages excessive uptake of the nutrients supplied in excess, decreasing the productivity of those nutrients. Unbalanced fertilization is an uneconomic waste of scarce resources.

▼ *Yield response to balanced plant nutrition: insufficiency of one plant nutrient limits the efficiency with which other plant nutrients are taken up, reducing crop yield.*





▲ *Decision-making process used by farmers for crop fertilization.*

In practice, the quantity of nutrients available for recycling via plant and animal residues is rarely sufficient to compensate for the amounts removed in agricultural products, even in low-productivity situations. In addition, losses inevitably occur, even in the best-managed systems. Consequently, mineral fertilizers have to play a key role in areas where increased agricultural production is required.

Economic aspects of fertilizer use

Farmers apply plant nutrients only if their effects on crop yields are profitable. The decision to apply external plant nutrients is generally based on economics (price and affordability) but is also conditioned by availability and the production risks involved. The pursuit of higher production has to be balanced against the need to maintain soil fertility and avoid soil degradation. The profitability of adopting IPNS should, however, be viewed over the long term, since improved efficiency in crop nutrient use tends to become apparent only after several seasons.

A number of economic and institutional factors must also be taken into account:

- the price relationship between plant nutrients and the crops to which they are applied, together with the market outlook for these crops, determines how profitable it will be to use fertilizer;
- income and the availability of credit decide whether farmers can afford to buy plant nutrients;
- lack of security of land tenure can reduce the incentive for farmers to use fertilizers.

Small-scale farmers with few resources are compelled to look for short-term results when applying plant nutrients. The removal of access constraints to markets and production technology, and protection from risks, would allow farmers to use plant nutrients economically and in ways that support sustainable crop production.

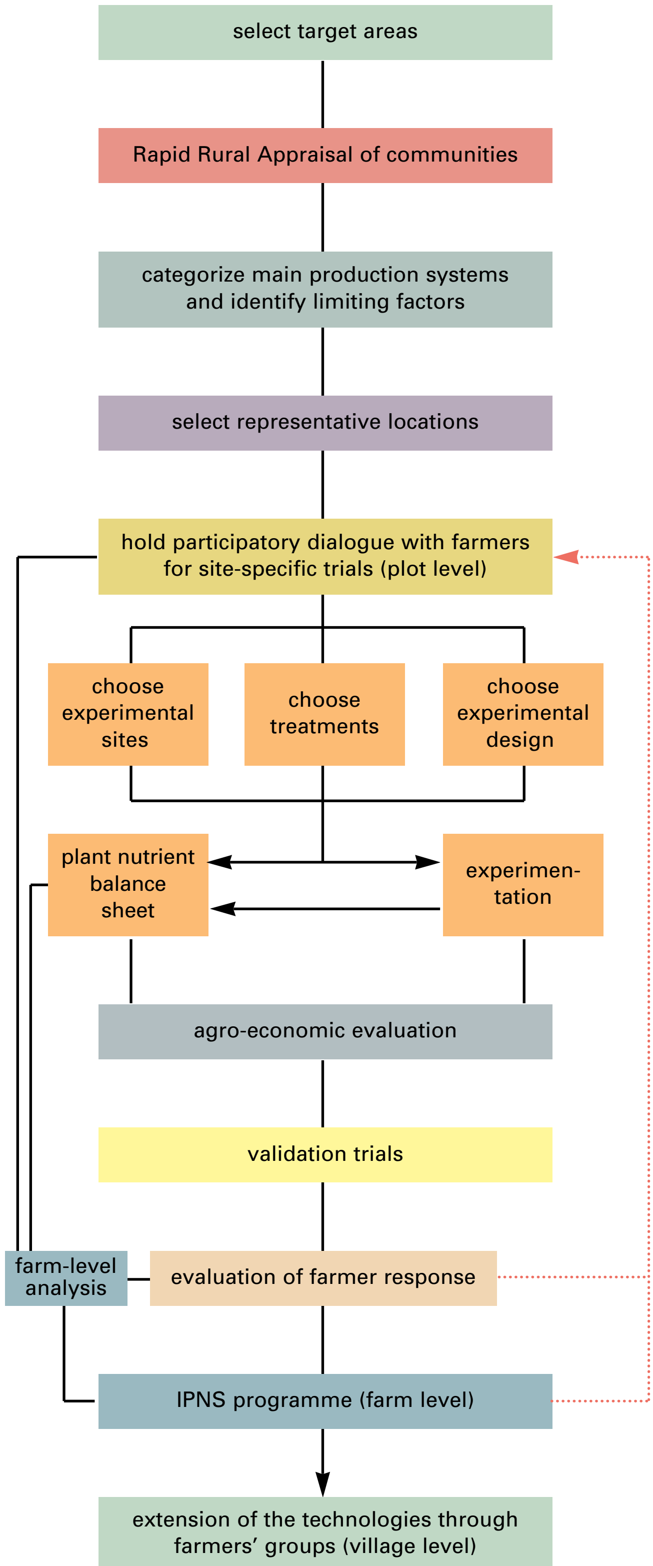
Advice on efficient plant nutrition

Providing good advice to farmers and enhancing their decision-making capacity is the best way to promote the sustainable intensification of agriculture. Such advice:

- requires a good knowledge of farmers' cropping systems, socio-economic conditions and decision-making processes;
- should use farmers' participation to identify and test suitable innovations;
- should be organized in steps from plot level to farm, village territory and small watershed level;
- should include short-term suggestions for the fertilization of crop rotations and longer-term suggestions for accumulating plant nutrients on the farm and improving soil fertility;
- must promote sustainability.

The organization of correct advice is costly and the sharing of this cost among the government, the farmers'

IPNS IMPLEMENTATION METHODOLOGY



communities and the private sector is desirable. The steps involved are summarized in the diagram *IPNS Implementation Methodology*.

The extent of the study can be defined only after initial discussions with farmers, extension agents and research workers in the area, and a rapid survey of the area. The latter should be conducted by a multidisciplinary team including plant and livestock scientists, social scientists and economists. The study should determine the physical, biological and socio-economic environments, sociocultural characteristics, and production system and land use. Discussions should also be held with farmers to determine their production objectives and constraints, and to get a general idea of their perceptions and living conditions.

▲ *Discussions between a multidisciplinary team and farmers.*

Plot level

Advice at plot level should be based on local on-farm experiments. These experiments will provide information on the impact of combined nutrient doses, timing of nutrient supply, and sources of nutrients on crop yields. The experiments should be simple and are of two types: site-specific trials and validation trials.

The data collected from the trials are used to derive nutrient response curves for the predominant cropping systems and conditions. These trials are usually managed by public sector researchers because they require a fair degree of control of variability as well as a high level of supervision. Farmer participation in information gathering and decision making is minimal.

▲ *On-farm experimental site.*

However, researchers can interact with the farmers and learn about their methods of production. Important considerations in planning site-specific trials are population definition, choice of sites, choice of treatments, experimental designs, and management of the experiment.

Sites for the trials should be representative of the farming conditions of the area being studied.

Site-specific, researcher-managed trials

Farmers must be involved in all stages of planning and execution of the trials so that they understand the aims and objectives of the experiment and are willing to participate. Researchers and extension workers must first listen to the farmers' concerns and establish a relationship with the farmer. Farmers must feel that they are equal partners in the experimentation process. The benefits of the research, the importance of farmer participation and the expectations of the relationship must be explained to farmers. Each participant — researcher, extension worker and farmer — must be apprised of his or her responsibilities (who does what, who takes what risks and who gets what products) so that all operations are conducted on time and there is no misunderstanding of roles.

All data collected from the trials should be screened, validated, analysed and interpreted by the researchers after completion of the trial. The results obtained will be used to adjust treatments for subsequent trials and to identify promising treatments which can be applied in validation trials.

Validation trials

When promising plant nutrition treatments have been identified, they are tested on farmers' fields in validation trials. Validation trials are conducted by farmers themselves under the overall supervision of extension workers and researchers. These trials generate valuable information on farmers' understanding, acceptance, rejection, adaptation or adoption of the proposed innovations.

The farms should be selected for characteristics (such as slope, integration of livestock and level of management) that are similar to those used for the site-specific trials. The farms should also be representative of all farmers in the area of study — both good and bad, so that the range of possible responses to the technology is obtained.

Data generated from these validation trials are screened, validated, analysed and interpreted by extension workers. The data are then compared with the references obtained from the researcher-managed trials to evaluate the farmers' progress and determine possible improvements.

Farm level

Farmers' decisions on how to use plant nutrients depend on the situation of the entire farm and its crop rotation system. Factors taken into consideration include: production objectives, available resources (both fixed and variable, such as land, labour, capital and credit), needs for home consumption, market opportunities and climatic conditions.

These factors must be well understood before alternative plant nutrition schemes can be suggested. In addition, advisers must identify the centres of decision making, the organization of land use and crop rotations, and the competing demands for scarce resources such as organic material, labour and capital.

As a first step, an apparent plant nutrient balance (inputs versus outputs) as well as the practices which may be contributing to nutrient losses or inefficient plant nutrient management should be analysed. This analysis may suggest alternative technologies. The box below gives some potential solutions.

Once all potential plant nutrient sources have been identified and possible technologies selected, farmers can determine the correct mix of these technologies to optimize their resource use and meet their production objectives. The new alternatives may involve an increase in labour requirements or financial investments, modification of the farm structure or adaptation of land use and crop rotations. Arrangements will, therefore, need to be made for a complementary supply of external inputs. In particular, attention should be given to farm-

MANAGEMENT SOLUTIONS TO PLANT NUTRIENT LOSSES

source of nutrient loss	*technology option*
Leaching, volatilization or immobilization after harvest	Cover crops to trap most of remaining nutrients Production of very short-term crops with limited instant demand for nutrients after the main crop has matured
Fires, leaching and runoff of crop residues and composts	Modification of methods of land preparation, livestock feeding, crop rotation or land use
Livestock waste products	Urine and dung collected, processed and re-applied to cropped area Better management of manure and slurries by modifying livestock housing and organizing cheap, labour-saving collection systems for wastes (these systems should be socially and culturally acceptable to the farmer)
Domestic and human waste products	Recycle wastes by organizing cheap, effective, labour-saving collection and processing systems. These systems should be safe, and socially and culturally acceptable Ferment wastes in tanks at high temperatures and mix wastes with crop residues

ers' purchasing capacity for these external inputs. The proposed technological package which entails the use of plant nutrients from different sources must be tested to verify its appropriateness to the farmers' situation and to evaluate farmers' acceptance of the technology. This is done through a network of local pilot farms which is used to evaluate the impact of change on farming conditions. The farms also serve as 'demonstration plots' for neighbouring farmers who may adopt the technology if they see it is to their benefit.

▲ *Green manuring of leguminous plants on a pilot farm.*

In implementing the technology on the pilot farms, farmers must agree on:

- their need to change from their current production system;
- the way in which they and the extension workers will implement the change; and
- mechanisms of risk management during the change.

For these reasons, the choice of farmers and the relationship between farmer and adviser are critical to success. Farmers should be representative of the region and willing to cooperate. Close interaction between extension workers and farmers is needed at all times so that farmers' questions can be answered. This also allows the extension worker to evaluate the farmers' response to the technology and find out why they accept or reject it. Sometimes, farmers modify the proposed technology. Extension workers can then determine the reasons for the change and alter treatments in subsequent seasons.

The network of pilot farms should run for at least one entire crop rotation, with the results for each season being used to adjust treatments for subsequent crops. Estimates should be made of crop production and productivity, as well as plant nutrient status, and economic variables such as cash flows, savings and labour inputs. The decision to change the mix of nutrient sources should be guided by whether the benefits of the innovation (both economic and social) outweigh the cost of the investment.

The process of planning, implementing and evaluating change at the farm level is costly and requires a cadre of trained researchers and extension workers, and costly equipment. It can therefore be done only through a limited series of case studies. These can then be used to generate guidelines, methods and reference material which can be adapted by other researchers and extension workers for their specific situations.

Village level

In many traditional low input/low output farming systems, plant nutrition management relies on local nutrient resources collected in areas other than those farmed. Development of an efficient plant nutrition management system should, therefore, extend beyond the farm to the village territory. The main considerations at the village level are:

- management of the transfer of plant nutrients from non-cropped to cropped areas;
- investments for soil and water conservation and their impact on plant nutrient efficiency;
- the effect of poor plant nutrition management practices on the village community; and
- farmers' groups and organizations.

Plant nutrients from non-cropped areas include litter from forests and fodder from pastures. Improving the transfer of these materials to the cropped area can enhance the plant nutrient content in the cropped area.

Some examples of improved management practices include the cultivation of leguminous forest species, alley cropping of forests with pasture crops, mineral fertilization of pastures, regulation of bush fires and development of systems for allocating manure produced by collective herds.

Soil and water conservation can greatly reduce losses of plant nutrients through runoff and leaching. In addition, water harvesting techniques and the development of irrigation will lead to increased efficiency of nutrient use. These investments require the cooperation of the entire village and must therefore be considered while developing efficient plant nutrition management systems.

Poor plant nutrient management by individual farmers results in a decrease in soil fertility because of heavy mining, erosion, silting and deforestation. Similarly, an oversupply of nutrients may pollute drinking water and poor management of organic wastes is a potential heath hazard. Thus the involvement of sound plant nutrient management by the entire farming community is essential in developing a system at the village level.

At the village level, farmers' groups can create favourable conditions for the procurement of inputs and access to credit. Farmers' associations, trade connections between these associations and the input sector as well as traders in agricultural products and banks should therefore be encouraged to support improved plant nutrition management by farmers.

Research backup

Advice on quantities of nutrients to be applied may be based on empirical results from field experiments, on soil or plant analysis, on a nutrient balance-sheet approach, on mathematical models of nutrient dynamics, or on a combination of methods. In the absence of more detailed information, knowledge of the quantities of nutrients removed by crops at the desired yield level provides a starting point for estimating nutrient requirements.

Field experiments are valuable in providing quantitative information on the supply of nutrients from soil and organic residues, and the short-term effects on crop yield from mineral fertilizers supplied in different forms and quantities. This provides a vital basis for advising farmers and for testing and improving advice systems.

Wherever possible, long-term field experiments should be set up so that residual effects of fertilizers and organic sources on crop growth and soil properties can be studied and taken into account when formulating nutrient recommendations. Such experiments can also provide information on interactions between nutrient applications and other agricultural activities, and on the likelihood of unforeseen problems such as environmental contamination or deficiency of a secondary or micronutrient. In this context, the need for balanced plant nutrition should be emphasized.

Research organizations are responsible for informing the public about the innovations and their potential impact.

Environmental issues

Many people are concerned about the possible side effects of plant nutrients on the environment. This concern refers both to the use of mineral fertilizers and organic sources of nutrients, the latter in connection with intensive livestock farming that leads to the production of so much organic waste that it cannot be used effectively, converted or disposed of. Four important issues have to be highlighted:

- Fertilizers are often referred to as agrochemicals, a term which groups plant nutrients with insecticides, herbicides and fungicides. A clear distinction must be made between fertilizers, which provide nutrients that are essential for plant growth, and biocides, compounds that kill, which are used for plant protection.
- The environmental effects of applying plant nutrients can be positive or negative, and statements on the issue should be objectively balanced.
- The amounts of plant nutrients, both mineral and organic, that are applied in developing countries are relatively low. Local excesses in some industrial countries should not prejudice increased agricultural production in the developing world.
- Environmental problems related to the application of plant nutrients depend less on the nature of the nutrients than on the amounts and the way they are applied. Detrimental effects are mostly due to overdoses or to improper or unbalanced use that can be corrected by improved management practices.

The positive effects are summarized in the box below and the negative effects in the text that follows.

Negative effects with high inputs

Not all nutrients applied to the soil are taken up by the growing crop and the remainder may become an environmental hazard. Unused nutrients can remain in the soil, be removed in water leaching through the soil or in runoff, or be lost to the atmosphere by volatilization. The relative importance of these phenomena depends on the physico-chemical and biological reactions in which the nutrients take part.

POSITIVE ENVIRONMENTAL EFFECTS OF PLANT NUTRIENTS

- efficient use of plant nutrients ensures that yields are higher than those obtained on the basis of inherent soil fertility by correcting either an overall deficiency or an imbalance of nutrients;
- nutrients removed from the soil through harvesting and export of produce can be replenished in order to maintain and enhance production potential;
- by increasing yields per unit area on good arable land, plant nutrients allow land of low quality, for example land susceptible to erosion, to be withdrawn from cultivation and reduce overall pressure on the land, including deforestation and overgrazing of non-cropped areas;
- plant nutrients ease the problem of erosion control on cropped areas because of the protection provided by a dense and vigorous crop cover;
- IPNS promote the correct management of plant nutrients on the farm and the watershed, optimizing the economic value of the nutrients and limiting nutrient losses to the environment.

Nitrogen: under normal farming conditions, on well-drained soils and with favourable temperature conditions, all soluble nitrogen compounds are fairly rapidly oxidized to nitrate. Nitrate is not absorbed to any appreciable extent by soil particles. Nitrogen is therefore the most likely fertilizer element to be leached out into surface water or groundwater, or to be lost to the atmosphere by denitrification, partly as nitrogen gas and partly as nitrous oxide, which is a greenhouse gas.

Nitrate derived from the breakdown of organic matter in soil, slurry or manure applied to land is also subject to leaching. In many temperate regions, this is often a more significant source of nitrate than mineral fertilizer. Improved farming practices can help reduce the leaching by maximizing utilization of the nitrate provided by the soil, and applying just the right amount of nitrogen at the right time for each crop. Researchers trying to understand changes in nitrate concentrations in drainage waters should take due account of changes in land use and agricultural practice, as well as fertilizer use.

In industrialized farming systems, intensive animal husbandry is a major cause of the leaching of nitrogen. This is partly due to untimely mineralization of nitrogen from urine, faeces, and manure or slurry. Nitrate produced when crop growth is not vigorous can be the origin of leaching or denitrification. The other main problem is ammonia volatilization, both from manure heaps and from soil soon after manure application. Ammonia can also be volatilized if urea fertilizer is applied to soil of high pH under warm and dry conditions.

Phosphorus: plants are supplied with phosphorus in the form of phosphate ions. They are immobilized in the soil, being strongly adsorbed by the surfaces of iron, aluminium and manganese oxides and hydroxides, and by clay particles. Applied phosphate that is not taken up by the crop remains in the soil unless it is washed off the land by runoff or by soil erosion. Phosphate can also occur in high concentrations in irrigation water and drainage water from inundated soils. Excess inputs of phosphates to surface waters can lead to eutrophication and algal blooms.

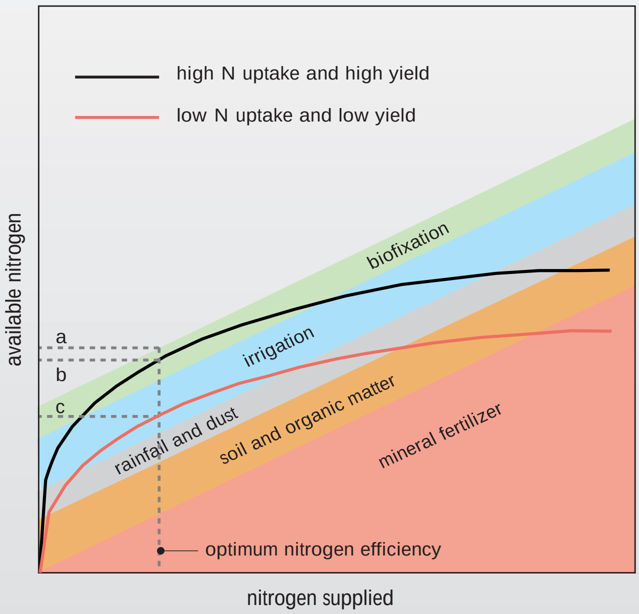
IPNS INCREASES NUTRIENT EFFICIENCY AND REDUCES LOSS TO THE ENVIRONMENT

Plant nutrients are supplied from sources such as mineral fertilizer, the soil, rainfall and dust, irrigation water and biofixation. As the graph shows. the contributions of these sources are cumulative.

The crop takes up a portion of the available nitrogen, regardless of its origin. Available nitrogen not taken up by the plant is lost to the environment. This loss is the difference between the total available and the total uptake — the difference between the top line of the biofixation block and the relevant uptake curve.

At low levels of supplied N, there is little uptake and so the loss of N to the environment is high. As the nitrogen supply increases, the plant takes up more of the nitrogen until it cannot increase its uptake any further. Supplying additional nitrogen results in increased losses to the environment.

Plant nutrient loss is minimized at the point where the distance between the uppermost line and the uptake curve is smallest. For a crop with a low level of uptake, the minimum loss of nitrogen is the difference (a-c). For a higher level of uptake, the minimum loss is (a-b). These minima occur at the ecological optimum level of N supply. To increase nutrient efficiency (uptake), farmers should practise IPNS and optimize all other production factors.



Phosphate fertilizers may contain cadmium when sedimentary rock phosphate is used as raw material. Cadmium is also added to the soil by aerial deposition. Current fertilizer usage presents no immediate hazard. However, cadmium should be removed when raw materials are processed, wherever possible.

Potassium: potassium ions, in addition to being taken up by plants, are adsorbed by the soil and can even be fixed within clay particles. Added potassium that is not taken up by the crop is therefore not very mobile in soils that contain clay. In sandy soils, some applied potassium may be leached out. Major losses of potassium are caused when the element is washed away in liquid manure from farmyards and dairies. Potassium in water has no detrimental effects but may indicate the presence of sewage or animal effluent. Potassium is not a major factor in the eutrophication of surface waters.

Negative effects with low inputs

Soil fertility: the constant removal of produce without or with insufficient replenishment of plant nutrients causes a steady decline of soil fertility. This mining of plant nutrients, leading to severe depletion of soil fertility, is a major environmental hazard in a number of developing countries.

Land expansion: if land and labour are available, low yields resulting from nutrient depletion force farmers to expand cultivated land, often at the expense of forested areas or marginal soils subject to erosion or desertification.

Amendments: large areas in the tropics are inherently poor in soil nutrients and suffer from acidity and aluminium toxicity. Organic recycling does not offer a solution since the biomass produced in such soils is itself extremely poor in essential plant nutrients. These soils cannot be made productive without amendments and a basic input of plant nutrients. Low or zero use of plant nutrients on such soils prevents the development of agricultural production on a sustained basis.

Overcoming the negative effects

The negative effects of applications of plant nutrients, both at low and high levels of input, can be avoided or remedied by good management. Balanced fertilization should overcome the hazards of nutrient depletion and of mining soil fertility. Judicious management of plant nutrients can prevent pollution, mainly through practices that reduce losses of nutrients to aquifers or the atmosphere. These practices include balanced, timely, targeted fertilization combined with other practices (such as improved varieties, water management and plant protection) that stimulate maximum uptake of plant nutrients by the crop. Due attention should also be given to controlling losses from soil erosion and runoff, and through appropriate land management. IPNS provide excellent means of doing this at all productivity levels if farmers are properly advised.

Policies for effective plant nutrition

Long-term planning and monitoring of the use of plant nutrients must reconcile four objectives:

- agronomic and economic efficiency to maximize agricultural output from available nutrients;
- increasing the production capacity of the natural resource base;
- consistency with a country's overall economic and environmental goals;
- safeguarding social security and equity for rural populations.

Assessment: efficient assessment of plant nutrient requirements is the basis for planning and for deciding on levels of domestic production and imports of fertilizer products and raw materials, including the use of foreign exchange to finance imports. Fertilizer demand projection is simply an assessment of the plant nutrient volumes that will be ordered by farmers and which are needed to correct any imbalances.

THE AGENDA FOR EFFECTIVE POLICY

Policies for effective plant nutrition should address the following topics:

- determining the balance between domestic food production and food imports for countries aiming at food self-reliance;
- assessing plant nutrient requirements;
- choosing the sources and combinations of plant nutrient supplies;
- determining domestic production and imports of fertilizer products and raw materials;
- setting price levels for nutrients vis-à-vis the price of produce;
- providing distribution, marketing and credit facilities, including adequate foreign exchange allocation;
- legislation; and
- supporting extension and research (access to technology).

Marketing: marketing systems should promote efficient fertilizer use and satisfy farmers' requirements while helping meet national food self-reliance goals. These systems require careful design and policies that strike the right balance between government and private participation in the production, import and distribution of fertilizers. This is a critical issue that is highly dependent on national economic and political conditions.

Transport and storage: transport and storage are part of the essential infrastructure needed for the efficient use of fertilizers. Costs will partly determine the need for alternative means of transport, and the location and size of storage facilities.

Training: demonstrations, training and extension on efficient crop-production and fertilizer-use techniques are essential components of farm-support policies. Extension requirements must be assessed and services established to address the technological level and experience of the farming community. Adequate technological packages, including the balanced use of mineral fertilizers as part of an IPNS, and basic knowledge of the economics of fertilizer use have to be introduced.

Pricing: price is an important factor in improving the income of farmers. Whether or not to subsidize the product or the inputs in order to stimulate production has long been a controversial issue. Most developing countries in Asia have used input subsidies in agriculture; developed countries support farm activities with other mechanisms, often with indirect or invisible effects, and not always to stimulate production. Subsidies given directly or indirectly to farmers for fertilizers have been the most important pricing factor in developing countries. They have been clearly shown to increase demand for plant nutrients. Some subsidies have been misused or carried too far, to the extent of burdening countries' budgets. Other incentives to fertilizer use include guaranteed support prices for agricultural produce, duty-free imports of fertilizer, and tax exemptions for credit and investment in fertilizers and crop production. These measures affect the profitability of fertilizer use and provide an economic motivation for increasing crop production.

Legislation: fertilizer legislation deals mostly with specifications on composition, in terms of nutrients and inert material, concentration of plant nutrients, physical properties, package characteristics, labelling and weight, storage and quality control.

Packaging: fertilizer packaging should reduce losses but not add substantially to the price of fertilizer. It should also convey the right information to users. Fertilizer distribution systems and requirements for storage and transport condition the quality of fertilizer packaging. The chemical and physical properties of the products and conditions of storage, especially at the end of the distribution chain, must also be considered.

Advice and planning should involve both government and the private sector. A focal point for fertilizer advice and planning is needed to establish a well-integrated fertilizer policy, coordinated with the country's agricultural and food-security policies, and in harmony with national priorities. This focal point can also advise on prices and marketing policy, and be responsible for demand forecasting and identifying research and extension priorities.

Financing: fertilizer is a product for which demand is often highly seasonal. Fertilizer traders' cash flow is therefore highly variable and traders will need commercial credit in foreign and domestic currency.

Bibliography

Couston, J. W. and Pratap Narayan. 1987. *Role of fertilizer pricing policies and subsidies in agricultural development.* Rome, FAO, 31 pp.

FAO. 1972. *Effects of intensive fertilizer use on the human environment.* FAO Soils Bulletin No. 16, Rome, FAO, 360 pp.

FAO. 1985. *Economic, financial and budget aspects of fertilizer use development.* FAO/FIAC Fertilizer Programme No. 3, Rome, FAO, 17 pp.

FAO. 1986. *International code of conduct on the distribution and use of pesticides.* Rome, FAO, 28 pp.

FAO. 1987. *Fertilizer strategies.* FAO Land and Water Development Series No. 10, Rome, FAO, 148 pp.

FAO. 1993. *Technical handbook on symbiotic nitrogen fixation, legume/rhizobium.* Rome, FAO,

FAO. 1995. *World agriculture: towards 2010.* N. Alexandratos (ed.). Chichester, United Kingdom, John Wiley, 488 pp.

FAO. 1995. *Integrated plant nutrition systems.* R. Dudal and R. N. Roy (eds.) FAO Fertilizer and Plant Nutrition Bulletin No. 12, Rome, FAO. 426 pp.

Fertilizer Association of Ireland. 1991. *Code of good practice for the environment.* Dublin, FAI.

IACR. 1988. *Keeping the balance, a Rothamsted guide: soil and fertilizer nitrogen.* Harpenden, United Kingdom, Institute of Arable Crops Research, Rothamsted Experimental Station, 4 pp.

IFA-EFMA. 1990. *Code of best agricultural practices to optimize fertilizer use.* International Fertilizer Industry Association/European Fertilizer Manufacturers Association, Paris, 4 pp.

MAF. 1991. *Code of good agriculture practice for the protection of water.* London, Ministry of Agriculture, Fisheries and Food Publications, 80 pp.

Roy, R. N. 1990. *Integrated plant nutrition systems: state of the art.* Commission on Fertilizers, 11th session, Rome, FAO, 15 pp.

Van Reuler, H., and Prins, W. H., eds.. 1993. *The role of plant nutrients for sustainable food production in sub-Saharan Africa.* Leidschendam, The Netherlands, VKP, 232 pp.

W9081E/1/7.98/1000